ASSESSING THE SCIENTIFIC INQUIRY PRACTICES OF TEACHERS
AND INVESTIGATING THEIR RELATIONSHIP WITH
STUDENT LEARNING

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Abstract

This study explored the nature of classroom instruction of teachers in the Philippines, particularly their enactment of specific inquiry-based teaching practices as they implemented the newly designed Grade 7 chemistry curriculum, and how each specific practice related to student learning outcomes. Specifically, it examined whether teachers’ inquiry practices of engaging in questioning, designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information were related to students’ chemistry achievement. Data were collected from chemistry tests (pretest and posttest) of 495 Grade 7 students, 57 lesson observations in 12 classes, and questionnaire responses of ten chemistry teachers. Test data were analyzed using Rasch (1960) modeling. The relationship between each practice of scientific inquiry and chemistry achievement was determined using multilevel modeling with Bayesian estimation. Observations revealed that teachers enacted the six practices of scientific inquiry in varying degrees in their classrooms. They seemed to be more comfortable to enact the practices of engaging in questioning and communicating information than the practices of designing and conducting investigations, collecting data, analyzing data, and developing explanations in chemistry teaching. Teacher-centered inquiry instruction was more evident than student-centered inquiry instruction, which suggests that inquiry in most chemistry classrooms was structured. The study found that out of six scientific inquiry practices, only engaging in questioning showed a significant positive relationship with students’ chemistry achievement. The findings have direct implications for education administrators in designing professional development programs, as well as science curriculum development, the teaching of science through inquiry, and future research.
Declaration

This is to certify that:

- the thesis comprises only my original work towards the PhD;
- due acknowledgement has been made in the text to all other material used; and
- the thesis is less than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices.

DENNIS L. DANIPOG
Preface

The chemistry tests (pretest and posttest) used in this study were developed collaboratively by the researchers of the Assessment, Curriculum and Technology Research Centre in Manila and the Assessment Research Centre in Melbourne. The researcher for this study was a member of the Assessment Research Centre test development team. He was responsible for the development of items on scientific inquiry, which were designed to match the proposed framework for developing indicators for inquiry-based teaching.

Dr Masa Pavlovic, Dr Zhonghua Zhang, and Dr Susan-Marie Harding from the Assessment Research Centre at the University of Melbourne performed the Rasch analysis of the chemistry tests to determine its psychometric properties. The results of this analysis were included in this study (see pages 219-225). The researcher for this study was responsible for interpreting the results of the Rasch analysis and writing up the findings in Chapter 6.

The Scientific Inquiry Teaching Observation Instrument (SITOI) was developed by the researcher for this study with the assistance of Dr Susan-Marie Harding and Professor Esther Care from the Assessment Research Centre and Dr Marlene Ferido from the University of the Philippines. Dr Susan-Marie Harding and Dr Zhonghua Zhang guided the analysis procedure for the SITOI.
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Chapter 1: Introduction

Any education that focuses predominantly on the detailed products of scientific labor—the facts of science—without developing an understanding of how those facts were established or that ignores the many important applications of science in the world misrepresents science and marginalizes the importance of engineering. (National Research Council, 2012, p. 42)

This statement from the National Research Council (NRC) in the United States through its 2012 Framework for K-12 Science Education suggested that placing too much emphasis on knowledge of science content and leaving behind its applications and the understanding of how this knowledge is generated and accepted, that is, scientific inquiry itself, misrepresents science education. As implied in this statement, scientific inquiry is one of the important elements of science education. Inquiry as an approach to teaching in science education has been a focus of interest for many years. For example, most conversations about reform-based science teaching include the word inquiry (Abd-El-Khalick et al., 2004; Anderson, 2002; Crawford, 2014; Kim, Tan, & Talaue, 2013; Schneider, Krajcik, & Blumenfeld, 2005). Further, curriculum reform movements in K to 12 science education since the time of Dewey (1910b) emphasize the importance of instruction that supports students’ adoption of and engagement in scientific inquiry practices (Abd-El-Khalick et al., 2004; Barrow, 2006; Hackling, Goodrum, & Rennie, 2001; Kennedy, 2013; Kim et al., 2013; NRC, 2012; Ramnarain, 2014; Wu & Hsieh, 2006). Aside from the United States, the aforementioned curriculum reform movements have been observed in other countries including Australia, Ireland, Singapore, South Africa, and Taiwan. These reform movements suggest that the pedagogical approaches
that teach students about and through inquiry play a significant role in science teaching and learning. From Dewey’s (1910b) work on science as a method or process of inquiry and on student-centered approaches to education to the present interest in an inquiry-based science teaching (Bevins & Price, 2016; Minner, Levy, & Century, 2010; Rundgren, 2017; Tuan, Chin, Tsai, & Cheng, 2005), inquiry has been increasingly adopted by many countries as one of the salient features in K to 12 science curriculum reforms (Abd-El-Khalick et al., 2004; Australian Curriculum and Assessment Reporting Authority [ACARA], 2014; Heinz et al., 2017; Kennedy, 2013; Kim et al., 2013; Ramnarain, 2014; Samuel & Ogunkola, 2013; Wilson, Taylor, Kowalski, & Carlson, 2010; Wu & Hsieh, 2006). This is because scientific inquiry has been considered to have the potential to improve scientific literacy in classrooms (Flick & Lederman, 2004), which has been described as the ultimate goal of science education (Lederman, 2004).

Many studies have reported that students’ greater achievement in science can be achieved through the use of inquiry-based teaching approach (e.g., Jiang & McComas, 2015; Minner et al., 2010; Mupira & Ramnarain, 2018; Wilson et al., 2010; Wu & Hsieh, 2006). However, there is a lack of detailed investigation of the practices of inquiry employed by teachers in the classroom, which may help students acquire greater achievement in science. Specifically, the relationship between specific practices of inquiry and student learning in science is not extensively investigated. According to Minner and DeLisi (2012), researchers placed a very little emphasis on investigating which specific practices of an inquiry-based teaching can lead to students’ greater achievement. The paucity of research focused on specific inquiry practices of teachers in classrooms and the relationship of these specific practices to learning is also related
to the lack of an observational instrument specifically designed to assess the specific inquiry practices implemented by teachers in the classroom. For this reason, a need for an observational tool that could directly assess inquiry instruction by looking at the granular view of scientific inquiry practices of teachers was identified in this study. This would allow a fine-grained investigation of the impact of specific inquiry practices on student learning in science. This study allows the identification of which practices of inquiry teaching have most potential to improve student learning since scientific inquiry has been increasingly used as a teaching approach and as one of the essential features of curriculum documents in pre-tertiary science education worldwide.

Furthermore, literature shows that most classroom research on inquiry-based teaching and learning in pre-tertiary science education have been conducted in developed countries (e.g., Crawford, 2012; Fitzgerald, Danaia, & McKinnon, 2017; Kim et al., 2013). Implementation of inquiry-based teaching in less developed countries may be more challenging than in developed countries. For instance, there has been relatively little research on the degree to which teachers can implement inquiry in schools with challenging teaching and learning environments (e.g., schools with lack of teaching resources and facilities, classrooms with large number of students) such as most public schools in the Philippines, and schools in many other less developed countries. Can teachers effectively implement the practices of scientific inquiry (which the developed countries are using in their classrooms) in the classroom of less developed countries? What is the nature of teachers’ enactment of inquiry teaching in less developed countries? These questions indicate the need for an empirical research on how inquiry-based teaching is translated to developing countries, and how it positively impacts student learning in these contexts. For this reason, this study was conducted to
describe how classroom teachers in a less developed country, the Philippines, implemented scientific inquiry as a teaching approach in challenging teaching and learning environments, and how it affected student learning outcomes. But, what is scientific inquiry? Does it mean the same thing to everyone? Does it mean the same thing in varied contexts?

**What is Scientific Inquiry?**

Scientific inquiry is defined in different ways depending on the context in which the term is used. In the scientific context, inquiry refers to “the diverse ways in which scientists study the natural world and propose explanations based on evidence derived from their work” (NRC, 1996, p. 23). According to Anderson (2007), the work of scientists, the nature of their investigations, and the abilities and understandings necessary to perform their work are at the heart of this definition of scientific inquiry.

In the educational context, scientific inquiry can be viewed as either a means or an end. Scientific inquiry as a *means* refers to teaching approaches used to help students develop inquiry skills and improve their understanding of science (Abd-El-Khalick et al., 2004). As a teaching approach, it should capture the essence of scientific investigation and the development of knowledge about the natural world (Bybee, 2004). Moreover, in combining the historical views of Dewey (1910b) and Schwab (1962) with modern views of current science education researchers (Bybee et al., 2006; Magnusson, Palincsar, & Templin, 2004; Osborne, Simon, Christodoulou, Howell-Richardson, & Richardson, 2013; Schwarz & Gwekwerere, 2007; Tytler, 2007), scientific inquiry as a teaching approach involves engaging students in using critical thinking skills, which includes asking questions, designing and carrying out
investigations, interpreting data as evidence, creating arguments, building models, and communicating findings in the pursuit of deepening their understanding by using logic and evidence about the natural world (Achieve Inc., 2013; Crawford, 2014; NRC, 2012). Scientific inquiry as an *end* refers to student learning outcomes. These outcomes can be viewed as (1) students’ ability to do scientific inquiry and (2) students’ knowledge about science (Abd-El-Khalick et al., 2004; Capps, Crawford, & Constas, 2012; Flick & Lederman, 2004).

In 2012, the Department of Education (DepEd) in the Philippines included scientific inquiry in the newly designed K to 12 science curriculum as one of the domains of learning science. This enhanced science curriculum was described as inquiry-based and student-centered (DepEd, 2016). It was designed around three domains of learning science:

- understanding and applying scientific knowledge in the local setting as well as global context whenever possible
- performing scientific processes and skills
- developing and demonstrating scientific disposition and values

The acquisition of these domains, as explained in the curriculum, was facilitated using different approaches including an inquiry-based approach (DepEd, 2016). In the K to 12 science curriculum guide, scientific inquiry was defined as the teaching and learning of inquiry processes and skills (methods of scientific investigation), emphasizing the use of evidence in constructing explanations (DepEd, 2016). Science content and science processes were intertwined in the K to 12 curriculum. As argued by DepEd, without the content, students will have difficulty utilizing science process skills.
since these processes are best learned in context. The science curriculum was organized around situations and problems that challenge and arouse students’ curiosity. Inquiry-based activities were included to develop students’ interest and allow them to become active learners. Furthermore, the concepts and skills in the curriculum were presented with increasing levels of complexity from one grade level to another in a spiral progression, with the intention of paving the way to a deeper understanding of core concepts. In this spiral progression approach, the scope and sequence of the content of the curriculum are developed such that concepts and skills are revisited at each grade level with increasing depth. As more facts and principles on each topic are encountered, learning of knowledge, skills, values, and attitudes increases in depth and breadth, creating a metaphorical spiral (Southeast Asian Ministers of Education Organization-Regional Center for Education Innovation and Technology [SEAMEO-INNOTECH], 2012).

The aforementioned meanings of scientific inquiry, as means and ends, are distinct from each other although they also have many connections. Underlying these conceptions of scientific inquiry is a constructivist approach to teaching, which focuses on engaging students physically and cognitively in the act of learning as active constructors of their own knowledge, rather than relying exclusively on transmission by a knowledgeable other (i.e., the teacher).

**Constructivism and scientific inquiry**

Constructivism in education offers an explanation on how knowledge is constructed by students for their learning (Henson 2003; Unal & Akpinar, 2006). Specifically, it suggests that students learn from direct experiences and interaction with
their environment, and through actively negotiating and combining newly presented information with their prior knowledge to form new understandings (Lew, 2010; Savasci & Berlin, 2012). The development of constructivism in education has been based on the ideas of respected thinkers, primarily, Dewey (1859-1952), Piaget (1896-1980), and Vygotsky (1896-1934).

Dewey was a prominent figure during the progressive educational reform movement in the United States (McCaughan, 2013). In this movement, learning was described as a self-construction process through experiences (Dewey, 1938). Dewey proposed that students are active agents who interact with their environments as part of the learning process (McCaughan, 2013). He argued that students should learn by doing (Henson, 2003; Platz & Arellano, 2011). He suggested that students should study problems that are related to their experiences and within their intellectual capability so that they are active learners in their search for answers (Dewey, 1938).

Thus, Dewey (1938) explicitly articulated the value of learning through the use of real-life experiences. In science teaching, this is evident particularly when students are given the opportunity to learn actively using first-hand experiences in scientific activities or research. As such, students can freely connect abstract science to its practical meanings in real-life problems and situations that are familiar to them. Here, the student is actively involved, and the teacher has a role as facilitator and guide. As Henson (2003) pointed out, Dewey’s approach to instruction marked the shift from teacher-centered to student-centered instruction in the classroom, at least in theory although not necessarily in practice.

The genetic epistemology of Piaget underpins the growth of constructivism in education (Burnett, 2010; Dykstra, 2012). Within the framework of his extensive and
seminal body of research, Piaget (1954) placed emphasis on constructing knowledge through cognitive processes of analyzing and interpreting. Piaget noted that children’s learning happens through processes of assimilating and accommodating information they receive through their experiences (Piaget, 1954). From this view, in order for students to construct new knowledge, classroom teachers should provide students with learning experiences that allow them to acquire information and integrate it with their understandings. There are opportunities to observe this approach in science classrooms, specifically when students are collecting information or data that they need for their science activities. They then analyze and interpret this new information in accordance with their understanding and existing scientific knowledge. As with Dewey’s approach to instruction, an approach based on Piaget’s understanding of the way that children build knowledge can be described as student-centered constructivism, where students construct knowledge for themselves (Gordon, 2009).

Furthermore, Piaget’s view on construction of knowledge can be juxtaposed with Kuhn’s view on the development of scientific knowledge. Kuhn’s ideas are well known and have been definitive of contemporary views on scientific knowledge development. Kuhn (1996) developed an explanation of the development of scientific knowledge in his publication The Structure of Scientific Revolutions. He argued that development of scientific knowledge is not uniform but has alternating normal and revolutionary phases. In the normal phase, the development of scientific knowledge is “continuous insofar as there is accumulation of puzzles solved” (Tsou, 2006, p. 211). In this manner, Piaget’s view is the same with Kuhn’s. On the other hand, in the revolutionary phase, the development of scientific knowledge is discontinuous and non-cumulative. This may look different from Piaget’s idea that portrayed a more
continuous view of knowledge development resulting from integrative processes of assimilation and accommodation. According to Piaget and Garcia (1989), development of new knowledge is not independent from previous knowledge; it is only a reorganization or an addition to existing knowledge.

Without negating views of learning that prioritized real-life experiences or those that stressed learning through internal cognitive processes, Vygotsky (1978) placed emphasis on learning through social interaction with the environment (Jaramillo, 1996). Vygotsky (1978) argued that knowledge is developed in the context of personal experiences in collaboration with others. He believed that learning is initially social in nature and then psychological or cognitive (Gordon, 2009). Based on this perspective, students learn from active engagement with the teacher and/or more advanced peers through socially organized learning activities in the classroom. This concept is referred to as learning within a zone of proximal development (Henson, 2003). This can be illustrated in a situation where the concepts in a lesson are too difficult for a student to learn alone. Working in isolation, the student may not be able to interpret the information or experience provided by the lesson. However, if the concepts are within the students’ zone of proximal development, then they can be grasped through working with more advanced peers (Gordon, 2009). This can be observed in science classes where students work in teams for their investigative project. Students sometimes collaborate with teachers or researchers to better understand the scientific nature of their project. This situation could allow students to engage in scientific thinking with knowledgeable others, which supported Vygotsky’s claim that over time students can progress from spontaneous thinking to scientific thinking (Alozie, Moye, & Krakcik, 2010).
The aforementioned schools of thought emphasized the importance of learning experiences in constructing knowledge, and became the roots of a constructivist approach to pedagogy. Based on the ideas of the prominent thinkers summarized above, it is clear that their position on knowledge construction is that knowledge is not transmitted directly from teacher to student, but is actively built up by the student. With this, the argument that human beings are active agents constructing knowledge by themselves has been a driving force for educators to believe that instructional activities should encourage students to construct knowledge through their own participation (Zhang, 2016). This constructivist view plays an important role in science teaching and learning and has become a dominant teaching paradigm in theories of education (Taber, 2010, 2011; Ültanir, 2012; Zhang, 2016).

Constructivism entered science education through focusing on students’ ideas and understandings (Kelly, 2013). Constructivists contend that students learn science by authentically engaging in the activities associated with being a scientist (Orgill & Thomas, 2007). They suggested that students must be given opportunities to engage in activities and reflect on those activities, rather than sitting passively in the classroom, in order to become scientifically literate individuals (Haney, Lumpe, & Czerniak, 2003).

These constructivist views of learning became a theoretical foundation for promoting scientific inquiry in science classrooms beginning in the early 1960s, and have become a major and officially endorsed approach in U.S. schools (Taber, 2010, 2011; Zhang, 2016). Because of this, a range of instructional models that engaged students in inquiry-based, hands-on experiences, and that allowed them to construct their understanding, have emerged (Taber, 2010; 2011; Zhang, 2016). These instructional models (e.g., 5E model [Bybee et al., 2006], Guided Inquiry model
had common features in that they provided students with questions or problems and required them to collect data and look for patterns, answers, and solutions. This approach has come to be identified as inquiry-based instruction (Jadrich & Bruxvoort, 2011). Inquiry-based instructional models are aligned with the ideas of the prominent thinkers mentioned above, and allow students to perform scientific practices, provide them with authentic issues that are meaningful to them, and teach them the science concepts and skills that they will need to become productive and scientifically literate citizens.

This view of science teaching has long been advocated (Capps & Crawford, 2013; Crawford, 2014; Zhang, 2016). In the early 1960s, Schwab and Brandwein (1962) argued for a need to adopt inquiry-based science teaching in schools. They asserted that inquiry-based science teaching is valuable as it provides learners with opportunities to experience the scientific processes and allows them to construct scientific knowledge through their own explorations. Schwab also encouraged science teachers to use the laboratory to assist students in their study of science concepts. He recommended that science be taught in an inquiry format. Since then, multiple versions of an inquiry-based teaching approach with slight differences have been developed (Taber, 2011; NRC, 2000; Zhang, 2016). Details on the historical background of scientific inquiry as a teaching approach, the aspects of scientific inquiry, and the models of inquiry-based teaching are discussed in Chapters 2 and 3.

What are the Challenges Facing Scientific Inquiry Teaching in the Classroom?

Today, scientific inquiry in the classroom is advocated by science education reform movements in different parts of the world (Abd-El-Khalick et al., 2004; Heinz et
al., 2017; Mumba, Chabalengula, & Hunter, 2007; Xie, Talin, & Sharif, 2014) and yet is surprisingly rare (Cheung, 2011; Crawford, 2014). Studies conducted in the United States, Korea, and Canada have shown that many teachers do not typically use scientific inquiry in their classrooms (Capps & Crawford, 2013; Kim & Tan, 2011; Trautmann, MaKinster, & Avery, 2004). In fact, research says that neither teachers nor students typically hold informed views of scientific inquiry (Lederman & Lederman, 2004; Lederman et al., 2014; Schwartz et al., 2002). As a result, most teachers have difficulty creating classroom environments that foster students’ scientific inquiry skills (Capps & Crawford, 2013; Fitzgerald et al., 2017; Kang & Keinonen, 2016; Lederman et al., 2014; Lederman & Lederman, 2004; Minstrell & van Zee, 2000; Saad & BouJaoude, 2012). They tend to teach science as a collection of facts, principles, and concepts without explicitly instructing students in the processes by which scientific knowledge is generated and accepted. According to Crawford (2014), classroom observations revealed that in today’s science classes many teachers are still delivering concepts and principles primarily through lecture mode, and their students are often passively listening and taking notes. Moreover, Crawford reported that if a lesson involves a laboratory experience, students are usually required to run through the procedures, step by step, in order to verify an already known result. In such cases, the laboratory lesson may resemble the kind of tightly structured, traditional science teaching practice found in many classrooms of the last century. According to Wallace and Kang (2004), if teachers’ understanding of scientific inquiry approaches is not clear, they may inhibit students from being involved in inquiry activities that include questioning, designing and carrying out investigations, interpreting data, and developing explanations for the phenomena.
It is clear from the findings of aforementioned international studies that scientific inquiry teaching is not readily implemented by teachers in many science classrooms around the globe. Why is this the case? What are the reasons for rare implementation of this science teaching approach in the classroom, despite its advocacy by science education reform movements worldwide and the importance placed on it by curriculum designers? Researchers have identified the following factors pertaining to the reluctance of teachers to use scientific inquiry teaching in classrooms: (1) lack of informed views about scientific inquiry and inquiry-based teaching; (2) lack of confidence and competence in using inquiry-based approaches; (3) lack of time for preparation and implementation; (4) inadequate professional development programs; (5) importance of preparation for examinations; and (6) student learning abilities (Capps & Crawford, 2013; Davis, 2003; Fitzgerald et al., 2017; Garet, Porter, Desimone, Birman, & Yoon, 2001; Kang & Keinonen, 2016; Lederman et al., 2014; Marshall, Smart, & Alston, 2016; Ramnarain, 2016; Saad & BouJaoude, 2012; Trautmann et al., 2004; Wang, Wu, Wu, & Tseng, 2014). Saad and BouJaoude (2012), for instance, argued that the culturally-based beliefs of the importance of preparation for examinations, and the importance of efficiency in covering the curriculum, had a powerful influence on impeding inquiry practices in the classroom. According to them, teachers may develop a goal of teaching facts or information to cover the content of the curriculum for students to pass examinations and get good grades, which could de-emphasize the importance of having positive attitudes toward inquiry. Ramnarain (2016) investigated the factors influencing the implementation of inquiry-based teaching in high schools in an underdeveloped urban area in South Africa and highlighted that a lack of professional science knowledge (e.g., content knowledge, pedagogical content knowledge, curricular
knowledge) contributed toward teachers’ uncertainty in inquiry-based teaching. Davis (2003) and Kang and Keinonen (2016) argued that class size and school resources could affect teachers’ inquiry practices in classrooms. Furthermore, Fitzgerald et al. (2017) explored teachers’ perspectives on the factors that prevented them from implementing inquiry-based teaching and learning approaches in Australian secondary school science classes. One important barrier that they identified was the lack of good models and definitions for inquiry-based teaching. They found that, although teachers were familiar with the term *inquiry-based teaching*, they were not sure about what it would involve in the reality of their own classrooms.

The barriers that teachers describe as impeding the enactment of scientific inquiry teaching in classrooms point to a lack of congruence between curriculum design and the classroom practices of teachers. Researchers have argued that, when an envisioned curriculum clashes with the reality of schools and classroom teaching, and the associated social, political, economic, and cultural aspects of a community, it is often transformed into incommensurate curriculum and then translated into incongruent enactments or classroom practices (Abd-El-Khalick et al., 2004; Anderson, 2002). This inconguency has long been recognized and is a widely noted phenomenon within the educational literature (e.g., Abd-El-Khalick et al., 2004; Elmore, 1996; Fitzgerald et al., 2017; Ramnarain, 2016; Smith & Southerland, 2007).

The scenario described above can also be observed in many science classrooms in the Philippines (Science Education Institute-Department of Science and Technology & University of the Philippines National Institute for Science and Mathematics Education Development [SEI-DOST & UP NISMED], 2011a). Bernardo, Limjap, Prudente, and Roleda (2008) examined the perceptions of 7,885 elementary and high
school Filipino students about their science classes. They reported important dimensions of the science classrooms in the Philippines from the eyes of the students. One of these dimensions is that students perceived their science teachers’ instructional practices as oriented towards helping them learn but these practices did not involve sufficient inquiry-oriented activities and did not provide sufficient support or encouragement for self-directed learning (Bernardo et al., 2008). The perceptions of the students are related to the findings of researchers at the Assessment, Curriculum and Technology Research Centre (ACTRC) in Manila. In 2014, ACTRC conducted a scoping study into the teaching of science inquiry skills of 22 Grade 8 science teachers across 11 schools in the Philippines. Multiple classroom observations were conducted in Grade 8 science classes and the participating teachers used a new science curriculum, one of the important features of which was the learning of scientific processes and skills in addition to learning of content. The ACTRC researchers found that teachers delivered some science inquiry skills while other skills included in the curriculum were seldom seen in classrooms (ACTRC, 2014).

Furthermore, in the study conducted by Gutierrez (2015), which involved 30 elementary science teachers in the Philippines who participated in a professional development program, she reported that most teachers placed too much emphasis on the content as specified in the curriculum; they set the scale of students’ knowledge acquisition by the quantity of the concepts that were introduced, rather than on the depth of understanding. She also reported that, even though the intention of teachers was to employ more inquiry-based practices in their classes, they still used the traditional didactic method due to the volume of topics they are expected to teach. This is related to the findings of de Mesa and de Guzman (2006) when they established a portrait of
Filipino teachers’ classroom practices. They reported that a majority of classroom activities were teacher-directed and teacher-controlled. Gutierrez (2015) identified additional challenges that the teachers encountered in implementing inquiry-based teaching. These were (1) lack of support, training, and availability of inquiry-based materials; and (2) the perceived difficulty and time-consuming nature of inquiry-based approaches.

The SEI-DOST and UP NISMED (2011a), through their publication *Framework for Philippine Science Teacher Education*, reported that there was evidence that the transmission approach to teaching may be contributing to the lack of interest in science that is observed among elementary and high school students across the Philippines. They identified the predominance of teacher-centered classrooms and teaching practices in many Philippine secondary schools as one of the reasons for a low percentage of Filipino students venturing into science-related careers in tertiary education (Science Education Institute-Department of Science and Technology [SEI-DOST], 2009). According to SEI-DOST and UP NISMED (2011a), many teachers turned to lecturing, instead of providing students with engaging and challenging activities that enabled them to develop creative ideas and solve problems, due to lack of content and pedagogical skills suitable for science teaching. They reported that many teachers teaching science subjects in schools were non-science majors. This implied that there was a shortage of qualified science teachers in the country. They also reported that the lack of qualified science teachers in many schools led to the practice of assigning teachers to teach science subjects despite their limited background.

In the Philippines, various professional development programs such as teacher training, seminar-workshops, short-term courses, and lesson study, have been designed
to assist elementary and secondary school teachers in their teaching of science (Gutierrez, 2015; SEI-DOST & UP NISMED, 2011a). In fact, a large number of Filipino teachers have been highly motivated to participate in regional and national professional development opportunities and have collaborated enthusiastically with science education specialists and university-based researchers to improve their own science teaching and learning (Gutierrez, 2015; SEAMEO-INNOTECH, 2015). Although significant gains have been made through continuing professional development for teachers (Lotter, Harwood, & Bonner, 2007; NRC, 2000), there is still an uncertainty about how inquiry is implemented in science classrooms in the Philippines (Garcia & Tan, 2004; SEI-DOST & UP NISMED, 2011a). According to Gutierrez (2015), teachers often find it difficult to sustain their practice after short-term professional development related to inquiry-based teaching. Filipino researchers who conducted research on curriculum implementation in schools (e.g., Lim & Prudente, 2013; Sanosa, 2013) reported that the focus of instruction towards test preparation in schools, the insufficiency of resources and school facilities, the limited time to finish the intended scope of the lesson, the lack of understanding about an inquiry-based curriculum framework, and the lack of skills in delivering the teaching plan were the factors that affected teachers in implementing the curriculum the way it was intended to be implemented in the classroom. The aforementioned situation in the Philippines demonstrated that the curriculum design was either incompletely followed, or translated differently, by teachers in classroom teaching. This mismatch between curriculum design and curriculum delivery was also observed in international classrooms, as discussed earlier. However, in the Philippines, expectations of a shift in science teaching to include inquiry-based practices was further complicated by the demands on
schools and teachers that they adapt to a large-scale overhaul of education. This is discussed in the next section.

**What is the New Basic Education System in the Philippines?**

Five years before the current study was initiated, efforts had been directed towards the improvement of classroom teaching and learning at the basic education level in the Philippines. From 1945 to 2010, basic education in the Philippines covered Grades 1-10 only. In 2011, the Department of Education initiated a basic education reform, which is known as the K to 12 Program. This program covered Kindergarten and 12 years of basic education: six years of Primary or Elementary education, four years of Junior High School, and two years of Senior High School. The rationale for this reform was to provide sufficient time for mastery of concepts and skills, develop lifelong learners, and prepare graduates for tertiary education, middle-level skills development, employment, and entrepreneurship (DepEd, 2013b; SEAMEO-INNOTECH, 2015). Details on the features of the K to 12 Program in the Philippines are discussed in Chapter 2.

As part of the K to 12 program, a new science curriculum was developed and implemented in schools across the country (Montebon, 2014). Through this new curriculum, science education aimed to develop scientific literacy among students and enable them to make judgments and decisions on the applications of scientific knowledge that may have significant impact in everyday life (DepEd, 2013a). The new curriculum was designed according to the three domains of learning science: (1) understanding and applying scientific knowledge in local setting as well as global context, (2) performing scientific processes and skills, and (3) developing and
demonstrating scientific disposition and values. These domains could be seen in major international science assessment frameworks of the time. For instance, in the Programme for International Student Assessment (PISA) framework for the 2015 scientific literacy assessment, these three domains were anchored to its four basic components: context (i.e., personal, local/national and global issues that demand some understanding of science and technology); knowledge (i.e., understanding of the major facts, concepts, and theories that form the basis of scientific knowledge); competencies (i.e., evaluate and design scientific inquiry, using scientific evidence, explaining phenomena scientifically); and attitudes (i.e., interest in science and technology, support for scientific inquiry, awareness of environmental issues) (Organisation for Economic Co-operation and Development [OECD], 2017). In the PISA 2006 science assessment framework, it was observed that each item involved the predominant use of the competencies (Bybee, McCrae, & Laurie, 2009).

The domains of learning science in the new curriculum could also be seen in the science assessment framework for the Trends in International Mathematics and Science Study (TIMSS) 2015 except for the attitude domain. This assessment framework placed an emphasis on two domains: content domain (specifying the subject matter to be assessed), and cognitive domain (specifying the thinking processes to be assessed) (Jones, Wheeler, & Centurino, 2013). In addition, science processes and skills were also included in the TIMSS 2015 science framework, which must be assessed in the context of the content domain and draw upon the range of thinking processes specified in the cognitive domain (Jones et al., 2013).

What made the new science curriculum distinct from the previous science curriculum in the Philippines was that it was designed to be student-centered and
inquiry-based, emphasizing the teaching and learning of inquiry skills (DepEd, 2013a). The organization of the science curriculum had also changed in that concepts and skills were revisited at each grade level with increasing depth, creating a ‘spiral’ progression, as described above. Implementation of this new science curriculum began in Grade 3 and Grade 7 (1st year Junior High School) in school year 2012-2013 and it was progressively introduced in other grade levels. At the time of writing, it was implemented in Grades 3 to 6, 7 to 10, and 11 to 12.

This major educational reform in the Philippines (SEAMEO-INNOTECH, 2015) took many years to implement in full, from implementation of Kindergarten in 2011 to implementation of Grade 12 Senior High School in 2018. The first cohort of students to progress through the full K to 12 Program were expected to graduate in the year 2024. During this period of major educational reform, the link between the intended, implemented, and achieved curricula could be expected to be particularly tenuous (Hume & Coll, 2010; Sherin & Drake, 2009). Research findings have shown that, in science and mathematics, there is significant difference between the intended and implemented curricula at both elementary and secondary level (Levitt, 2001; Phaeton & Stears, 2017; Smith & Southerland, 2007). The intended curriculum is determined by an organization and usually consists of goals and expectations set by curriculum policy makers and curriculum developers along with textbooks, official syllabi, or curriculum standards set by a particular organization (Kuiper, Folmer, & Ottevanger, 2013, Phaeton & Stears, 2017; van den Akker, 2003). For the K to 12 science program in the Philippines, the formal documents used in classrooms were the Curriculum Guide, Teachers’ Guide, and the Learners’ Modules. According to Williams, Ferido, and Metila (2013), the degree to which the intended curriculum is clear and specific, in the
context of its goals and values, has direct implications for its interpretation by teachers and text writers, and therefore particularly for its chance of success.

The implemented curriculum refers to the educational processes happening in the classroom. It is usually described in terms of the learning opportunities offered to students and depends on curricula, educational standards, assessment, teaching and learning resources available, and other implemented structural arrangements of schooling (Mereku & Mereku, 2015). In this study, this curriculum is described in terms of the ways in which scientific inquiry practices are being implemented by teachers, and any relevant classroom contextual factors (e.g., class size). This will vary across classes and schools. The degree to which this curriculum will vary beyond the reasonable individual differences in teaching style will have immediate implications for the opportunities for students to learn (Williams et al., 2013).

The achieved curriculum refers to student learning outcomes after receiving instruction (Thijs & van den Akker, 2009; van den Akker, 2003, 2010). It is usually described in terms of the main capabilities or other specific qualities that students are expected to demonstrate as a result of successful learning (Mereku & Mereku, 2015).

The alignment of the intended, implemented, and achieved curricula is important as it determines the kind of result the teaching and learning process yields (Phaeton & Stears, 2017). According to Squires (2012), curriculum alignment has been found to have a positive effect on student achievement. At some point, it can be observed that what is articulated in the curriculum documents and what happens during instruction may be quite dissimilar (Phaeton & Stears, 2017). This may result in a gap between the intended and implemented curricula (Sethole, 2004), which is usually observed during periods of major reform (Hume & Coll, 2010; Sherin & Drake, 2009). There is an
argument therefore, with the recent science curriculum reform in the Philippines, for examining its alignment to practices in schools.

**Research Questions**

Although many empirical pieces of evidence have suggested that inquiry-based instruction can lead to greater student achievement in science (Fogleman, McNeill, & Krajcik, 2011; Jiang & McComas, 2015; Minner et al., 2010; Mupira & Ramnarain, 2018; Sadeh & Zion, 2009; Tuan et al., 2005; Wilson et al., 2010; Wu & Hsieh, 2006), only a few studies have been conducted to investigate the specific scientific inquiry practices that teachers enact in classrooms (Dudu & Vhurumuku, 2012; Poon, Lee, Tan, & Lim, 2012; Secker, 2002), and which of these practices are related to greater achievement in science. This is also related to the lack of available observational instruments that can directly assess the specific inquiry practices of classroom teachers. Moreover, there has been relatively little research focused on how scientific inquiry as a teaching approach, which is advocated by most developed countries, is translated to less developed countries, and how it positively affects student learning in these contexts. The present study addressed these issues.

This study investigated the enactment of specific inquiry practices of teachers in a less developed country, the Philippines, as they implemented the new inquiry-based science curriculum, specifically the Grade 7 chemistry curriculum, and examined how each of these specific inquiry practices are related to student learning outcomes. Specifically, this research addressed the following questions:
1. How have teachers implemented inquiry teaching in junior high school chemistry classrooms in the Philippines? Which specific practices of teachers in junior high school chemistry classrooms exhibited components of scientific inquiry? To what extent are these practices translated to Philippine junior high school chemistry classrooms observed in this study?

2. What is the relationship between the practices of scientific inquiry implemented by teachers (engaging in questioning, designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information) and students’ learning in chemistry?

**Significance of the Study**

Scientific inquiry as a teaching approach at the basic education level has been advocated internationally to improve student learning in science. It has been increasingly used by many countries as one of the essential components of pre-tertiary science education. However, there has been little research to identify which specific practices of scientific inquiry of teachers could lead to better learning of students in science. This study addressed this issue by identifying the degree to which specific inquiry-based teaching practices of teachers could help students improve their learning in chemistry. Furthermore, much of the research to date on scientific inquiry teaching has been conducted in developed countries, in which teachers have access to relatively high levels of resourcing (e.g., Crawford, 2007; Fitzgerald et al., 2017; Kennedy, 2013; Kim et al., 2013). There is little that explores how teachers work to implement inquiry-based teaching practices in developing countries where school and teacher resources
may be much more limited, and implementation of inquiry-based teaching practices more problematic. This study provided a platform to understand how teachers enact inquiry-based reform documents in challenging teaching and learning environments such as most science classrooms in the Philippines, and may provide insights for others working in and with school systems in developing countries. Finally, the study also contributed to our knowledge through the development of a validated and multifaceted observational instrument for measuring teachers’ scientific inquiry practices in the classroom.

Scope of the Study

This study was limited to investigating Grade 7 science teachers’ specific instructional practices on engaging in questioning, designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information, and their students’ achievement in chemistry (inquiry skills and content knowledge) in Philippine classrooms. The new science curriculum in the Philippines was initiated with Grade 7 junior high school implementation. With this, students entering Grade 7 junior high school went through the previous basic education curriculum, where the spiral progression of concepts and scientific inquiry in science were not clearly articulated. In Philippine basic education, a school year was divided into four different quarters of schooling period. For Grade 7 Science, students studied chemistry in the first quarter, biology in the second quarter, physics in the third quarter, and earth and space in the fourth quarter. So, in Grade 7 junior high school, students took chemistry as their first unit of science study. These conditions provided the opportunity for a baseline measurement of student understanding and skills that was
unhindered by knowledge of the subject acquired in other units of the science curriculum. It provided an opportunity to establish a starting point to determine student progress in chemistry. In addition, based on the K to 12 science curriculum guide in the Philippines, only in Grade 7 chemistry was scientific inquiry explicitly listed as a conceptual topic to be covered by teachers. Students in this grade level began to do guided and semi-guided investigations in chemistry, emphasizing fair test experimentation (DepEd, 2016). Lazonder and Harmsen (2016) summarized findings of studies on scientific reasoning conducted by different researchers (e.g., Koerber, Sodian, Thoermer, & Nett, 2005; Piekny, Gruber, & Maehler, 2014; Piekny & Maehler, 2013; Varma, 2014) and they reported that learners from the age five onward possessed a basic ability to generate hypotheses, design and conduct experiments, and evaluate evidence, and therefore seem ready for inquiry-based learning. With the aforementioned points, Grade 7 junior high school and the chemistry component of the Grade 7 curriculum were considered to be the focus of this study.

All teacher- and student-participants were drawn from four public secondary schools in the National Capital Region (NCR) since these schools could give the biggest sample size. The study was conducted during the first quarter (from June to August) of school year 2015-2016 because it was during this period that scientific inquiry was one of the conceptual topics in the Grade 7 chemistry curriculum.

Structure of this Dissertation

There are seven chapters in this dissertation. This chapter has outlined different challenges of implementing inquiry-based teaching in science classrooms at the international and local (Philippines) contexts to clearly define the problem to be
investigated. Chapter 2 presents the historical background of scientific inquiry as a teaching approach in international and Philippine classrooms to clarify its various meanings, and to show the early and current justifications for the use of inquiry as an approach to teaching science at the basic education level. It also presents a brief explanation on how inquiry is situated in the Philippines’ K to 12 science curriculum. Chapter 3 presents and synthesizes the research literature on scientific inquiry in science classrooms. It also discusses the assessment methods for inquiry-based teaching and learning in science. The important aspects of scientific inquiry and the features of different inquiry-based instructional models are presented in order to achieve a comprehensive theoretical understanding of an inquiry-based teaching approach. A critical review of the existing observational instruments that have been developed to assess inquiry-based instruction in the classroom is also presented. This review, with examination of different inquiry-based instructional models, paves the way to inform the key elements of inquiry-based teaching to be built into the measurement instruments developed and used in the current study. The chapter also discusses a body of research on how inquiry is used by teachers and how it is likely to affect student outcomes. Descriptions of the chemistry test to measure student outcomes are also presented.

Chapter 4 discusses the research methods of the study. It includes an explanation of the process of developing the observation instrument for assessing inquiry-based teaching and of developing the chemistry test for measuring student outcomes. The process of analyzing tests (pretest and posttest) using Rasch (1960) modeling and the process of determining the relationship between variables through multilevel modeling are also discussed. Chapter 5 presents the results of multiple classroom observations of instructional practices of teachers that are related to scientific inquiry. Together with the
literature review on inquiry-based teaching, a discussion of observation findings, and specifically the amount and type of inquiry-based teaching practices implemented in chemistry classrooms as well as the degree of initiation of these practices, is included to establish an understanding of the nature of inquiry-based instruction of teachers under the newly reformed curriculum.

The results of Rasch (1960) analyses of the ACTRC chemistry tests and of the student tests and the results of the multilevel analysis of the relationship between teaching practices and learning outcomes are presented in Chapter 6. The results of chemistry tests are presented to document the progress of each class in chemistry. Multilevel models are established in this chapter to determine the relationship between teachers’ specific inquiry practices and students’ learning in chemistry. The established relationships are then discussed in conjunction with the results of the analysis of selected posttest items and observed teachers’ inquiry practices. Finally, Chapter 7 presents the discussion of the research findings with conclusions about the policy, curriculum development, and science teaching, the future research implications of the findings, and the limitations of the study.
Chapter 2: Tracing the History of Scientific Inquiry in Classrooms

This chapter is divided into two parts. The first part traces the history of scientific inquiry as a teaching approach in international classrooms. It presents the nature of inquiry in basic science education from the nineteenth century to the present time. The second part traces the history of scientific inquiry as a teaching approach in Philippine classrooms. It discusses how inquiry was incorporated into Philippine basic science education and how it was highlighted in the new science curriculum (DepEd, 2016).

Historical Perspectives on Scientific Inquiry in International Classrooms

Scientific inquiry has been part of the educational landscape at least since the middle of the 19th century (Bybee & DeBoer, 1994; DeBoer, 2001, 2004). In fact, education literature for over the past 100 years clearly showed that scientific inquiry in classrooms is not a new idea (Anderson, 2002; Crawford, 2014; Lederman, 2004). As a teaching approach, scientific inquiry mirrors the processes that scientists use to study the natural world by emphasizing student questioning, investigation, and problem solving. It uses the general processes of science as its teaching methodology. The following sections discuss the historical bases of scientific inquiry, and present a number of arguments that have been made over the years to justify its use as a teaching approach in the science classrooms around the globe. With this background information, it is easy to make sense of the reasons why scientific inquiry continues to be advocated as a science teaching approach.
Scientific inquiry in the 19th century

During the 19th century, science was introduced into the school curriculum as an inductive, laboratory-based study (DeBoer, 2004). As such, scientific inquiry was advocated for classroom teaching by means of laboratory and investigations. Three notable persons supported this movement. They were Thomas Huxley (1825-1895), Herbert Spencer (1820-1903), and Charles Eliot (1834-1926). A prominent British biologist and a key advocate for science, Thomas Huxley, emphasized the importance of science in the school curriculum. Huxley (1899) pointed out:

The great peculiarity of scientific training, that in virtue of which it cannot be replaced by any other discipline whatsoever, is this bringing of the mind directly into contact with fact, and practicing the intellect in the complete form of induction; that is to say in drawing conclusions from particular facts made known by immediate observation of nature. In teaching him botany, he must handle the plants and dissect the flowers for himself; in teaching him physics and chemistry, you must not be solicitous to fill him with information, but you must be careful that what he learns he knows of his own knowledge, and especially, tell him that it is his duty to doubt until he is compelled, by the absolute authority of nature, to believe that which is written in books. (pp. 126-127)

Huxley’s view on how science should be taught became the justification for the emerging science laboratory. The idea of laboratory instruction and teaching science as a process of investigation was supported by another prominent 19th century British scientist, Herbert Spencer. In the book published by Spencer in 1864, where his essay entitled What Knowledge is of Most Worth can be found, he emphasized that the laboratory should provide the opportunity for students to develop a clear conception of natural phenomena, something that could not be accomplished through book learning
alone, and to practice drawing conclusions from observations, which he called judgment. Spencer argued that the generalizations that were discovered by students through their own inquiries would be remembered longer and the process of inquiry would make the students independent from the authority of the teacher. The implications of Spencer’s argument were that teaching science through inquiry led students to make their own investigations and to draw their own inferences. It also implied that students should perhaps be told as little as possible, but rather be induced to discover as much as possible.

Spencer’s (1864) argument for incorporating scientific inquiry in classrooms received support from Charles Eliot’s (1898) view of science teaching. Eliot was an American chemist and president of Harvard University from 1869 to 1895. He emphasized that students’ direct and independent contact with the objects and phenomena of nature that could be accomplished in the laboratory would provide a clear and unbiased view of the world, which could not be achieved through book study alone. Further, he pointed out that learning how to conduct independent investigations would free students from the authority of both the text and the teacher. Based on all the aforementioned, it can be argued that the purpose of advocating inquiry-based teaching into the classroom by means of the laboratory in the 19th century was to develop students’ inductive reasoning skills and their ability to acquire knowledge independently.

Although, in the 19th century, secondary schools were in the early stage of development and attended only by the privileged in preparation for college (Chiapetta, 2008), studying science in the classroom started to be promoted by scientists from Europe and the United States (DeBoer, 2004). Science became part of the school
curriculum because of its perceived ability to develop the intellect in ways that were
different (e.g., observing the natural world and drawing conclusions from this
observation) from what was usually done in schools. From this point, it can be argued
that the inclusion of science into the curriculum may be seen as a way for individual
personal development to produce educated people to meet the demands for a skilled
workforce. Since science was highlighted for its ability to develop intellect, it can also
be argued that studying science in the 19th century focused on familiarity with the facts
and principles of science. Moreover, scientists advocated the laboratory and student
investigation as a means of introducing scientific inquiry in science classrooms in order
to develop inductive reasoning skills, which was something that the other school
subjects could not do. This was another justification for studying science during that
time. The idea of introducing scientific inquiry in the classrooms through the laboratory
was to give students the opportunity to develop their own way of seeking knowledge for
personal development.

Scientific inquiry in the 20th century

During the first half of the 20th century, there was a continuing interest in
teaching students the scientific way of thinking in the context of problems and projects
that were interesting to them and that had social relevance (DeBoer, 2004). The topic of
discussion was the appropriate use of laboratory as to whether it should be used to
strengthen concepts, to verify scientific principles, to teach laboratory techniques, or to
provide a place for students to engage in genuine investigations (DeBoer, 2004). In the
end, most science educators during that time decided to use the laboratory as a place
where students could work on problems of interest to them that had social, as well as scientific, relevance and importance.

In addition, emphasis was also given to the importance of student-centered approaches to education, which was credited in large part to the influence of Dewey (1938). The student-centered approach is based on the philosophy that students learn best from experiences that are engaging, meaningful, challenging, and relevant. In this approach, the ‘sense-making’ rests with students, and the teacher acts as a facilitator to support the learning as students engage in scientific practices (Granger et al., 2012). Crawford (2014) traced the history of scientific inquiry in classrooms in the United States, reiterating Dewey’s (1910b) point that if science is taught only as a well-established body of facts, an opportunity to engage students in learning how to think scientifically will be missed. According to Dewey (1910b):

Science is more than a body of knowledge to be learned, there is a process or method to learn as well (p. 14). Science teaching has suffered because science has been so frequently presented just as so much ready-made knowledge, so much subject-matter of fact and law, rather than as the effective method of inquiry into any subject-matter (p. 124).

Dewey’s (1910b) statement implied that teachers might have taught science with an emphasis on facts and not enough emphasis on how to think about the way science works. Consequently, Dewey recommended the inclusion of scientific inquiry in classrooms. In his publication entitled How We Think (1910a), Dewey presented students’ behaviors that relate to scientific inquiry. These behaviors were (1) defining the problem, (2) noting conditions associated with the problem, (3) formulating an hypothesis for solving the problem, (4) elaborating the value of various solutions, and (5) testing the ideas to see which provide the best solution for the problem. These
behaviors show that in scientific inquiry, students may have the autonomy to establish and control their own learning for the construction of new knowledge. Thus, in this period, scientific inquiry was seen as a way to foster independent learners of science who are able to apply the processes of inquiry in solving problems of personal and social concern.

Many significant events in the early 20th century (e.g., World War 1, the influenza pandemic, the Great Depression) brought about political and social pressures that shaped the goals of public education (Chiapetta, 2008). With this, education leaned towards a pragmatic approach in order to find solutions to the pressing problems that the rapidly changing world had faced—issues related to public health, urbanization, immigration, and other socially-based problems. This implies that school education during the first half of the 20th century was directed towards more practical work for students because this approach could have the potential to address issues having importance in society. From these societal changes, it can be argued that they influenced science teaching in basic education. That is why science was usually taught in schools by stressing its practical aspect so that students could take their place as productive members of society (Chiapetta, 2008; DeBoer, 2004). Thus, in this period, social relevance began to take precedence over the goal of individual personal development. It is also important to note that the composition of secondary school education changed over time, with the extension of secondary education to a much larger proportion of the youth population. Because of this, a larger population can be seen at least in the lower years of secondary education in the 20th century than in the 19th century when secondary education was attended only by a privileged individual.
In this changing approach to education, scientific inquiry teaching was now seen as a way to develop the abilities needed to solve specific problems having social significance rather than as a way to ‘discipline the mind’ through inductive reasoning (DeBoer, 2004). During the first half of the 20th century, it was emphasized that students should be encouraged to apply an inquiry-style of solving problems of social concern. Dewey (1910a) argued that students should be inquirers regarding the nature of their physical and social environments and active participants in the construction of society. The process of science and the term inquiry began to popularized (Chiapetta, 2008). From these ideal views on science teaching, students may receive the opportunities to acquire skills and dispositions to formulate questions for inquiry that were significant and meaningful to them.

Despite the emphasis given to inquiry in science education, this teaching approach was not equally adopted in basic education during this period (Bull, Gilbert, Barwick, Hipkins, & Baker, 2010). Knowledge-centered approaches, in which the primary focus was to replicate the structures of the discipline, were mostly observed in secondary school classrooms while student-centered approaches, which were oriented around the student’s needs, predominated in primary school classrooms (Bull et al., 2010). According to Bull et al. (2010), many science teachers expressed strong resistance when curriculum reformers designed the secondary school science curriculum as more inclusive, relevant, or student-centered. Some teachers argued that science is a body of objective facts that cannot be diluted by teaching approaches designed to meet the needs of learners (Bull et al., 2010). This suggests that Dewey’s (1910a) ideal approach to teaching science was not widely or readily implemented in secondary school classrooms. This may be due to teachers’ earlier teaching beliefs and conceptions
or teachers’ lack of knowledge and skills to implement the intended approach. This situation implies that a mismatch between curriculum design and classroom practice can be observed during that the first half of the 20th century.

**Scientific inquiry in the period of science curriculum reform movement**

With the purpose of improving science education, a curriculum reform movement began, particularly in the United States, in the 1950s and lasted throughout the 1970s (Yager, 2000). Leaders of this movement believed that science should be taught in classrooms as it is practiced by scientists in order to give it the most authenticity possible. Curriculum reforms suggested that fundamental ideas of science should be taught to students through investigations that mirrored the way scientists themselves generated new knowledge (DeBoer, 2004). This meant that authentic scientific inquiry, research that scientists actually carry out (Chinn & Malhotra, 2002), would become the model for classroom teaching and learning. In looking at the major difference between this period’s version of inquiry teaching and the earlier versions, this version was linked even more closely to authentic scientific inquiry in order to make it as intellectually rigorous as possible. Theorists argued that learning science is learning it in the way that scientists understood it, including both the content and the modes of inquiry that were used (DeBoer, 2004; Schwab, 1962). Whether it is learned through the laboratory or through a textbook, the conclusions of science and the evidence that supported those conclusions would go hand-in-hand.

The individual most often associated with the reform movement’s notion of scientific inquiry was Joseph Schwab (1909-1988). According to Schwab (1962), scientific content and processes were intimately connected and inseparable. Because of
this, content should be taught in relation to the methods that generated new knowledge. However, it is important to note that Schwab’s main interest was not in preparing students to be inquirers into the nature of the physical world but to have the fullest and most complete understanding of science as possible, both its content and its methods. He argued that in this way, students could develop a firm foundation for further study of science if they were to become scientists, or they would simply be sympathetic to the scientific enterprise if they did not carve out science careers.

Although Schwab (1962) and other educational leaders of the time (e.g., Herron, 1971; Hurd, 1958; Rutherford, 1964) recognized the usefulness of direct teaching in scientific discovery, they believed that it was more important to have students conduct their own investigations because they believed this promoted deeper intellectual engagement with the content and more meaningful understanding of the nature of scientific processes.

**Scientific inquiry in contemporary times**

Scientific inquiry in classrooms became more visible in the publications of the United States policy documents for K to 12 science education in the late 1980s and early 1990s (Crawford, 2014). For example, *Science for All Americans* (American Association for the Advancement of Science [AAAS], 1989) is a document that recommended science teaching be consistent with the nature of scientific inquiry. This document emphasized that “students need to get acquainted with the things around them—including devices, organisms, materials, shapes, and numbers—and to observe them, collect them, handle them, describe them, become puzzled by them, ask questions about them, argue about them, and then try to find answers to their questions” (AAAS,
1989, p. 201). After this publication, the *National Science Education Standards* (NRC, 1996) was published which made clear that scientific inquiry was the preferred method of teaching science in the United States. This is an all-encompassing document that includes a wide range of content and process goals. In this document and the follow-up volume, *Inquiry and the National Science Education Standards* (NRC, 2000), scientific inquiry is described as “a set of interrelated processes by which students pose questions about the natural world and investigate phenomena; in doing so, students acquire knowledge and develop a right understanding of concepts, principles, models, and theories” (NRC, 1996, p. 214). Finally, the most recent iteration of scientific inquiry in classrooms in the United States occurs in the new *Framework for K-12 Science Education* (NRC, 2012) and the *Next Generation Science Standards* (NGSS) (Achieve, Inc., 2013). In the new Framework, science learning is structured around three dimensions: (1) the disciplinary core ideas, (2) the scientific and engineering practices, and (3) the key crosscutting concepts (Pellegrino, Wilson, Koenig, & Beatty, 2014). The second dimension highlights the scientific practices commonly used by scientists but, this time, engineering practices were included in the Framework to help students appreciate that “engineering in scientific investigation requires not only skill but also knowledge specific to each practice” (NRC, 2012, p. 30). The NGSS described specific goals for science learning in the form of performance expectations, statements about what students should know and be able to do at each grade level, and thus what should be tested at each grade level. Each performance expectation incorporates the three dimensions. Both documents emphasized that science and engineering education should support the integration of these three dimensions that are needed by students to be able to engage in scientific inquiry and engineering design.
It is notable that all the aforementioned documents argued for the importance of scientific inquiry in classrooms in giving an accurate portrayal of scientific investigation, in contributing to one’s personal intellectual development, and in offering a way of thinking that would be used in the solution of everyday problems. But perhaps the primary justification for using scientific inquiry, particularly in the NRC’s publications, is the argument that it is a more effective teaching strategy, more engaging, and that students learn more from inquiry-based approaches to teaching (DeBoer, 2004). However, it is important to recognize that there appears to be no single way to think about what scientific inquiry is and no single argument that justifies its use. It is a multifaceted approach to teaching that can be used to accomplish different purposes for different reasons. Although the K to 12 science education reform documents in the United States highlighted the importance of inquiry, and referred to inquiry as a central teaching strategy, researchers in the United States (e.g., Capps & Crawford, 2013; Crawford, 2007; Minstrell & van Zee, 2000) claimed that few teachers actually used inquiry to teach science in the classroom. According to them teachers usually have limited views of inquiry-based instruction, which are reflected in their classroom teaching practice.

During this time, inquiry became prominent in curricula for basic science education in other parts of the world and most countries emulated the United States reform documents on inquiry science education (Abd-El-Khalick et al., 2004). In Europe, inquiry-based teaching and learning are part of science instruction, curricula, and teacher professional development programs (Heinz et al., 2017). Features of inquiry, like dialogues, discussion, and collaborative working are frequently recommended in the European educational policy documents (Heinz et al., 2017).
According to Ropohl, Ronnebeck, Bernholt, & Koller (2013), several European Union (EU)-funded projects (e.g., Science-Teacher Education Advanced Methods [S-TEAM], Strategies for Assessment of Inquiry Learning in Science [SAILS], Promoting Inquiry in Mathematics and Science Education [PRIMAS], Professional Reflection-Oriented Focus on Inquiry-based Learning and Education through Science [PROFILES]) have been initiated in the field of inquiry-based science education since 2008. Most of these projects focused on the professional development of teachers in implementing inquiry in their classrooms, promotion of widespread use of inquiry in teaching and learning of science and mathematics, and development of inquiry-based resources and materials (Ropohl et al., 2013).

While scientific inquiry is the main focus of the European basic science education policy, there is a lack of knowledge about the conditions that influence its implementation (Heinz et al., 2017). European researchers (e.g., Heinz et al., 2017; Ropohl et al., 2013) attributed this to the considerable variation that exists between the educational systems in each EU country, which has resulted in implementation of inquiry-based teaching and learning in varying degrees in each country’s science education program.

The South African basic education system also advocated scientific inquiry in the teaching and learning of science (Ramnarain, 2016). The school science curriculum advocated inquiry, which encouraged learners to “explore objects, situations and events in their immediate environment, to collect data and record information, and draw conclusions accurately” (Department of Education, 2002, p.34). This was also emphasized in the new Curriculum and Assessment Policy Statement (CAPS) document which stated that physical sciences is a subject that “promotes knowledge and skills in
scientific inquiry and problem solving; the construction and application of scientific and technological knowledge; an understanding of the nature of science and its relationships” (Department of Basic Education, 2011, p.8). According to Ramnarain (2016), the implementation of inquiry teaching and learning in the diverse South African educational landscape is inextricably context-dependent, and such implementation interacts in significant ways with national educational policy, science teachers’ background, professional development, school culture, governance, and resources, among a number of other factors.

In Australia, the curriculum for pre-tertiary science education contains two strands, namely the nature and influence of science and science inquiry skills, particularly on skills essential for working scientifically (ACARA, 2014). The skills, knowledge, and information associated with scientific inquiry were embedded in the scope and sequence of general capabilities in Science, History, Geography, Economics and Business, Civics and Citizenship, Critical and Creative Thinking (CCT), and Information and Communication Technology (ICT) (Lupton, 2014). This clearly shows that inquiry was given emphasis in the Australian primary and secondary education systems. With this, Australian teachers and schools were mandated to incorporate inquiry at some level into their regular classroom practice (Fitzgerald et al., 2017). However, implementing this approach in a typical science classroom was challenging for Australian teachers due to the influence of extrinsic (e.g., time) and intrinsic (e.g., views on inquiry-based teaching) factors (Fitzgerald et al., 2017).

Asian countries such as China (Ministry of Education of the People’s Republic of China [MEPRC], 2001), Korea (Ministry of Education [MOE], 2007), Singapore (Ministry of Education [MOE], 2007), and Taiwan (Ministry of Education [ME], 1999)
have included scientific inquiry as one of the important features of the school science curriculum. They all have a common goal of developing students’ inquiry and research abilities. For example, in Korea, the MOE initiated the revision of the science curriculum by adding mandatory open inquiry practice for at least six hours per year from Grade 3 to Grade 10 (MOE, 2007). The revised science curriculum has been implemented in primary and secondary schools since 2010 (Park & Lee, 2011). The purpose of revision was for the students to conduct inquiry, from planning of experiments to reporting of results, and to collaborate with other students in school (MOE, 2007). Korean researchers (e.g., Kim, Yoon, Lee, & Cho, 2010; Park & Lee, 2011) have explored the implementation of the science curriculum in classrooms. They found that, contrary to the Government’s expectation, teachers were mainly responsible for determining the research topics of students, and students often conducted inquiry alone as an out-of-school assignment. According to the researchers, these findings were attributed to some factors like insufficient time, tight curricula, large class sizes, and low confidence in teaching and practicing of inquiry (Kim et al., 2010).

The Philippines is a new addition to the list of Asian countries giving importance to scientific inquiry in basic science education. In 2012, the Philippine Department of Education initiated a science curriculum reform where scientific inquiry was included as one of the salient features of the curriculum (DepEd, 2013b). The present research explored the implementation of this inquiry-based science curriculum in Philippine classrooms and this is described in more detail below.
Historical Perspectives on Scientific Inquiry in Philippine Classrooms

How was scientific inquiry incorporated into pre-tertiary science education in the Philippines?

In the Philippines, the upsurge of research, curriculum development, and teacher training in science for pre-tertiary education began in the 1960s and continued into the 1970s (UP NISMED & Foundation for the Promotion of Science and Mathematics Education and Research [FPSMER], 2001). Since its early years, the University of the Philippines Science Education Center (UP SEC), now known as the University of the Philippines National Institute for Science and Mathematics Education Development (UP NISMED), had developed science textbooks, laboratory manuals, and teachers’ guides with an emphasis on inquiry learning. Development of these materials was made possible because of the establishment of UP SEC with curriculum development as its primary mandate. This reform promoted active involvement of the students in doing activities in the classroom with an emphasis on the relationship of concepts and processes to develop content knowledge and science process skills. Key indicators of desirable habits, scientific disposition, science process skills, and values along with the cognitive objectives were also included in each teaching unit (UP NISMED & FPSMER, 2001).

The developed materials required a new teacher orientation in science teaching. Because of this, teachers went through in-service training programs such as workshops, seminars on teaching strategies, equipment improvisation, and assessment procedures. For many years, starting in 1993, teacher-training programs in the Philippines zeroed in on the use of practical work approaches to teaching and learning (SEI-DOST & UP NISMED, 2011a). This approach requires science teachers to use hands-on activities to
stimulate students’ curiosity and imagination. During this period, in-service training programs had successfully exposed many teachers to new student-centered materials and approaches. However, teachers’ and school administrators’ commitment to sustain the programs was criticized as inadequate (UP NISMED & FPSMER, 2001). After applying the ideas learned in the training, many teachers went back to the same lecture-oriented method of the past (UP NISMED & FPSMER, 2001). In 2012, the Philippine Department of Education and its stakeholder allies responded to the urgent and critical need to improve the quality of basic education through the K to 12 education reforms.

**A brief background on K to 12 education reform in the Philippines**

As described in Chapter 1, the K to 12 program in the Philippines covers Kindergarten and 12 years of school education (six years of primary education, four years of junior high school, and two years of senior high school) to provide sufficient time for mastery of concepts and skills and to develop lifelong learners. This program was first implemented in Kindergarten in the school year (SY) 2011-2012. The enhanced curriculum for Grade 1 and Grade 7 (1st year junior high school) was rolled out in SY 2012-2013, and progressively introduced in other grade levels in succeeding school years. Meanwhile, Grade 11 was introduced in SY 2016-2017 and Grade 12 was introduced in SY 2017-2018. In this scheme, the first batch of high school students to go through K to 12 will graduate in March 2018. The K to 12 curriculum framework aims to foster a holistically developed Filipino with 21st century skills so that Filipino graduates will be prepared for higher education, middle-level skills, employment, and entrepreneurship (SEAMEO-INNOTECH, 2015). Compared with the previous ten-year basic education system, which was congested and outdated in terms of desired
competencies and content (SEAMEO-INNOTECH, 2015), the K to 12 curriculum was enriched to make it more relevant and responsive to students’ needs (DepEd, 2013b).

The Philippine Education for All 2015 Review Report (SEAMEO-INNOTECH, 2015) outlined the following features of K to 12 curriculum reforms which aim to address the shortcomings of the previous curriculum. It can be summarized as follows:

1. The K to 12 curriculum aims to be decongested. The new curriculum focuses on understanding for mastery and has removed unnecessarily repeated competencies.

2. The K to 12 curriculum aims to be seamless. This ensures smooth transition between grade levels and continuum of competencies through spiral progression where learning of knowledge, skills, values, and attitudes increases in depth and breadth. There is also continuity of competencies and standards from elementary to secondary level through a unified curriculum framework. The unified standards and competencies ensure integration of what learners learn across grade levels and across learning areas for more meaningful learning.

3. The K to 12 curriculum aims to be relevant and responsive as it focuses on the Filipino learner. It is developmentally appropriate (age-appropriate) and focuses on succeeding in the 21st century. Moreover, the curriculum responds to the needs of the community. For example, an agricultural town may offer agricultural elective courses; a coastal area, fishery elective courses; and an urban area, industrial arts. Learning will be systematically matched with labor market requirements.
4. The K to 12 curriculum aims to be learner-centered. It focuses on the optimum development of the Filipino learners.

5. The K to 12 curriculum aims to be enriched. It uses integrative, inquiry-based and constructive approaches to develop the competencies of the learners (SEAMEO-INNOTECH, 2015).

How is inquiry incorporated into the K to 12 education reform in the Philippines?

The new K to 12 science curriculum in the Philippines now includes statements outlining the progression of inquiry skills and expectations of the rate at which students will develop these skills (Ferido, Robertson, Care, & Bustos, 2015). The curriculum emphasizes the understanding and application of scientific knowledge, learning scientific inquiry skills, and developing and demonstrating scientific disposition and beliefs (DepEd, 2016). In 2014, a group of researchers from the ACTRC, a partnership between the University of Melbourne and the University of the Philippines, conducted a scoping study into the teaching of scientific inquiry skills using the new K to 12 curriculum—Delivery of Science Inquiry Skills in K to 12 Curriculum (ACTRC, 2014). They found that scientific inquiry skills such as observing, classifying, measuring, inferring, and hypothesizing were represented at some point in the key stage standards of the new K to 12 curriculum guide (K-3, Grade 4-6, 7-10 and 11-12) but these skills were less well represented in all grade level standards (K, Grade 1, Grade 2, etc.) and sparsely represented in some parts of the learning competencies for the different science units at the grade levels (e.g., Living Things and their Environment, Grade 8). However, scientific inquiry skills are clearly represented in the newly developed Learners’
Modules and Teachers’ Guides, although some skills appear repeatedly in those texts, while others are not mentioned. These new elements of the curriculum address some of the recommendations resulting from a comparison of the Philippines curriculum with other Southeast Asian countries (Care & Griffin, 2011).

In addition, the organization of the science curriculum has also changed so that concepts and inquiry skills are now revisited at each grade level with increasing depth (spiral progression approach). This approach is a significant change in the new curriculum as previously science was taught by discipline (discipline-based) per grade level in secondary schools. For example, in Grade 8, students studied biology for the whole school year, in Grade 9, students took chemistry, and physics was taught at Grade 10. The intention of this change is to better equip school leavers to make a contribution as “scientifically, technologically, and environmentally literate and productive members of society” (DepEd, 2016, p. 2). The new curriculum has been accompanied by changes to the recommended assessment practices to support the assessment of students’ skills (DepEd, 2012).

The concept of scientific inquiry in classrooms is not new to Filipino teachers. It had been already mentioned in various science curriculum documents (e.g., DepEd, 2002a, 2002b; SEI-DOST & UP NISMED, 2011b). Professional development for teachers is widely conducted to properly orient and present the benefits of inquiry-based teaching (Gutierez, 2015; SEI-DOST & UP NISMED, 2011a). However, it appears there may still be exists a big gap in the effective implementation of scientific inquiry in the classroom (Gutierez, 2015; Montebon, 2014; SEI-DOST & UP NISMED, 2011a).
Chapter Summary

Researchers have different views about inquiry teaching in the science classroom. Thus, in this chapter, tracing the history of scientific inquiry has been laid out and synthesized to clarify the various meanings that this teaching approach has had and to review the arguments used to justify its use in classrooms. The historical perspectives on scientific inquiry in classrooms revealed four aspects—students doing inquiry-based practice, students learning science concepts through inquiry, students learning the nature of scientists’ inquiry-based practice, and teachers teaching science through inquiry. The justification for using scientific inquiry as a teaching approach in classrooms has changed according to the educational philosophy of its supporters (e.g., Dewey, 1910b; Schwab, 1962). Despite the early arguments presented to justify its use in classrooms (e.g., Spencer, 1864; Dewey, 1910b; Schwab, 1962), history showed that scientific inquiry remained an essential component of science education throughout the years (Chiapetta, 2008; DeBoer, 2004). Understanding the variety of ways that scientific inquiry can be used and the range of meanings it can have should aid educators in moving toward effective pedagogies that deepen students’ engagement with scientific ideas and processes, thus motivating them and giving them a better sense of what science involves. Enacting inquiry-based curricula in classrooms designed by organizations was challenging for teachers, as shown in the analysis of the historical background of inquiry (Capps & Crawford, 2013; Fitzgerald et al., 2017; Ramnarain, 2016; UP NISMED & FPSMER, 2001). It is evident that sometimes the intended inquiry-based curriculum was not implemented in classrooms (Bull et al., 2010; Heinz et al., 2017; Kim et al., 2010).
With a renewed focus on teachers enacting inquiry-based pedagogy, there is a need for research to track the progress of scientific inquiry teaching and learning in classrooms (Crawford, 2014). This is to address the lack of detailed investigation of the specific practices of inquiry employed by teachers in the classroom and of how each of these practices is related to science learning. This renewed focus on inquiry was given emphasis in the K to 12 education reform in the Philippines (SEAMEO-INNOTECH, 2015), specifically in the new science curriculum (DepEd, 2016; Ferido et al., 2015). It can be noted that inquiry had gained recognition in Philippine science education in 1970s (UP NISMED & FPSMER, 2001). The present study explored inquiry-based teaching and learning in Philippine classrooms under the K to 12 education reform. This aimed to address the lack of empirical research on specific practices of inquiry-based teaching employed by science teachers in developing countries. This study provided an image of how teachers in a developing country, like the Philippines, used inquiry as a teaching approach in the presence of particular challenges in the teaching and learning environments. This could inform educators on the diversity of inquiry-based teaching implementation particularly those who are working in the same education environment in other developing countries. The aspects that have been mainly addressed in this study were the specific inquiry teaching practices of teachers while using the new science curriculum, teachers’ participation in the professional development on using the new curriculum conducted by the Department of Education in the Philippines, and student learning in science in relation to specific inquiry teaching practices of teachers. As inquiry becomes the central focus of teaching and science classroom research, many researchers have identified the characteristics of scientific inquiry that are relevant for basic science education. More details about this are discussed in Chapter 3.
Chapter 3: Reviewing What Research Says About Scientific Inquiry and How it is Assessed in Classrooms

This chapter is divided into two parts. The first part reviews the research literature on scientific inquiry in pre-tertiary science education. It presents research-based information on general characteristics of scientific inquiry that are useful in basic education, on inquiry teaching models and how they were used in classroom research, on teachers’ implementation of inquiry teaching in the classroom, and on student learning through inquiry. Since this study involves observation of inquiry teaching practices of teachers and measurement of student learning outcomes, the second part reviews the methods used to assess inquiry teaching and learning in the science classroom. It discusses tools such as observation protocols, teacher questionnaires, and science tests that were used to assess teachers’ inquiry teaching and students’ learning in science. In addition, it discusses a Rasch (1960) modeling approach to measurement, which is argued to be beneficial for determining student learning outcomes.

How is Scientific Inquiry Characterized in the Research Literature?

Researchers and educators have identified general characteristics of scientific inquiry that are particularly relevant to pre-tertiary science education. Crawford (2007) conducted a study that examined the knowledge, beliefs, and efforts of five prospective teachers to enact scientific inquiry in high school classrooms. In her study, Crawford presented seven characteristics of scientific inquiry, which were based on the NRC’s (1996, 2000) science education reform documents in the United States, the National Science Education Standards and the Inquiry and the National Science Education...
Standards. She used these characteristics as a framework for data analysis in inquiry teaching research. Below are the characteristics of scientific inquiry identified by Crawford (2007, p. 618):

1. Scientific inquiry involves asking and answering a question and comparing the answer with what scientists already know about the world.
2. Data analyses are directed by questions of interest, involve representation of data in meaningful ways, and involve the development of patterns and explanations that are logically consistent.
3. Investigations have multiple purposes and use multiple methods.
4. Scientists formulate and test their explanations by examining evidence, and they suggest alternative explanations.
5. Scientists often work in teams with different individuals contributing different ideas.
6. Creativity is found in all aspects of scientific work.
7. Scientists make the results of their investigations public.

It can be inferred from these characteristics that scientific inquiry has the following components: scientific questions, investigations, data, explanations based on evidence, collective works in science, and dissemination of scientific results. Some of these components can be observed in science classrooms as strategies of teachers to teach science (e.g., questioning), or as activities of students to do science (e.g., performing investigations). With this, it can be argued that in school science education, scientific inquiry components can be used as a teaching approach, which may allow students to experience how to do the processes of science. Based on this argument, it is therefore
important for classroom teachers to be informed of the characteristics of scientific inquiry so that they can guide their students in doing inquiry.

Reform documents in K to 12 science education that focus on scientific inquiry—*Benchmarks for Science Literacy* (AAAS, 1993), *National Science Education Standards* (NRC, 1996), *Inquiry and the National Science Education Standards* (NRC, 2000), and *Scientific Research in Education* (NRC, 2002) along with science educators (e.g., Chinn & Malhotra, 2002; Flick & Lederman, 2004; Minstrell & van Zee, 2000; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003; Windschitl, 2004), and researchers who have explored scientists in practice (e.g., Dunbar, 2001; Knorr-Cetina, 1999) have provided key descriptions about the nature of scientific inquiry that became the framework for identifying the general characteristics of scientific inquiry developed by Schwartz, Lederman, and Lederman (2008). This group of researchers identified the common aspects of scientific inquiry from the aforementioned framework which led them to develop descriptions about scientific inquiry that are relevant and important for basic science education. They called these descriptions the *Aspects of the Nature of Scientific Inquiry*. According to Schwartz et al. (2008), these aspects are not new and they were consistent with the description of scientific inquiry suggested by Schwab in 1962. As discussed in the earlier section of this dissertation, Schwab was recognized as the individual most often associated with the curriculum reform movement’s notion of scientific inquiry (DeBoer, 2004). The general aspects of the nature of scientific inquiry developed by Schwartz et al. (2008) are presented below.

1. Scientific question guide investigations
2. Multiple methods of scientific investigations
3. Multiple purposes of scientific investigations
4. Justification of scientific knowledge

5. Recognition and handling of anomalous data

6. Distinctions between data and evidence

7. Community of practice

These aspects of scientific inquiry were used as indicators in the questionnaire developed by Schwartz et al. (2008) in order to assess students’ views of scientific inquiry. Based on these aspects, scientific inquiry involves scientific questions, different kinds and purposes of investigations, scientific explanations based on evidence, difference between data and evidence, and communication and peer review. It can be noticed that most of these components of inquiry are also identified in the previously discussed characteristics of inquiry. It can be argued that in school science education it is important to explicitly discuss with students what is meant by each of these components so that they know not only how to do the process but also the reasons or justifications for doing it.

In Chapter 2, it was mentioned that the most recent iteration of scientific inquiry in K to 12 classrooms in the United States was presented in the new document *Framework for K-12 Science Education* (NRC, 2012). With this, a group of researchers led by Lederman et al. (2014) referred to this document to revise and update the aspects of the nature of scientific inquiry developed by Schwartz et al. in 2008. This time, they came up with eight aspects of scientific inquiry which are educationally and developmentally appropriate for K to 12 students. The following outlines the aspects of scientific inquiry developed by Lederman et al. (2014, p. 68).

1. Scientific investigations all begin with a question but do not necessarily test a hypothesis.
2. There is no single set and sequence of steps followed in all scientific investigations (i.e., there is no single scientific method).

3. Inquiry procedures are guided by the question asked.

4. All scientists performing the same procedures may not get the same conclusions.

5. Inquiry procedures can influence the conclusions.

6. Research conclusions must be consistent with the collected data.

7. Scientific data are not the same as scientific evidence.

8. Explanations are developed from a combination of collected data and what is already known.

Lederman et al. (2014) used these aspects of scientific inquiry as a framework for the development of the *Views About Scientific Inquiry* questionnaire. According to Lederman et al. (2014), these eight aspects represent the necessary knowledge about scientific inquiry that the students need to acquire, in addition to learning how to perform the processes of scientific inquiry. It can be argued that these aspects of scientific inquiry are also important for teachers to learn, especially if they are using inquiry as a teaching approach in science, in order for them to implement this approach appropriately.

The foregoing different sets of aspects of scientific inquiry were examined to identify the common characteristics of inquiry that the researchers considered relevant to school science education. Based on literature, the researchers who developed these aspects have extensively explored inquiry in the science classrooms. It is important to note that these sets of aspects of scientific inquiry were not completely addressed in the present study. Although these researchers and educators offered different sets of
characteristics of scientific inquiry, they all have exhibited commonalities in the following characteristics. These common characteristics were derived after examining the aforementioned aspects of scientific inquiry.

1. Scientific inquiry involves asking questions.
2. Different methods of investigation can be designed in scientific inquiry.
3. Scientific inquiry involves data and evidence, which are distinct from each other.
4. Explanations are generated from doing scientific inquiry based on evidence.
5. Results are presented to the community by means of communicating information.

These five general characteristics of scientific inquiry were given emphasis and significance in the development of the following instructional models available in the literature, which can be used in classrooms to teach science through inquiry. These characteristics were juxtaposed with teaching practices of teachers to characterize the nature of their inquiry-based teaching in classrooms.

What are the Models of Scientific Inquiry and the Evidence of Using these in Classroom Research?

In teaching science in K to 12 classrooms, teachers may use a number of instructional models which range from teacher-centered to those that are student-centered (Treagust & Tsui, 2014). These instructional models, which are also called learning cycles (Atkin & Karplus, 1962), teaching sequences (Driver & Oldham 1986), heuristics (Magnusson et al., 2004), or pedagogical frameworks (Poon et al., 2012),
offer broad guidance on the steps that a teacher might use to plan and deliver a lesson. In science teaching, some instructional models were designed to promote inquiry teaching and learning in the classroom (Marshall, Horton, & Smart, 2009). In addition, most K to 12 science curriculum documents around the globe include scientific inquiry as one of their essential features. With the emphasis given to inquiry in science teaching, models of scientific inquiry, as outlined below, have been used in different countries (e.g., Iran, Kenya, Singapore, Taiwan, Turkey, and the United States) to help teachers deliver inquiry-based approaches in the classroom. It is acknowledged that every model used to promote scientific inquiry in classrooms has its own merits, but the review of scientific inquiry models in this study was limited to those that are designed for science education at the primary and secondary school settings, have reference to a constructivist or socio-constructivist focus, and are more directly focused on students’ learning in an inquiry science environment. A review of the essential components of scientific inquiry as a teaching approach and a summary of each model of scientific inquiry as shown in instructional models and science curriculum documents used in science education at the primary and secondary schools are presented below. Details on how the models of scientific inquiry applied in classroom research are also discussed.

Inquiry in science instructional models

Models used as framework for developing materials for inquiry teaching

The BSCS 5E model. This research-based instructional model is a theoretically driven framework used in the development of new curriculum materials for use in science teaching, and in teachers’ professional development programs (Bybee et al., 2006). Aside from the United States, this model was used in other countries (e.g., Iran,
Kenya, Singapore, Taiwan, and Turkey) to teach science in schools (Fazelian, Ebrahim, & Soraghi, 2010; Lin et al., 2014; Opara & Waswa, 2013; Poon et al., 2012; Sen & Oskay, 2017). It consists of five phases—the 5 Es—engage, explore, explain, elaborate, and evaluate (Biological Sciences Curriculum Study [BSCS] & International Business Machines [IBM], 1989; Bybee, 2004). Each phase has a specific function and contributes to the teacher’s coherent instruction and to the learners’ formulation of a better understanding of scientific and technological knowledge, attitudes, and skills (Bybee et al., 2006). Researchers have carried out extensive efficacy studies of curricular materials based on the 5E model and have shown evidence of increased mastery of subject matter compared with other modes of instruction such as typical laboratory experiences (Bybee et al., 2006; Poon et al., 2012). Each phase of the 5E model can be summarized as follows:

1. Engagement—engage students in the concept, process, or skill to be explored
2. Exploration—students actively explore their environment or manipulate materials
3. Explanation—students pay attention to a particular aspect of their engagement and exploration experiences and teachers provide opportunities for them to verbalize their conceptual understanding, or demonstrate their skills or knowledge
4. Elaboration—extend students’ conceptual understanding and practice skills or behavior to develop deeper and broader understanding, more information, and adequate skills
5. Evaluation—assess students’ understanding and abilities
In the publication entitled *The BSCS 5E Instructional Model Creating Teachable Moments*, Bybee (2015) emphasized that the BSCS 5E instructional model provides classroom teachers with an approach to teaching that changes the emphasis within lessons and provides a sequence that increases the probability of teachable moments. According to Bybee, teachable moments occur in classrooms when students were totally engaged because of phenomena, events, or situations that brought forth a need to know and increased motivation to learning. These moments can be created in classrooms through the BSCS 5E model. Although the BSCS 5E model and scientific inquiry are not exactly the same, the BSCS 5E is an instructional model that is based on constructivism which offers strong guidance and support for a teaching approach that promotes inquiry among students. It can be argued that each phase of this model provides experiences and strategies for students to construct their own learning within the context of experiences consistent with scientific inquiry.

*The EIMA model.* This research-based instructional model is a framework used for developing inquiry-based lesson materials and scientific models in science teaching (Poon et al., 2012; Schwarz & Gwekwerere 2007). It consists of four phases: engage, investigate, model, and apply (EIMA). In this model, scientific modeling is given greater emphasis to give students the opportunity to create and refine explanations for the phenomena they investigate. Based on a small-scale study of 24 pre-service teachers, this model was found to be effective in helping them learn how to design lesson materials around model-based scientific inquiry (Schwarz & Gwekwerere 2007). The pre-service teachers also taught the lesson plans that they designed in their field placements with the use of the EIMA model. After using this in classrooms, most pre-service teachers (two thirds of the class) changed their teaching orientations from
traditional didactic approaches to reform-based approaches such as inquiry. With this, Schwarz and Gwekwerere (2007) argued that using the EIMA model could enable pre-service teachers to socially construct, synthesize, and apply their knowledge for enacting reform-based teaching approaches such as inquiry. Below is a description of each phase:

1. Engage—engage students’ prior knowledge and interest in a topic
2. Investigate—collect and analyze data to generate patterns or rules
3. Model—use data to create models that provide coherent explanations for the observations
4. Apply—test and apply models in novel situations

The guided-inquiry model. This model consists of five phases—engage, prepare to investigate, investigate, prepare to report, and report (Magnusson & Palincsar, 1995; Magnusson et al., 2004) which can be summarized as follows:

1. Engage—engage students in questioning
2. Prepare to investigate—involves students in preparing questions, materials, methods, design, and test of explanation
3. Investigate—students derive knowledge claims about the physical world and their community
4. Prepare to report—students are asked to determine claims and evidence
5. Report—students are asked to share the results of their investigative activity to the community

In Indonesia, the guided-inquiry model was used as a framework for developing science learning materials for teachers to use in inquiry-based teaching (Putra, Widodo, & Jatmiko, 2016). After implementing this material with pre-service teachers in a one-
semester period, researchers found that there was an improvement in the science literacy skills of prospective teachers. In the United States, this model was used in teaching students with learning disabilities and has shown positive outcomes in students’ engagement and learning of science (Palincsar, Collins, Marano, & Magnusson, 2000). Similar positive results were observed in science achievement, attitude, and process skills of mainstream primary and middle school students in Turkey and Greece when their teachers used the guided-inquiry instruction approach (Koksal & Berberoglu, 2014; Vlassi & Karaliota, 2013).

Based on the phases of this instructional model, it is arguable that it is aligned with socio-cognitive perspective of learning in which knowledge can be developed through the practices of a community (Magnusson et al., 2004). The two instructional models previously discussed seemed to align more with cognitive constructivist perspective of learning. But all of them support inquiry teaching and inquiry learning in the science classroom.

**A model that emphasized authentic inquiry in science teaching**

The 3D inquiry model. This recent model of scientific inquiry depends on three dimensions (3D)—conceptual, procedural, and personal. Bevins and Price (2016) argued that some existing models reduce the essence of inquiry by focusing more on a sequence of tasks driven by a mechanistic approach which, according to them, is unhelpful in the context of authentic inquiry. Because of this, they proposed the 3D inquiry model, and they argued that using this model could avoid algorithmic and passive learning, a consideration that is essential for inquiry teaching in the science classroom as it reflects more closely authentic science than other inquiry models. They
also claimed that this model could promote student motivation and has the potential for encouraging student autonomy. Bevins and Price (2016) argued that the 3D model in total is novel and they proposed to use an action research approach to develop this model with classroom teachers and students. The three interrelated dimensions can be summarized as follows:

1. Conceptual dimension—this demonstrates scientists’ thinking about phenomena and can generate questions and suggestions for inquiry. This dimension includes theories of science to explain phenomena and verifiable facts about a particular situation.

2. Procedural dimension—this ensures evidence is generated reliably, interpreted with reference to the underlying ideas and the observed data and communicated appropriately. Other procedures that make up this dimension are identifying and controlling variables, careful experimentation, hypothesis generation, and data analysis.

3. Personal dimension—this provides the willingness to create and manage an authentic inquiry. This is the dimension that elevates the algorithmic procedures of Dimension 2 into a dynamic, active process that has the potential to generate new knowledge.

**Inquiry in science curriculum documents**

**Essential features of scientific inquiry**

The NRC (2000) through its publication entitled *Inquiry and the National Science Education Standards* outlines the five features of inquiry in science classrooms. These features have been used extensively in science education research as a framework
for discussing inquiry-based instruction in classrooms (Capps, Crawford, & Constas, 2012; Crawford, 2012; Kang, Orgill, & Crippen, 2008; Kim et al., 2013; Yang, Soprano, & McAllister, 2012). For instance, Kang et al. (2008) investigated teachers’ conceptions of inquiry in terms of the characteristics of inquiry activities used in their classrooms. These characteristics identified by the teachers were juxtaposed to the five essential features of inquiry in order to characterize their conceptions of classroom inquiry. Crawford (2012) also used the five essential features of inquiry to describe how classroom teachers engage their Grade 5 students in doing authentic science. She then investigated the impact of their inquiry instruction on student learning of science concepts, principles, and nature of science. She found that when students were engaged in authentic science through performing the essential features of inquiry, students acquired better understanding of concepts and nature of science. Moreover, Yang et al. (2012) conducted an analysis of inquiry components in the science curriculum of Taiwan using the five essential features of inquiry. They determined the variations of inquiry involved in the science activities included in the curriculum. The summary of each feature is presented below:

1. Engages in scientifically-oriented questions—involve students in a scientifically-oriented question
2. Collects evidence—give priority to evidence in responding to the question
3. Formulates explanations from evidence—use evidence to develop an explanation
4. Connects explanations with knowledge—examine sources of scientific knowledge and form the links to explanations
5. Communicates and justifies explanations—form reasonable and logical argument to communicate explanations

**Elements of inquiry-based education (IBE)**

In one of the European Union (EU) funded research projects in science education called the *European Science and Technology in Action Building Links with Industry, Schools, and Home (ESTABLISH)*, science curricula for basic education in eleven participating EU countries were analyzed, and fundamental abilities of students in Inquiry-Based Education (IBE) were outlined based on the nine elements of IBE proposed by Linn, Davis, and Bell (2004) as indicated below.

1. **Diagnosing problems**—identify the core of the problems and use prior knowledge to be able to form working hypothesis

2. **Critiquing experiments**—formulate arguments, state outcomes in a comparative way, and suggest further developments

3. **Distinguishing alternatives**—identify key elements of the problem and express alternatives in suitable form

4. **Planning investigations**—students set a time frame, steps involved, resources required, and training in use of any equipment

5. **Testing hypothesis**—test hypothesis which follows from observations, facts previously gathered, or preliminary theories

6. **Searching for information**—define what to search using the right resources and identify sources of information relating to intervening variables

7. **Constructing models**—construct models that can be checked, proved, disproved, adapted, and improved
8. Debating with peers—discuss and regard different interpretations of experimental results and work collaboratively

9. Forming coherent arguments—students form arguments and conclusion based on evidence

Based on curriculum analysis, most of these elements were explicitly stated in the national curricula of the eleven European countries (Cyprus, Czech Republic, Germany, Estonia, Ireland, Italy, Malta, Netherlands, Poland, Slovakia, and Sweden) which participated in the ESTABLISH project (McLoughlin, 2011).

**Scientific practices for K to 12 classrooms**

In the new *Framework for K-12 Science Education* of the United States, NRC (2012) outlined the following eight scientific practices that are essential elements for K to 12 science curriculum. These practices are derived from those that scientists and engineers actually engage in as part of their work, which can be summarized as follows:

1. Asking questions—ask questions about the natural and human-built worlds; distinguish a scientific question from a non-scientific one

2. Developing and using models—construct drawings or diagrams as representations of events or systems; represent and explain phenomena with multiple types of models

3. Planning and carrying out investigations—plan experimental or field-research procedures, identify relevant independent and dependent variables, and when appropriate, the need for controls

4. Analyzing and interpreting data—analyze data systematically, either to look for salient patterns or to test whether data are consistent with an initial
hypothesis; use spreadsheets, databases, tables, charts, graphs, mathematics
to collate, summarize, and display data

5. Using mathematics and computational thinking—recognize dimensional
quantities and use appropriate units in scientific applications of mathematical
formulas and graphs; express relationships and quantities in appropriate
mathematical forms

6. Constructing explanations—construct own explanations of phenomena using
knowledge of accepted scientific theory and linking to models and evidence

7. Engaging in argument from evidence—construct a scientific argument
showing how data support a claim

8. Obtaining, evaluating, and communicating information—use tables,
diagrams, and graphs as well as mathematical expressions, to communicate
their understanding or to ask questions about a system under study

This framework is embedded in the Next Generation Science Standards (NGSS)
in the United States where these eight scientific inquiry practices are clearly presented
and articulated (National Academies, 2013). The NGSS reflects the framework by
focusing on a small set of core ideas, emphasizing deep understanding and application
of content, and building a coherent progression of concepts over the course of students’
K-12 science education (National Academies, 2013). As of November 2017, nineteen
states and the District of Columbia have adopted the NGSS and are currently working to
implement this in districts and schools (National Science Teachers Association, 2017).
Science leaders across the United States have embraced the vision of the framework,
whether or not their states are planning to adopt NGSS (Penuel, Harris, & Debarger,
2015).
Summary of the foregoing scientific inquiry models identified through research

Researchers have different views about teaching science in K to 12 classrooms. However, the emphasis placed on scientific inquiry appears to be an essential theme of K to 12 science education documents. After examining all the aforementioned models of scientific inquiry as shown in instructional models and science curriculum documents, it can be argued that they provide:

1. A clear scientific orientation of inquiry teaching and learning activities in classrooms.
2. Several defining characteristics of inquiry in the science classrooms.
3. A systematic approach to science instruction.
4. A wider perspective of scientific inquiry and teaching strategies.

Based on the above models, it is evident that there is no single and fixed method of inquiry teaching in the science classroom. However, it can be argued that most of the key features of inquiry models as shown in the instructional models and curriculum documents suggest commonalities in the following six major components of inquiry teaching in the classroom (Fogleman et al., 2011; Minner et al., 2010; Wilson et al., 2010):

1. Engaging in questioning
2. Designing and conducting investigations
3. Collecting and organizing data
4. Analyzing and interpreting data
5. Developing explanations and conclusion
6. Communicating information
The aforementioned scientific inquiry models have been developed based on research (e.g., Bransford, Brown, & Cocking, 1999; Johnson, Johnson, & Holubec, 1986; Karplus & Their, 1967; Linn et al., 2004; Magnusson, Krajcik, & Borko, 1999; NRC, 2000; Schwab, 1962; Shulman, 1987) or some may have expanded on previous instructional models, which can be used in classroom teaching. However, it can be argued that the responsibility rests with classroom teachers to evaluate alternative instructional models and employ the most appropriate approaches in their specific classrooms. As discussed earlier, these inquiry models have been used in many classrooms worldwide but this does not mean that teachers applied the model in the same way in their own science teaching. Irrespective of how the models of scientific inquiry have been conceptualized in the past 50 years or so, and features of inquiry have changed during this period, research (e.g., Abd-El-Khalick et al., 2004; Anderson, 2002; Phaeton & Stears, 2017) has consistently indicated that what is enacted in classrooms is mostly incommensurate with visions of inquiry put forth in reform documents. This means that a mismatch between the intended and implemented curricula tends to occur in schools (Sethole, 2004).

A Review of Research on Scientific Inquiry in the Classroom

In reviewing related studies on inquiry in the science classroom, three lines of research emerged. The first line of research, which comprised most of the studies (e.g., Crawford, 2000, 2012; James Long & Bae, 2018; Kang et al., 2008; Keys & Kennedy, 1999; Lotter, Harwood, & Bonner, 2007; Park Rogers & Abell, 2008), focused on implementation of inquiry in science classrooms and students’ and teachers’ views or perceptions of a scientific inquiry teaching approach. The studies belonging to this
group are mainly exploratory and descriptive and could not give a decisive answer about the effectiveness of the approach. Next, a second line of research described specific elements of scientific inquiry as a teaching approach (Bybee et al., 2006; Magnusson et al., 2004; Poon et al., 2012; Schwarz & Gwekwerere, 2007; van Rens, Pilot, & van der Schee, 2010). In this group of studies, improving or revising the existing inquiry instructional model is the central focus by scrutinizing their constituent elements. In this case, the effectiveness of the method should be considered in light of the specific element under investigation, not in terms of the method as a whole. Lastly, the third line of research examines the effectiveness of an inquiry-based teaching approach as a whole to science learning (Areepattamannil, 2012; Fogleman et al., 2011; Jiang & McComas, 2015; Koksal & Berberoglu, 2014; Lavonen & Laaksonen, 2009; McNeil, 2009; Minner et al., 2010; Wallace & Kang, 2004; Wilson et al., 2010). It is very common to see from the studies belonging to this group that a comparative approach is used, for example, by differentiating a student-centered format from a teacher-centered one, or by investigating changes before and after a curriculum shift or teaching intervention. The effectiveness of the approach is usually measured in terms of knowledge, skills, competencies, or affective variables.

The next sections present related studies that specifically focus on the first line (implementation of inquiry in classroom) and third line (effectiveness of inquiry to learning) of research since this project focuses on investigating teachers’ implementation of scientific inquiry practices in the Philippine classrooms and its impact on student learning. Furthermore, knowledge and skills are the focus of this review since these are often considered most revealing in terms of effectiveness.
How is inquiry implemented in contemporary science classrooms?

Research shows that the quality of science education in schools is greatly influenced by the quality of teaching practice of teachers (Hattie, 2003; UP NISMED, DOST, & DepEd, 2010). Various science education reform movements have recognized the role of teachers as a major factor in student learning (DepEd, 2013b; Duschl, Schweingruber, & Shouse, 2007; Kang et al., 2008; NRC, 1996, 2012). For students to understand inquiry and use it to learn science, their teachers need to be well-versed in scientific inquiry (NRC, 2000). For this reason, investigating how teachers implement scientific inquiry teaching practices and determining the extent to which these practices are implemented in classrooms are important research foci.

Based on the characteristics and models of scientific inquiry, it can be argued that an inquiry-based teaching approach is a complex and sophisticated way of teaching science that requires the teacher to have a firm understanding of the processes of scientific inquiry. Several studies indicate that teachers are able to use scientific inquiry in their classrooms in various ways despite the implementation challenges associated with this teaching approach (Capps & Crawford, 2013; Kang et al., 2008; van Driel, Beijaard, & Verloop, 2001; Wagh, Cook-Whitt, & Wilensky, 2017). Keys and Kennedy (1999) used the case study method and participant-observer techniques to examine the teaching practices of an elementary school teacher with 11 years of experience. Data were collected through field notes during lessons, informal interviews, and transcripts of three formal interviews. Four main themes emerged: (1) the teacher planned instruction to explore questions that arose in context naturally from science activities, (2) the teacher helped students take responsibility for hands-on work, (3) the teacher supported students in constructing explanations and concepts from data, and (4) the
teacher provided opportunities for students to apply scientific knowledge. The researchers also identified major challenges for the teacher in carrying out scientific inquiry practices in the classroom such as lack of time, the challenge of turning questions back onto students, and difficulty in teaching mandated concepts through inquiry.

In another study, Crawford (2000) documented and examined the beliefs and practices of an experienced rural public high school science teacher to determine how the teacher created an inquiry-based classroom environment. The researcher collected data for more than a year. The report focused on 20 students in an ecology class. Data were collected through teacher interviews, notes of informal conversations, videotapes of classroom and field trips, interviews with eight randomly selected students, student products, and an end-of-year anonymous student questionnaire. Six key characteristics emerged: (1) situating instruction in authentic problems, (2) grappling with data, (3) collaboration of students and teacher, (4) connecting students with the community, (5) the teacher modeling behaviors of a scientist, and (6) fostering students in taking ownership of their own learning. In addition, Crawford found that the teacher exhibited ten roles when implementing scientific inquiry in the classroom. These roles were motivator, diagnostician, guide, innovator, experimenter, researcher, modeler, mentor, collaborator, and learner.

Crawford’s finding is different from Anderson’s (2002) argument that teachers typically employ a universal stepwise procedure, the scientific method, in implementing scientific inquiry in their classrooms. Researchers have pointed out that this method of implementation can fail to capture the creative and imaginative nature of the scientific endeavor (Abd-El-Khalick & BouJaoude, 1997; Akerson, Abd-El-Khalick, &
Lederman, 2000; Lederman, 1992). In one study, teachers provided students with a problem to solve by themselves (Lotter et al., 2007). This study confirmed the claims of Crawford (2012) and Lederman et al. (2014) that scientific inquiry is typically implemented in classrooms by letting students perform simple hands-on science activities. According to the researchers, the aforementioned implementation illustrated a narrow and incomplete image of real scientific investigation in the classroom (Magnusson et al., 1999; van Rens et al., 2010; Wellington, 2000).

In the research conducted by Kang et al. (2008), the NRC’s five essential features of inquiry, which have been discussed previously, were used to characterize teachers’ implementation of scientific inquiry in classrooms. Researchers found that participating teachers used only three of the five essential features of inquiry detailed in the standards documents (NRC, 1996, 2000) when expressing their ideas of classroom inquiry. They also found that there are teachers who place more emphasis on some features of inquiry than others. For example, teachers more frequently implemented the features of giving priority to evidence, and formulating explanations based on evidence in teaching science, than that of engaging in scientifically oriented questions. Teachers rarely implemented the features of evaluating explanations in connection with scientific knowledge and communicating explanations.

In the Philippines, a scoping study into the teaching of inquiry skills under the new K to 12 science curriculum was conducted by ACTRC in 2014. To evaluate the degree to which the new emphasis on inquiry skills was being adopted, researchers compared the intended curriculum (what is to be taught) with the implemented curriculum (what is being taught). To ascertain the implemented curriculum, classroom observations were conducted for 22 Grade 8 science teachers across 11 schools,
resulting in a total of 204 one-hour observations. These revealed that some scientific inquiry skills were frequently referred to by teachers. For example, students were regularly asked ‘how’ and ‘why’ questions, which focus on scientific inquiry, in addition to ‘what’ questions, which focus on content knowledge. Teachers also asked students to record observations and measurements and to connect explanations with existing scientific knowledge. In addition to having classroom observations, ACTRC researchers also examined teachers’ lesson plans and conducted interviews with the teachers and the eleven science department heads. These measures revealed that the teachers understood scientific inquiry as a method that requires students to engage in hands-on tasks, gather evidence, formulate explanations, and draw conclusions. However, some scientific inquiry skills, such as the use of scientific instruments, the tabulation of results, and the testing of variables were seldom seen in classrooms. Although the ACTRC researchers examined the teaching of scientific inquiry in science classrooms, the relationship of teacher implementation of specific inquiry-based practices to student learning was not investigated. Minner and DeLisi (2012) reported that researchers often placed very little emphasis on investigating which specific practices of scientific inquiry can lead to students’ greater achievement in science. With this, it can be argued that there is a dearth of research focusing on the relationship between the specific practices of inquiry employed by teachers in classrooms and students’ learning in science. The present study aims to address this issue.

In summary, these different studies have pointed to various ways teachers are carrying out scientific inquiry practices in their classrooms in different contexts. However, it is important to investigate the actual practices of teachers in their classrooms over several lessons and even over multiple years to understand the
complexities involved when a teacher strives to implement scientific inquiry in light of reform-based curriculum and national mandates. This study aims to further explore the explicit classroom practices enacted by teachers in the Philippines that are related to the following components of scientific inquiry: (1) engaging in questioning, (2) designing and conducting investigations, (3) collecting data, (4) analyzing data, (5) developing explanations, and (6) communicating information. These six components were derived from the synthesis drawn from literature on the different models and aspects of scientific inquiry previously discussed (e.g., Bybee et al., 2006; Lederman et al., 2014; Linn et al., 2004; Magnusson et al., 2004; NRC, 2000, 2012; Schwarz & Gwekwerere 2007). In addition, this research also seeks to explore the impact of teachers’ scientific inquiry practices on students’ science learning.

What is the evidence that scientific inquiry practices improve student learning?

The role of a teacher in the classroom has been established as a major factor in student learning (Beese & Liang, 2010; Duschl et al., 2007; Granger et al., 2012; Hattie, 2003; O’Dwyer, Wang, & Shields, 2015; NRC, 1996). Many reform documents in K to 12 science education (e.g., Achieve, Inc., 2013; NRC, 2000, 2012) reported results of studies (Duschl & Grandy, 2008; Schmidt, McKnight, & Raizen, 1997) indicating that teacher practices such as presenting science only as a body of facts, using primarily lecture modes, stressing vocabulary-driven drill-practice, and using only teacher-centered versus student-centered approaches, are less effective in supporting student learning. Surveys of students in science reveal that they were more inspired by teachers who engaged them in tasks that enabled them to inquire and solve problems (Bernardo
et al., 2008; Hagay & Baram-Tsabari, 2015; Garcia & Tan, 2004; Rivera Maulucci, Brown, Grey, & Sullivan, 2014).

Several studies have shown that teachers play a major role in changing classroom dynamics and promoting student learning through scientific inquiry (Liu, Lee, & Linn, 2010; Schneider & Krajcik, 2002; Varma, Husic, & Linn, 2008). Wallace and Kang (2004) found that students whose teachers persistently implement and promote inquiry in their classrooms have more positive attitudes towards scientific inquiry. This was evident when students demonstrated motivation to be involved in inquiry processes (Hagay & Baram-Tsabari, 2015) such as when they were asked to conduct investigation activities and draw conclusions from data (Jiang & McComas, 2015). In addition, Osborne (2014) argued that as students become immersed in scientific inquiry (e.g., asking questions), they begin to understand the importance of the driving question to any scientific research, they ask questions about what they observe, and they refine their notion of what makes a good scientific question.

In 2009, McNeil explored the enactment of chemistry curriculum by six middle-school teachers. The focus of the curriculum was on constructing arguments by students using an adapted version of Toulmin’s (1958) model of argumentation, which includes three components: claim, evidence, and reasoning. A total of 568 middle school students participated in the study. Data collection lasted for eight weeks and consisted of videotaped classroom lessons, student pretest and posttest, and teacher questionnaires. Findings revealed that there is a significant relationship between teachers’ instructional practices on argumentation and students’ learning about scientific argumentation, evidence, reasoning, and content knowledge. Teachers who defined scientific argumentation differently from the curriculum, meaning their definitions were not
aligned with the intended learning goal in the curriculum materials, had the lowest student gains in terms of argumentation. This study also emphasized that teachers carry out reform-based curricula in different ways, something curriculum designers need to take into account.

Further evidence of the role of scientific inquiry in promoting student learning has been provided by Wilson et al. (2010) who designed a randomized, experimental study to compare the effectiveness of inquiry-based instruction, organized around the Biological Sciences Curriculum Study (BSCS) 5E Instructional Model, with traditional instruction of the same unit. Fifty-eight middle school students were randomly assigned to one of two groups. The same teacher taught both groups of students with the same learning goals. The outcomes measured were scientific knowledge, scientific reasoning through application of models, and construction and critique of scientific argumentation. Students from the inquiry-based group demonstrated significantly higher levels of achievement than those in the traditional group. This effect was consistent across a range of learning goals, knowledge, reasoning, and argumentation, and time frames.

In a synthesis of literature on inquiry-based instruction, Minner et al. (2010) analyzed 138 studies published between 1984 and 2002. They found a clear pattern favoring inquiry-based instructional practices, particularly practices that emphasize active thinking and the drawing of conclusions from data. In this research, articles were selected based on sufficient information of determining the presence or absence of inquiry-based science instruction, as operationally defined for this project. Research designs of the majority of the studies were quasi-experimental, experimental, and qualitative. Most of the studies focused on K to 12 science classrooms wherein teachers had limited training and preparation. Findings also showed that 51% of the studies
indicated positive effects of inquiry-based instruction on content learning and retention, 33% of the studies showed mixed impacts, 14% showed no impact, and 2% showed negative impact. Researchers noted that, although the evidence is not completely positive, those students who engaged in instruction within an investigation cycle, which has an emphasis on student active thinking or responsibility for learning, exhibited enhanced content learning.

Furthermore, Fogleman et al. (2011) examined 19 middle school teachers on how they implemented an inquiry-based science curriculum. In this study, researchers aimed to determine the influence of a teacher’s curricular adaptations on student learning by using hierarchical linear modeling. Data were collected through curriculum surveys, videotape observations, and pretest and posttests from 1,234 students. Researchers found that teacher experience and the amount of student initiation of investigation activities during instruction were the variables that significantly predicted student learning. Findings showed that teachers who had previously taught the inquiry-based science curriculum had greater student learning gains. Students who completed investigations had greater learning gains when compared to students whose teachers used only demonstrations or carried out the inquiry on their own. The study implied that it takes time for teachers to effectively implement innovative science curriculum and that it is important that students actively engage in inquiry investigations.

The aforementioned studies presented positive impacts of inquiry-based teaching on classroom learning. However, there were also studies that reported the opposite of these results. For example, in the United States, Pine et al. (2006) compared the science learning of fifth grade students who used hands-on inquiry-based curricula with the performance of fifth grade students who used traditional textbooks. The sample students
were from 41 classrooms in nine school districts. The researchers explored students’ understanding of scientific phenomena and their performance in conducting inquiry experiments, specifically their abilities in planning experiments, making observations, collecting and analyzing data, and making inferences. The results of multilevel modeling showed that hands-on inquiry-based curricula did not outperform traditional textbooks in improving students’ science learning. In Finland, Lavonen and Laaksonen (2009) examined the science learning of Finnish students using the Programme for International Student Assessment (PISA) 2006 scientific literacy assessment data. The results of regression analysis revealed that the most negative predictor for PISA science performance of students was the frequency of science inquiry activities in class. Further, in Qatar, Areepattamannil (2012) investigated the effects of inquiry-based instruction on students’ science achievement. There were 5,120 students involved in this study from 85 schools. Consistent with other studies, hierarchical linear modeling showed that science teaching and learning using scientific inquiry such as hands-on activities had “substantial negative effects” on students’ science achievement (p. 134).

Some researchers clearly expressed their concerns with scientific inquiry in classrooms and explicitly questioned this approach to science teaching. For example, in the research of Klahr and Nigam (2004) on examining students’ ability to design scientific investigations, they compared students’ performance under two conditions: direct instruction and student-centered discovery approach. They found that direct instruction (teacher-directed) was more effective in facilitating student learning, particularly in learning scientific investigation skills, than student-centered discovery approaches to instruction. They claimed that their findings challenged the long-standing assumptions of the superiority of a student-centered inquiry-based approach to science
learning. In another article, Kirschner, Sweller, and Clark (2006) contrasted minimally guided instructional approaches (e.g., inquiry-based teaching, problem-based learning) with approaches that provide direct instructional guidance in the context of their knowledge of human cognitive architecture, expert-novice differences, and cognitive load. They argued that minimally guided instructional approaches are ineffective and inefficient. Specifically, they argued that inquiry-based teaching places huge burdens on students’ cognitive capacity by requiring them find solutions to a problem; consequently, there are insufficient cognitive resources for new learning to occur.

It is clear from these studies that there is inconsistency in the results concerning the impact of scientific inquiry on student learning. It is also clear that there is a very little research that investigated the impact of different elements of scientific inquiry teaching to learning. This is because there is a lack of fine-grained examination of teachers’ practices of scientific inquiry in classrooms as evident from most studies mentioned above. This suggests that further investigation is needed to track scientific inquiry teaching of teachers in classrooms in order to provide an evidenced-based documentation of specific teaching practices related to scientific inquiry. It is also important to examine the impact of each specific inquiry teaching practice in order to find other evidence, which may provide a clear interpretation of the effect of scientific inquiry on science learning. In the Philippines, scientific inquiry teaching was emphasized as one of the important features of the new science curriculum for pre-tertiary education. The impact of this new curriculum emphasis on student learning is not yet known. The present study addresses this issue by identifying the specific inquiry-based teaching practices that the teachers used in classrooms and then examining the impact of each of these practices to student learning in chemistry. This provided an
understanding of teachers’ enactment of specific inquiry teaching practices in challenging classrooms of a developing country and how it affects student learning. This may inform others who work in school education particularly in developing countries.

Measuring Scientific Inquiry Approaches to Instruction

Assessment of scientific inquiry in science classrooms offers rich possibilities, both in terms of inquiry skills and competencies and inquiry teaching approaches. Assessment has a strong impact on what is taught and how it is taught (Harlen, 2007). With this, it is important that assessments and standards coverage are addressed in the instructional process. This reflects alignment of assessment to the curriculum (Squires, 2012). But it is important to note that implementing a curriculum is not a smooth process as it may not occur as intended, which reflects loopholes that create a gap between the expectations of curriculum designers and what really takes place within the classroom (Phaeton & Stears, 2017; Thijs & van den Akker, 2009). The relationship between curriculum, learning, and assessment goals, respectively, is thus not only crucial when analyzing and evaluating the effectiveness of inquiry-based approaches (Furtak, Seidel, Iverson, & Briggs, 2012) but also with respect to the success and sustainability of innovative approaches in education (Wilson & Sloane, 2000). The pedagogical approaches that teach about and through scientific investigation clearly play a significant role in science teaching and learning. However, tools are needed in order to conduct research documenting inquiry approaches to instruction and illustrating the specific elements of science instruction that are potentially associated with student learning outcomes. This section presents some of the tools that are used to assess inquiry-based teaching and learning in the science classrooms.
What instruments are available to measure scientific inquiry instruction in science classrooms?

For inquiry-based teaching

There are two types of measurement tools reported in the literature to determine the degree of inquiry-based teaching in science classrooms (e.g., Heinz, Lipowsky, Groschner, & Seidel, 2012; Ropohl et al., 2013). These tools are (1) teacher self-report questionnaires and (2) observation protocols.

Teacher self-report questionnaires

Teacher self-report questionnaires are used to measure the implementation of inquiry teaching in classrooms by asking teachers to indicate how often the inquiry practices occur in their instruction or how much time they spend on enacting scientific inquiry activities in their classrooms. Teacher self-report questionnaires are usually presented in the form of Likert-type scale instruments. The following are some examples of teacher questionnaires used to assess inquiry-based teaching in science classrooms:

The Teaching Science as Inquiry (TSI) (Smolleck, Zembal-Saul, & Yoder, 2006) was developed to measure pre-service teachers’ self-efficacy in regard to the teaching of science as inquiry. It uses 69 Likert-type items to measure pre-service teachers’ personal self-efficacy and outcome expectancy. The researchers used the five essential features of classroom inquiry through the Inquiry and the National Science Education Standards (NRC, 2000) as a basis for developing items for the questionnaire. The TSI is used by asking pre-service teachers to rate themselves in performing these example types of items in order to capture their inquiry teaching in the classroom: (a) providing opportunities for students to discuss the experiments in which they participated, (b)
allowing students to devise their own problems to investigate, and (c) engaging students in a learning environment that allows diversity of problems and methods. It can be noted that this questionnaire focuses more on teacher self-reported efficacy on teaching science as inquiry than on explicit practices of inquiry-based teaching.

A number of research studies have used this questionnaire to explore teachers’ self-efficacy in inquiry-based science teaching (e.g., Saglam & Sahin, 2017; Smolleck & Yoder; 2008; Southerland et al., 2016; Walker, Spencer, Claiborne-Payton, & Whiteman, 2017). In a study conducted by Smolleck and Yoder (2008), the TSI was used to measure the self-efficacy in inquiry-based teaching and learning of pre-service elementary teachers in the United States who were enrolled in five sections of a science methods course. Researchers reported that the TSI measured an increase in self-efficacy scores from pretest to posttest. They attributed this increase to pre-service teachers’ experiences within the inquiry-based science methods course. Based on the result of this study, they argued that the TSI demonstrated content and construct validity with high internal reliability when used with pre-service elementary science teachers. Aside from pre-service teachers, the TSI was also used for investigating the self-efficacy of in-service teachers. For instance, in Turkey, this questionnaire was used to investigate the effect of inquiry-based professional development activities on self-efficacy of in-service teachers in inquiry-based science teaching (Saglam & Sahin, 2017). Researchers reported that there was a significant development in teachers’ self-efficacy in inquiry teaching.

*The Inquiry Science Implementation Scale (ISIS)* (Brandon, Young, Pottenger, & Taum, 2009) was developed to assess teachers’ implementation of experimental activities for students in the classroom. It consists of 22 Likert-type items with a 5-point
rating scale (from 1=never to 5=always). This questionnaire asks teachers to indicate how frequently they include inquiry activities in their science teaching, such as asking students to (a) write down the problem before the experiment, (b) make predictions about the experiment, and (c) share predictions, data or findings with the class. Teachers are also asked to specify their strategies to respond to student questions about experiments. The limitation of this questionnaire is that it focuses on only one aspect of scientific inquiry teaching, which is conducting experiments (Ropohl et al., 2013). This may limit the description of the nature of inquiry teaching in the classroom.

Researchers in the United States and Ireland (e.g., Nadelson, Seifert, Moll, & Coats, 2012; Donnelly, O’Reilly, & McGarr, 2013) used the ISIS in exploring teachers’ implementation of inquiry-based teaching practices in a professional development (PD) program and virtual chemistry laboratory class. In the study of Nadelson et al. (2012), this questionnaire was used in a science, technology, engineering, and mathematics (STEM) PD program, which was called the i-STEM project, to assess teachers’ inquiry-based instructional practices, specifically their teaching of investigation in class. This PD program aimed to enhance teachers’ content knowledge, use of inquiry instruction, and efficacy for teaching STEM. The participants in this PD program were 230 teachers from Grade 3 to Grade 9 in one American state. These participants were asked to respond to the ISIS before and after the professional development program. In another study, the ISIS was used in a virtual chemistry laboratory to capture secondary school Irish teachers’ implementation of science investigation in chemistry classes (Donnelly et al., 2013). Researchers used the ISIS in a pretest-posttest manner. This study explored how a virtual chemistry laboratory supported greater teacher implementation of inquiry-based approaches to practical work. They also used the ISIS in a ‘talk-aloud’ manner.
They argued that the talk-aloud protocol for this questionnaire provided insight into teachers’ rationale in selecting particular items, and thus gave a novel way to using the ISIS as a qualitative tool for a case study approach.

*The Science Instructional Practices Survey (SIPS)* (Hayes, Lee, DiStefano, O’Connor, & Seitz, 2016) assesses a broad range of instructional practices that support student inquiry in science, as well as communication and critical thinking skills. It is designed to assess pedagogical approaches relevant to science education in the current context of the *Next Generation Science Standards (NGSS)* reform in the United States. The SIPS is used by asking teachers to rate their efforts to engage their students in using science and engineering practices as part of their classroom instruction. It consists of 31 Likert-type items or indicators on how often the students and teachers demonstrate the science and engineering practices in the classroom (e.g., generate questions or predictions to explore; encourage students to explain concepts to one another).

Although this questionnaire measures the degree of teachers’ implementation of inquiry-based teaching in the classroom, its items are suitable only to the NGSS-related instructional practices developed in the United States, which includes engineering practices. Thus, the SIPS was developed for use in the United States K to 12 science classrooms (Hayes et al., 2016). In a recent study, the SIPS was used to assess the scientific practices of 32 middle and high school science teachers in one American state after they participated in a workshop on modeling instruction in biology (LeFever, Malone, & Irving, 2018). Specifically, researchers used the SIPS in a pretest-posttest manner to determine whether the workshop affects the way the teachers use models and modeling in teaching biology.
It is clear that the aforementioned teacher self-report questionnaires could offer useful information to describe the nature of inquiry-based science instruction in the classroom. However, any teacher self-report questionnaire (e.g., Likert-type scales) that captures classroom practices has inherent issues of reliability and validity (Goe, Bell, & Little, 2008). Goe et al. (2008) reported that self-report responses are susceptible to the impact of social desirability, which is “the tendency on the part of individuals to present themselves in a favorable light” (Moorman & Podsakoff, 1992 p.132). They reported that this phenomenon would include both the conscious misrepresentation of teaching practices to “look good” as well as unintentional misreporting due to a teacher’s perception that he or she is correctly implementing a practice when in fact it is not being implemented with fidelity. This phenomenon also includes insufficient reporting of the details on important aspects of classroom teaching, as sometimes teachers may choose not to reveal all their teaching style. With this, Goe et al. (2008) argued that potential bias may lead to both overreporting and underreporting of practices, making the data difficult to interpret. In addition, ratings can be influenced by the degree of teachers’ understanding about the construct being studied. This means that teachers may adjust their understanding of the extent of inquiry teaching as they come to understand the nature of inquiry advocated by a particular science curriculum. Due to the noted limitations of teacher self-report questionnaires, this study considered another way of assessing teachers’ instructional practices, which is observation of classroom instruction through the use of an observation instrument. The present study explored various observation protocols as presented below, which is beneficial in the development of an observation instrument.


Observation protocols

In order to determine whether inquiry-based instruction occurs in the classroom and to provide teachers with a tool that could support them in inquiry-based teaching, an effective and valid observation protocol to measure the quantity and quality of this teaching approach is necessary. The use of classroom observation instruments can provide a more detailed description of teachers’ instructional practices than other methods of evaluating teachers’ instruction (e.g., student report about teachers’ instruction, teacher self-report) (Halpin & Kieffer, 2015). This means that observation instruments can provide a strong basis for supporting formative feedback to teachers. In addition, observation instruments can facilitate research about the association between instructional practices and student learning outcomes (e.g., academic performance) (Halpin & Kieffer, 2015), which is the focus of the present study. For this reason, an observation instrument was considered for use in this study to document the nature of teachers’ inquiry instructional practices. Many classroom observation instruments have tick-off sheets in which the observers are asked to mark each occurrence of a specific practice within a predefined time frame. Other observation instruments have rating sheets where teachers’ practices are rated on different point scales. The following are some of the most common observation instruments used for assessing teachers’ inquiry-based instruction in science classrooms:

The Inside the Classroom Observation and Analytic Protocol (Horizon Research, 2000) was designed to assess the quality of lessons observed in K to 12 science and mathematics classrooms. Specifically, it assesses four aspects of science/mathematics lesson instruction: (1) design of the lesson, (2) implementation of the lesson, (3) science/mathematics content, and (4) classroom culture. In this
instrument, the items or indicators for each of these aspects are based on standards of quality instruction in science and mathematics as outlined in K to 12 curriculum reform documents in the United States—the National Science Education Standards (NRC, 1996), the Curriculum and Evaluation Standards for School Mathematics (National Council of Teachers of Mathematics [NCTM], 1989), the Professional Teaching Standards for School Mathematics (NCTM, 1991), and the Assessment Standards for School Mathematics (NCTM, 1995). With this, this instrument allows classroom observers to make judgments about how well the teachers’ instruction aligned with these curriculum standards. Responses for the individual items or indicators are given on a five-point scale (1=Not at all, 5=To a great extent). Although this observation instrument could provide a solid and broad view of teachers’ instructional practices in science and mathematics, it does not offer a thorough and granular understanding of scientific inquiry teaching practices in science classrooms. This is because it mainly focuses on general strategies in teaching science and mathematics, thus lacking in specific teaching indicators on methods of science investigation. This was supported by Marshall, Smart, and Horton (2009) when they reviewed this observation instrument. They reported that this instrument does not provide a rigorous understanding of inquiry teaching practices in the classroom.

The Reformed Teaching Observation Protocol (RTOP) (Sawada et al., 2002) was developed by the Evaluation Facilitation Group (EFG) of the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT). The RTOP is specifically designed for assessing ‘reformed teaching’ in science and mathematics classrooms. It provides quantitative information on the degree of achieving reform in science and mathematics teaching. Items in the RTOP were drawn from a pool of existing items
derived from different sources: (1) research studies in science and mathematics standards conducted from 1989 to 2000, (2) existing observation instruments, and (3) works of ACEPT staff and EFG. The RTOP is composed of 25 items grouped into three categories: Lesson Design and Implementation, Content, and Classroom Culture. These items are brief and specific statements about these three categories. Each statement in an item has a rating scale from 0 (not occurred=the item never occurred in the lesson) to 4 (very descriptive=the item is very descriptive of the lesson). The lesson design and implementation group included five items about the ACEPT definition of the structure and nature of reformed teaching. The content group has ten items, which subdivide into two parts. The first is propositional knowledge, which assesses the quality of the lesson content (e.g., the lesson promoted strongly coherent conceptual understanding), and the second is procedural knowledge, which captures the ACEPT understanding of the inquiry process (e.g., students made predictions, estimations and/or hypothesis and devised means for testing them). Lastly, the classroom culture group consists of ten items focusing on the climate of reformed classroom (e.g., communicative interaction between student and teacher). The reliability of the entire instrument is 0.97 and for the subgroups, the reliability ranges from 0.80 to 0.93 (Sawada et al., 2002). This observation instrument draws on major curriculum standards in the United States developed by the NCTM, NRC, and AAAS.

Although the RTOP provides teachers and researchers with a clear method of assessing a constructivist approach to teaching, it lacks a fine-grained way of assessing instructional practices of teachers that are related to scientific inquiry in the classroom. The instrument includes very few items or indicators on scientific inquiry teaching practices. A fine-grained way of assessing inquiry-based teaching practices (e.g., adding
teaching indicators on specific classroom practices related to scientific inquiry in the instrument) could offer recommendations for teachers particularly on the examples of inquiry practices that can be used in their classrooms. This could be beneficial for them as they improve their implementation of inquiry-based instruction. Moreover, the focus of this observation instrument was assessment of the macro view of science and mathematics teaching, which meant that its method was directed towards assessing general strategies used in reformed classroom teaching.

*The Science Teacher Inquiry Rubric (STIR)* (Bodzin & Beerer, 2003) provides a brief protocol that is aligned with the definition of scientific inquiry in classrooms set forth by the *National Science Education Standards (NSES)* for K to 12 science (NRC, 1996) in the United States. This instrument translated each of the five essential features of classroom inquiry, as presented in the text *Inquiry and the National Science Education Standards* (NRC, 2000), into indicators or statements that portray inquiry teaching practices and that capture the essence of each feature. Thus, it consists of a rubric with different statements about inquiry teaching activities for each feature of inquiry. The NRC’s five essential features of classroom inquiry provide important characteristics of inquiry-based science instruction. In this instrument, the statements in each feature vary based on the amount of teacher direction or the amount of student initiation in doing inquiry activities. Although this observation instrument can be used to monitor teachers’ inquiry-based instruction, it does not provide insight into the specific teaching practices related to different elements of scientific inquiry (e.g., designing investigation) that teachers must implement in the classroom. This observation instrument was designed only to determine whether the NSES were achieved during instruction.
The Electronic Quality of Inquiry Protocol (EQUIP) (Marshall et al., 2009) provides a protocol to guide teachers in increasing the quantity and quality of inquiry-based instruction in the classroom. The development of this instrument was informed by several existing observation protocols (e.g., Horizon Research, 2000; Sampson, 2004; Sawada et al., 2000). The EQUIP was not developed for all classroom situations. It mainly focuses on assessing the factors that affect the quality of inquiry-based instruction and not on other teaching methods implemented in the classroom. There are four specific factors that this instrument aimed to assess. These are Instruction, Discourse, Assessment, and Curriculum. Each of these factors is associated with different indicators. The total number of indicators included in this instrument is 19. The EQUIP has a rubric created for each indicator. The rubric was used to distinguish various levels of inquiry-based instructional proficiency of teachers for a specific lesson: Pre-inquiry (Level 1), Developing Inquiry (Level 2), Proficient Inquiry (Level 3), and Exemplary Inquiry (Level 4). This rubric was also used as a benchmark to challenge teachers to reflect about how to improve their implementation of inquiry teaching in the classroom. In terms of statistical evidence, this instrument was supported by validity checks and confirmatory analysis with high internal consistency (alpha value=0.880-0.889) and solid interrater agreement ($r^2=0.856$) (Marshall et al., 2009).

With this information about the EQUIP, it is clear that using this instrument in the classroom to assess inquiry-based instruction could encourage teachers to strive to increase the quantity and quality of their inquiry teaching since this instrument includes several factors that support inquiry-based teaching and learning. However, due to its focus on assessing these factors, this instrument lacks information on classroom practices related to the processes of science, which is scientific inquiry itself. Most of
the elements of scientific inquiry were not included in the rubric. This is problematic especially when assessing classroom instruction involving scientific investigations.

*The Inquiry into Science Instruction Observation Protocol (ISIOP)* (Minner & DeLisi, 2012) was created to determine the extent of teachers’ implementation of quality science teaching in classrooms, including science instruction that incorporates scientific practices and habits of mind. Specifically, it is designed to comprehensively document the nature of teachers’ implementation of scientific instruction. The teacher-enacted curricula are the priority to capture by the ISIOP, which means that it focuses on teachers’ own practices in classroom teaching rather than what reform documents claim they should be doing. Recall that in Chapter 1, researchers reported that a mismatch between the intended and implemented curricula was usually observed in the classroom particularly in the period of major changes (Hume & Coll, 2010; Sethole, 2004; Sherin & Drake, 2009). The ISIOP may provide a way to monitor the degree of implementation of the intended curriculum by teachers in the classroom. The conceptual framework for the development of the ISIOP was based on the 2012 *Framework for K-12 Science Education* (NRC, 2012) in the United States, which emphasized the importance of instruction that supports students’ adoption of and engagement in scientific practices. The development of items for the ISIOP and its content validity were based on an extensive literature review of the nature of scientific inquiry through the research project entitled *Has Inquiry Made a Difference? A Synthesis of Research on the Impact of Inquiry* (Minner & DeLisi, 2012; Minner et al., 2010). One of the unique aspects of the ISIOP, which was not noted in previously reviewed observation instruments, is the inclusion of more items or teaching indicators on specific scientific practices drawn exclusively from the science education literature. This aspect of the
ISIOP is crucial particularly in capturing the nature of scientific inquiry teaching of teachers in classrooms. In addition, it is based on a comprehensive framework of teachers’ practices, which are different from those that present in other observation instruments, such as focusing on general classroom practices or on student practices. Aside from the scientific investigation teaching indicators, the ISIOP has also included teaching indicators on verbal practices and classroom instructional leadership practices. It has a checklist and a rating scale that reflect a comprehensive view of classroom practice that is standards-based and inquiry-oriented. It also includes teaching indicators that have been either theorized or demonstrated to be associated with student learning. This observation instrument can offer a granular way of assessing inquiry-based practices of teachers in teaching science. However, evidence of the reliability and precision of this instrument has not been firmly established (Minner & DeLisi, 2012).

One of the objectives of this study is to examine the classroom practices of science teachers in the Philippines, and particularly those practices that are related to scientific inquiry. This aspect of the study is needed in order to characterize the nature of inquiry-based instruction in the classroom as teachers implement the newly designed Grade 7 chemistry curriculum. Although curriculum alignment is not the direct focus of the present study, exploring teachers’ practices under the new curriculum reform may provide additional information on the degree of match between teachers’ science instruction and the new curriculum emphasis, which is the teaching and learning of scientific inquiry in addition to the acquisition of content or scientific knowledge (DepEd, 2016). With this, meaningful assessment is needed through the use of a valid instrument that focuses directly on measuring the implementation of specific inquiry-based instructional practices of teachers that can facilitate inquiry-based learning in
science. For this study, a granular view of teaching practices related to the six elements of scientific inquiry—engaging in questioning, designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information—is crucial to thoroughly capture the nature of inquiry-based instruction of teachers.

It is acknowledged that the information about the aforementioned observation instruments has significant value for conducting classroom research on inquiry teaching in science. The literature reported that these instruments have provided leadership in the area of science instruction observation (Banilower, 2005; Heath, Lakshmanan, Perlmutter, & Davis, 2010; Marshall et al., 2009; Smith, Jones, Gilbert, & Wieman, 2013). However, it can be argued that the contents of most of these instruments are geared towards describing the broader strategies of teaching science which are not sufficient for capturing the specific inquiry practices of teachers in classrooms. This may affect researchers in conducting a detailed examination of teachers’ inquiry teaching practices. Although these observation instruments could offer some information about the nature of classroom inquiry, they possess the following limitations, which could affect the characterization of specific inquiry teaching practices of teachers:

1. There is lack of specific teaching indicators or items related to the aforementioned six elements of scientific inquiry.
2. The elements of scientific inquiry are not explicitly specified in the instrument.
3. Most of these instruments are focusing on assessing broader instructional strategies in science as well as other aspects of teaching and learning process (e.g., assessment strategies).
4. Most of these instruments are not directly focusing on the teacher (except for the ISIOP).

5. Since scientific inquiry in the classroom became more visible in the United States K to 12 science reform documents (e.g., AAAS, 1989; NRC, 1996, 2000), which were emulated by most countries (Abd-El-Khalick et al., 2004), these instruments were developed in the context of United States K to 12 science education.

For this reason, the present study created an observation instrument with direct focus on assessing scientific inquiry teaching in the classroom. The development of an observational tool that is directly aligned with science inquiry and contains specific teaching indicators is indeed important since there is a lack of instrument specifically designed to assess the specific inquiry practices of teachers. The observational instruments developed by science education researchers were mostly assessing general science teaching strategies and not focusing on granular view of inquiry practices of teachers. With this, the Scientific Inquiry Teaching Observation Instrument (SITOI) was developed for this study.

**The Scientific Inquiry Teaching Observation Instrument (SITOI)**

This observational tool was designed to measure teachers’ implementation of specific classroom practices that are related to the elements of scientific inquiry. The SITOI offers a granular view of inquiry-based teaching practices of teachers in the classroom. It is composed of thirty-one items on specific inquiry practices, grouped into the six major components of scientific inquiry—engaging in questioning, designing and conducting investigations, collecting data, analyzing data, developing explanations, and
communicating information. These components were derived from the synthesis of literature on models and aspects of scientific inquiry as previously discussed in the summary of the scientific inquiry models section. The items in the SITOI were ranging from teacher-centered to student-centered practices. More details on the development process for this observation instrument are presented in Chapter 4.

What assessments are available to measure students’ learning of science concepts and learning of and about inquiry?

For inquiry-based learning

As students’ inquiry-based learning has been recognized as an important instructional objective and overarching goal in the United States K to 12 science education (NRC, 1996, 2000), various standardized and convergent assessments have been developed to assess this type of learning (Lederman et al., 2014). In this study, an instrument that assesses students’ learning of concepts and inquiry processes and skills is needed to measure inquiry-based learning in chemistry. In the past decades, both quantitative and qualitative assessments have been developed and used in conducting research related to science learning. These assessments were usually multiple-choice tests or Likert-type questionnaires written from the perspectives of experts (Liang et al., 2006). Multiple-choice tests have been commonly used for evaluating large samples of students (Boone & Scantlebury, 2006). Some examples of assessments that measure students’ inquiry-based learning were Views About Scientific Inquiry (Lederman et al., 2014), Science Process Skills Inventory (Bourdeau & Arnold, 2009), and Science Inquiry Literacy Test (Wenning, 2007). In addition, international assessment programs such as the Trends in International Mathematics and Science Study (TIMSS) and the
Programme for International Student Assessment (PISA) issued by international organizations (e.g., Organisation for Economic Co-operation and Development [OECD], International Association for the Evaluation of Educational Achievement [IEA]) have offered ways to assess students' inquiry-based science learning.

The TIMSS is a well-established international assessment of science and mathematics in grades four and eight (Mullis, 2017). The IEA has been conducting international assessments of science and mathematics through TIMSS for nearly 20 years (Mullis, 2017). TIMSS began in 1995 and has been conducted every four years since. According to Mullis (2017), about 60 countries use TIMSS trend data to monitor the effectiveness of their educational systems in a global context. Martin, Mullis, and Froy (2017) reported that TIMSS is designed to provide countries with information about their students’ science and mathematics achievement that can be used to inform evidence-based decisions for improving educational policy and practice. This is evident in various studies around the globe (e.g., Bray & Kobakhidze, 2014; Carnoy, Khavenson, & Ivanova, 2015; Nilsen, 2015; Topcu, Erbilgin, & Arikan, 2016). As science and mathematics assessments, TIMSS is a valuable resource for monitoring educational effectiveness because science, technology, engineering, and mathematics (STEM) are key curriculum areas (Mullis, 2017).

The TIMSS science assessment in Grades four and eight is organized around two dimensions: (1) content dimension, which specifies the subject matter to be assessed, and (2) cognitive dimension, which specifies the thinking processes to be assessed (Centurino & Jones, 2017). The content domains differ for Grade four (life science, physical science, and earth science) and Grade eight (biology, chemistry, physics, and earth science), which reflects the nature and difficulty of the science taught
at each grade. In Grade four, life science has more emphasis than its counterpart, biology, in Grade eight. Chemistry and physics are assessed in Grade eight as separate content domains and received more emphasis than in Grade four, where they are assessed as one content domain (physical science). The content domains in each grade include several major topic areas, and each topic area includes one or more topics. Each topic has specific objectives that represent the students’ expected knowledge, abilities, and skills assessed within each topic. TIMSS science assessments also include three cognitive domains (knowing, applying, and reasoning) that are similar in both grades, which encompassed the range of cognitive processes involved in learning science concepts, and then applying these concepts and reasoning with them (Centurino & Jones, 2017).

In addition to the content and cognitive domains, TIMSS science also assesses inquiry practices, which include skills from daily life and school studies that students use in a systematic way to conduct scientific inquiry and investigation and that are fundamental to all science disciplines (Centurino & Jones, 2017). According to Mullis, Martin, Goh, and Cotter (2016), inquiry has increasingly been given emphasis in many countries’ current science curricula, standards, and frameworks, and so this is an important component of TIMSS science assessments. In the upcoming TIMSS 2019 science assessments, five scientific inquiry practices are included: (1) asking questions based on observations, (2) generating evidence, (3) working with data, (4) answering the research question, and (5) making an argument from evidence (Centurino & Jones, 2017). Centurino and Jones (2017) argued that scientific inquiry practice is strongly connected to the area of science under study and, therefore cannot be assessed in isolation. They suggested that these practices are assessed in the context of science
content domains and by drawing upon the range of thinking processes specified in the cognitive domains.

Further, the student responses to the items in each TIMSS assessment are aggregated and converted to the TIMSS science and mathematics scale metrics at each grade level to provide an overall picture of the assessment results for each country (Martin et al., 2017). The TIMSS achievement scales provided established metrics which countries can use to compare students’ progress in science and mathematics from assessment to assessment in Grades four and eight. All results from TIMSS assessments have been reported on the same scale metrics, making it possible to measure growth or decline in countries’ achievement distributions from assessment to assessment (Martin et al., 2017).

One of the important features of TIMSS science assessments that could be beneficial for the present study, specifically in assessing student learning, is that scientific inquiry is assessed together with science content. This feature is important for this study particularly in developing chemistry test items on inquiry skills in the context of chemistry content. Although TIMSS is a well-established science and mathematics assessment, there were some issues reported by Wang (2011) from his in-depth analysis on TIMSS assessment items such as (1) items with scientific and mathematical flaws, (2) items with uneven difficulty levels, and (3) uncertainty of guessing embedded in TIMSS.

The PISA is an international survey which occurs every three years to evaluate education systems worldwide by testing the skills and knowledge of 15-year-old students (OECD, 2018). The survey program was established by OECD in 1997 and represents a commitment by the OECD member countries to monitor the outcomes of
their education systems in terms of student achievement, within a common international framework (Bybee et al., 2009). Specifically, PISA focuses on assessing three major domains—science, mathematics, and reading—with information about students’ home background and their views of learning and learning environments (Bybee et al., 2009). The results of PISA have been mainly used by researchers to examine educational policies (e.g., Araujo, Saltelli, & Schnepf, 2017; Breakspear, 2012; Froese-Germain, 2010; Rautalin & Alasuutari, 2009). Since the first PISA survey in 2000, the number of participating countries has continually increased from 28 OECD countries and four non-OECD partner countries (Bybee et al., 2009) to 72 countries and economies in 2015 (OECD, 2018). This increase in number of participating countries may demonstrate confidence in PISA as an important assessment program.

According to Bybee et al. (2009), PISA science has placed more emphasis on assessing students in terms of the important knowledge and skills they will need in their adult life and less in terms of mastering school curricula. This aspect differentiates PISA from TIMSS. In PISA science, scientific literacy has been emphasized as the major domain for assessment (OECD, 2017). Scientific literacy is defined in the PISA assessment framework by the three competencies: (1) to explain phenomena scientifically, (2) to evaluate and design scientific inquiry, and (3) to interpret data and evidence scientifically (OECD, 2017). PISA science assesses the extent to which 15-year-olds are capable of displaying these three competencies appropriately within a range of personal, local/national, and global contexts (OECD, 2017). For PISA, these competencies are only tested using the knowledge already acquired by 15-year-old students. In addition to competencies, PISA science includes other aspects to assess scientific literacy: context (personal, local/national, and global issues that demand some
understanding of science and technology), scientific knowledge (content, procedural, and epistemic), and attitude towards science (interest in, attention to, and response to science and technology) (OECD, 2017). Bybee et al. (2009) reported that PISA items are arranged in units—groups of independently scored items (questions) based on a common stimulus. All the three competencies and the three forms of scientific knowledge were included in PISA test units and, in most cases, each test unit assessed multiple competencies and knowledge categories (OECD, 2017). However, individual test items only assessed one form of knowledge and one competency. PISA used three classes of items to assess competencies and scientific knowledge: simple multiple choice, complex multiple choice, and constructed-response items.

Bybee et al. (2009) reported that PISA science results were reported using a combined scientific literacy scale, which has a mean score of 500 points among the OECD countries with a standard deviation of 100 points. In addition to reporting the results on a combined scale, the OECD also reported results using proficiency levels representing a comprehensive range of scientific literacy. Level 1 indicates students at the lowest or least proficient level, and level 6 indicates students at the highest or most proficient level. According to Turner (2009), based on their scores, students were assigned to the highest proficiency level for which they would be expected to answer correctly a majority of assessment items spread across levels of difficulty.

One of the major strengths of the PISA science assessment is its emphasis on assessing scientific competencies in relevant life situations, which represents a novel approach to scientific literacy assessment (Bybee et al., 2009). The knowledge and skills assessed in PISA are considered prerequisites to efficient learning in adulthood and for full participation in society (Bussiere, Knighton, & Pennock, 2007; Bybee et al.,...
However, these features of PISA science assessment are not aligned with features of chemistry assessments needed to assess student learning in the present study. The focus of assessments for this study is on assessing content and skills that are specified in the new Grade 7 chemistry curriculum in the Philippines, which is something that is not in line with the focus of PISA science assessment.

*The Views About Scientific Inquiry (VASI)* questionnaire was developed by Lederman et al. (2014) to measure students’ understanding about the nature of scientific inquiry, which according to them is an integral component of scientific literacy. This group of researchers argued that conducting scientific inquiry and knowledge about scientific inquiry are both important, but knowledge about scientific inquiry is not typically assessed in the classroom. They claimed that various science education reform documents such as in the United States (e.g., NRC, 1996, 2000, 2012) have placed importance on developing students’ understanding about scientific inquiry, but assessment measures for this were not readily available for use by teachers in the classroom. With this, Lederman et al. (2014) created the VASI questionnaire.

The VASI questionnaire was designed to assess students’ understanding of the following eight aspects of scientific inquiry as suggested by Lederman et al. (2014, p. 68): (1) scientific investigations all begin with a question and do not necessarily test a hypothesis, (2) there is no single set or sequence of steps followed in all investigations, (3) inquiry procedures are guided by the question asked, (4) all scientists performing the same procedures may not get the same results, (5) inquiry procedures can influence results, (6) research conclusions must be consistent with the data collected, (7) scientific data are not the same as scientific evidence, and (8) explanations are developed from a combination of collected data and what is already known. According to Lederman et al.
(2014), these aspects of scientific inquiry were based on previous research (e.g., Schwab, 1962; Flick & Lederman, 2004; Osborne et al., 2003) and educationally appropriate for middle and high school students.

The VASI is composed of seven open-ended response questions, which ask students to give more than simple declarative answers by providing examples to further elaborate their understanding about the eight aspects of scientific inquiry. A table of specifications that links each question to various aspects of scientific inquiry is provided for scoring. In evaluating student responses, views about scientific inquiry are categorized as informed, mixed, naïve, or unclear. The validity and interrater reliability for this questionnaire were established with agreement on over 90% of the questions scored (Lederman et al., 2014). The VASI questionnaire was used in countries other than the United States to assess students’ knowledge about scientific inquiry (e.g., Gaigher, Lederman, & Lederman, 2014; Hakanen & Lavonen, 2017; Yang, Park, Shin, & Lim, 2017). In Finland, for instance, the VASI questionnaire was used to explore the views of 149 grade seven students’ in the aspects of scientific inquiry (Hakanen & Lavonen, 2017). Researchers reported that, based on the results of VASI questionnaire, the sample students did not possess informed understanding of the nature of scientific inquiry but they emphasized that these students have informed understanding on the aspect “scientific data are not the same as scientific evidence”. Moreover, the VASI was also used to examine the views of 282 Korean grade eight students about scientific inquiry (Yang et al., 2017). Based on VASI, researchers reported that students understand scientific inquiry in everyday contexts; however, students did not have informed understanding of the terms data, evidence, and experiment, which is in contrast with the case of Finnish students.
To assess student chemistry learning in this study, assessments need to focus on assessing knowledge on chemistry content and skills in doing scientific inquiry as specified in the enhanced science curriculum. It is clear that the VASI questionnaire provided detailed information about the aspects of scientific inquiry that are important for middle and high school students to learn in science classroom; however, its primary focus is on assessing students’ knowledge about the nature of scientific inquiry, which is something different from the skills of doing scientific inquiry.

The Science Process Skills Inventory (SPSI) was developed by Bourdeau and Arnold (2009) to measure the development of science inquiry skills of middle school students in the United States. It is an 11-item scale that mirrors the steps of the science inquiry process. Based on SPSI (Bourdeau & Arnold, 2009), these steps of inquiry process include forming and asking scientific questions, designing scientific procedures, collecting and recording data, analyzing results, using models to describe results, and creating scientific presentations. The SPSI was used by asking students to respond to each item using a 4-point Likert scale (1=never, 2=sometimes, 3=usually, 4=always) indicating how often they practice each of the items when doing science. According to Bourdeau and Arnold (2009), the recommended scoring for this instrument is the calculation of the composite science process skills score, which can be obtained by summing the individual ratings for each item. The range for the composite score is 11-44. Principal component analysis (PCA) was used to assess the latent structure of the SPSI pretest and posttest scales, which indicated consistency with a single factor solution for the scale. In terms of internal-consistency reliability, Cronbach alpha coefficients for pretest and posttest range from 0.84 to 0.94 (Arnold, Bourdeau, & Nott, 2013).
Few studies reported the use of the SPSI in exploring students’ learning of scientific inquiry skills (e.g., Arnold et al., 2013; Soomro, Qaisrani, & Uqaili, 2011). One study was conducted in Pakistan wherein the researchers used the SPSI to measure the ability of 40 grade ten students in using science process skills in physics (Soomro et al., 2011). They investigated whether students’ development of process skills was more favorable in a learning environment that used the 5E teaching model than in a learning environment that used traditional teaching methods. They used SPSI in a pretest-posttest control group research design. Based on the results of SPSI, they reported that the 5E teaching model was more effective in improving students’ attitudes towards science process skills in physics than traditional teaching methods.

It seems that the SPSI is not a widely used assessment for inquiry-based learning. But the advantage of using the SPSI is that it may provide a clear profile of student development of inquiry skills since it assessed a variety of specific scientific inquiry practices of students in the classroom. This is evident in the composition of its items, which represent the important steps of a complete inquiry process (Arnold et al., 2013). Despite this strength of the SPSI, it could not offer ways to assess students’ learning of science content since its main focus is on the process of science only.

The Scientific Inquiry Literacy Test (ScInqLiT) was developed by Wenning (2007) as a diagnostic multiple choice test relevant for scientific inquiry. Wenning (2007) claimed that this test was not designed to “authentically assess student abilities to conduct scientific inquiry” (p. 24). It was designed to offer measures of students’ development of scientific inquiry knowledge, which is ideal for the pretesting and posttesting of the development of such knowledge (Hanauer, Hatfull, & Jacobs-Sera, 2009). In order to define clearly what is to be measured in the test, Wenning (2007)
developed a framework that operationally defines scientific inquiry at a level appropriate to the understanding of high school students. This framework contains proposed stages of scientific inquiry process, which were reviewed by physics teaching majors, scientists, and educators. The following are the stages of scientific inquiry suggested by Wenning (2007): (1) identify a problem to be investigated, (2) formulate a hypothesis or model using induction from logic and evidence, (3) generate a prediction from the hypothesis or model using deduction, (4) design experimental procedures to test the prediction, (5) conduct a scientific experiment, observation or simulation to test the hypothesis or model, (6) collect meaningful data, organize, and analyze data accurately and precisely, (7) apply numerical and statistical methods to reach conclusions, (8) explain unexpected results, and (9) use available technology to report, display, and defend results. The initial 40 multiple choice test items were developed based on these stages of inquiry process. These items were analyzed to determine item difficulty and discrimination. After a series of pilot testing, five items were deleted and leaving the final version of the test with 35 items.

Although the ScInqLiT was specifically designed to assess secondary school students’ knowledge of scientific inquiry processes (e.g., Greene, O’Hair, Pedersen, Nanny, & O’Hair, n.d.; Wenning, 2007), this test was also used to assess prospective science teachers’ inquiry literacy (e.g., Kusnadi, Rustaman, Redjeki, & Aryantha, 2017). Researchers in Indonesia used the ScInqLiT to assess the development of scientific inquiry literacy of prospective biology teachers after participating in an inquiry-based laboratory project in Microbiology (Kusnadi et al., 2017). Specifically, they assessed the research and laboratory skills and the attitudes toward science of prospective teachers.
According to Wenning (2007), ScInqLiT is best used as a research instrument for identifying weaknesses in student understanding of scientific inquiry processes, improving science instructional practice, and determining program effectiveness in relation to teaching scientific inquiry skills. In addition, ScInqLiT could determine the level of students’ procedural knowledge on scientific inquiry, which may inform the assessment of inquiry learning in this study. The only limitation of this test is the absence of items that specifically assess science content knowledge, which is vital in the assessment of scientific learning.

A review of all these approaches to assessment presents four aspects that are important to consider when assessing inquiry-based science learning. These are scientific content, scientific process, scientific inquiry skills, and attitude towards science. Based on this review, scientific inquiry in the classroom seems to be a multifaceted activity that requires knowledge and skills to solve a problem. For this reason, the assessment of inquiry-based science learning may require the following: (1) knowledge of scientific concepts and facts, or the content/substantive knowledge (Hanauer et al., 2009; OECD, 2017); (2) knowledge of procedural aspects of how to do scientific inquiry, or the procedural knowledge (Hanauer et al., 2009; OECD, 2017); (3) skills on science processes (e.g., problem solving, conceptualizing results, and developing explanation) (OECD, 2017); and (4) attitude towards science (OECD, 2017).

From all the assessments mentioned above, only the PISA science assessment has been observed to include all the aforementioned aspects. Most assessments canvassed were designed to focus on one aspect of scientific learning—either assessing content or assessing process skills. The OECD (2017) and a number of science
education researchers (e.g., Norris & Philips, 2003; Ødegaard, Haug, Mork, & Sørvik, 2014; Lederman, Lederman, & Antink, 2013) emphasized that learning the content of science alongside learning about the practices or processes of science or scientific inquiry is an integral component of scientific literacy. This information is beneficial to inform the present study on investigating the relationship of scientific inquiry practices and student learning.

In this study, the chemistry test needed to address the content and inquiry skills as specified in the new science curriculum in the Philippines. Although the instruments reviewed above have their own strengths, they did not meet the requirement of assessing the learning of chemistry content alongside learning of inquiry skills as specified in the new curriculum. Thus, this study utilized the ACTRC chemistry tests developed specifically for Grade 7 students in the Philippines, as these were specifically designed to both match the curriculum being taught (content) and measure specific inquiry skills.

The ACTRC Chemistry Tests

A key focus of this study is to consider how the teaching of scientific inquiry skills impacts on student learning growth. To do this, a measure of student learning needed to be identified. In order to assess students’ learning outcomes, the chemistry tests developed by ACTRC were used in this study. This is because the tests were developed based on the new science curriculum in the Philippines. The design of the tests was aligned with the content and structure of the new science curriculum and specifically the chemistry component for Grade 7. The key concepts and skills used in test development were derived from the chemistry component of the curriculum. This is
beneficial for the present study since it explored Grade 7 students’ learning (content and inquiry skills) in chemistry under the new curriculum reform. The ACTRC chemistry tests also include items on scientific inquiry that are aligned with six different elements of inquiry as discussed in the previous section of this chapter—engaging in questioning, designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information. As a member of the test development team, the author of this thesis mainly contributed to the development of items on scientific inquiry for the ACTRC chemistry tests. These items were designed in accordance with the framework for the development of assessment indicators for inquiry-based teaching of teachers in chemistry, proposed by the author for this study. This proposed framework will be presented in Chapter 4. The items on scientific inquiry are additional to the items on content, which are based on the Grade 7 chemistry component of the new science curriculum. Furthermore, the ACTRC chemistry tests and scales were designed to measure student gain or growth within and across year levels. The test alignment to the curriculum was reviewed and checked by the appropriate experts and the scaling process utilized Rasch analysis. The curriculum alignment and associated interval scales are characteristics of the ACTRC chemistry tests which are beneficial for this study, particularly in measuring students’ learning in chemistry across different time points. Details on test development process are discussed in Chapter 4.

**The Rasch model**

The use of Rasch (1960) modeling has been considered by many to be one of the best approaches for measurement (Boone, Townsend, & Staver, 2010; Liu, 2010;
Sondergeld & Johnson, 2014). Today, many researchers have used Rasch modeling in both developing tests and obtaining student ability and item difficulty estimates (e.g., Areepattamannil & Khine, 2017; Boone & Scantlebury, 2006; Karim, Shah, Din, Ahmad, & Lubis, 2014; Phillipson & Tse, 2007). This is because the Rasch model can address some measurement issues that the Classical Test Theory (CTT), which was ever prevalent in measurement history, fails to deal with.

CTT is a measurement framework that focuses on models at the test-score level that link test scores to true scores rather than item scores to true scores (Hambleton & Jones, 1993). Although the major focus of CTT is on test-level information, item statistics such as item difficulty and item discrimination are also important for the CTT model (Fan, 1998). According to Fan (1998), CTT is not using a complex theoretical model to relate a person’s ability to success on a particular item. Instead, CTT collectively considers a pool of persons and empirically examines their success rate on an item. However, CTT has two major limitations. First, the person statistics (i.e., observed score) are test dependent. Second, the item statistics (i.e., item difficulty and item discrimination) are person dependent. MacDonald and Paunonen (2002) reported that similar statistical interdependencies exist between the observed scores and the item discrimination indices of CTT. These limitations of CTT pose some difficulties in its application to some measurement situations (e.g., test equating) (Fan, 1998). The aforementioned dependencies could limit the utility of the person and item statistics in practical test development work and in test equating which could complicate any measurement analysis (e.g., measurement of growth) (Hambleton & Jones, 1993).

In the Rasch model, the probability of a person’s successful response in an item is expressed mathematically as follows (Wright & Stone, 1979):
\[ P(X_{vi} = 1|\beta_v; \delta_i) = \frac{\exp(\beta_v - \delta_i)}{1 + \exp(\beta_v - \delta_i)} \]

In this equation, \( X_{vi} \) indicates the success or failure of person \( v \) on the item \( i \). When \( X_{vi} = 1 \), it means success (or a correct response) on the item, and if \( X_{vi} = 0 \) this means failure (or an incorrect response) on the item. \( \beta_v \) is a person-parameter, representing the ability level of person \( v \) on the latent variable scale, and \( \delta_i \) is the difficulty of the item which is on the same measurement scale as \( \beta_v \).

Through this equation, the Rasch model explained that a student whose ability is equal to the item difficulty has 50% chance of answering the item correctly. If an item’s difficulty is lower than a student’s ability then the student has greater than 50% chance of answering the item correctly. If an item’s difficulty is higher than a student’s ability then the student has less than 50% chance of answering the item correctly. Further, the above equation representing the Rasch model defines a unit called “logits” for student ability and item difficulty estimates (Wright, 1977).

Assessment data analysis using the Rasch (1960) modeling approach provides researchers with many techniques to evaluate assessment reliability and validity. It provides a deeper understanding of the instrument’s strengths and weaknesses than the CTT’s approach to measurement. In this study, the Rasch (1960) modeling approach was employed to analyze chemistry assessments of Grade 7 students. The Rasch (1960) model has wide application due to its property of invariance. The Rasch model property of parameter invariance is essential for measuring growth or comparing measures obtained from different student samples or measurement conditions. The degree to which parameter invariance is achieved is the degree to which it is possible to make
valid inferences about student growth (Pavlovic, 2017). Furthermore, for parameter invariance to hold, it is necessary to have the development of interval scales since the item parameter estimates are not dependent on persons who took the test items, and the person ability estimates are not dependent on the administered test items. Therefore, in contrast with CTT, the key benefit in using the Rasch model in this study is its property of parameter invariance and the consequent student ability estimates to compare results obtained by two different chemistry tests. In addition, the Rasch model was used because it has tight standards for the data to be analyzed. It is not designed to fit the data, but instead is derived to define measurement (Wright, 1992). Therefore, it is an ideal model that addresses the requirements of scientific measurement (Boone, Staver, & Yale 2014). Moreover, Rasch modeling was also preferred for the present study particularly due to its capacity to create ways of measuring gain or growth to determine student learning outcomes, and to equate the two chemistry tests to compare results.

The other possible measurement models such as Item Response Theory (IRT) [e.g., two-parameter logistic (2PL) and three-parameter logistic (3PL) models (Birnbaum, 1968)] have weaker standards for the data to be analyzed, which means that items are not rejected since the model adjusts to adapt to the contours of the data (Wright, 1992). The Rasch model and Item Response Theory (IRT) are often conflated. Some researchers associate the Rasch model with the family of IRT models (e.g., 2PL, 3PL), and they argue that it should be considered as a one-parameter logistic (1PL) IRT model (Boone & Scantlebury, 2006). Although the mathematics of the Rasch model may look like the one-parameter IRT model for dichotomously scored test items, according to Boone et al. (2014), there is a core philosophical difference between the Rasch model and IRT models. The Rasch model is not altered to fit a data set. This
makes the Rasch model the only model that meets the requirements of objective measurement set forth by Thurstone (1928). On the other hand, IRT models are data-centered. They are altered (more parameters are added) to fit a data set. Due to this difference, it is misleading to classify the Rasch model as an IRT model. High-quality measurement should not depend on the sample being measured, and the Rasch model is sample independent. For these reasons, the Rasch model was used in this study to analyze the student test data.

Chapter Summary

Several studies have suggested that scientific inquiry as a teaching approach can meet a variety of educational goals (Anderson, 2002; Crawford, 2012, 2014; Hagay & Baram-Tsabari, 2015; Heinz et al., 2017; Minner et al., 2010; Osborne, 2014). For example, inquiry-based instruction has been posited as more effective than traditional approaches in teaching a variety of specific science concepts (Duschl & Grandy, 2008; Wilson et al., 2010). In addition, empirical evidence suggests that inquiry-based approaches may be effective in promoting positive attitudes toward learning science (Hagay & Baram-Tsabari, 2015; Rivera et al., 2014; Wallace & Kang, 2004). These pieces of evidence indicate that using scientific inquiry in classrooms may have a positive impact on student learning and attitudes toward life-long science learning.

However, other research is not as positive. Some researchers explicitly question the effectiveness of inquiry as a teaching approach in classrooms (e.g., Kirschner et al., 2006; Klahr & Nigam, 2004). There are also studies that report negative impacts of inquiry-based teaching on student learning in science (e.g., Areepattamannil, 2012; Lavonen & Laaksonen, 2009; Pine et al., 2006). These observed inconsistencies of the
results strongly suggest the need for further research to identify the impact of scientific inquiry on students’ learning progress in science.

Furthermore, the overwhelming majority of research on scientific inquiry and its relationship with students learning to date has been conducted in developed countries. Teachers and students in these countries typically have access to resources (such as physical resources and teacher support) that are not readily available in less developed countries. Further, teaching practice in developed countries takes place under conditions that may facilitate the use and effectiveness of scientific inquiry practices (such as smaller class size). It is not yet known whether and how teaching through scientific inquiry translates to less developed countries and if it is able to positively impact on student learning in these contexts.

In addition, there is a lack of understanding about which aspects of scientific inquiry practices, if any, are related to student learning growth. This study set out to specify precisely specific scientific inquiry teacher behaviors, and investigate their relationship with learning growth. To meet these research objectives, an observational tool (the SITOI) was created that captured and classified a range of scientific inquiry teacher practices. This allowed a more fine-grained examination of the relationship between practices and student learning growth.

Furthermore, the review of different assessments designed to measure student outcomes (e.g., Bourdeau & Arnold, 2009; Mullis, 2017; OECD, 2017; Wenning, 2007) revealed that most assessments were designed to assess only one aspect of science learning—either content or inquiry skills. With this, the present study used the ACTRC chemistry tests that assess both the content and inquiry skills as specified in the new
curriculum. The Rasch (1960) model was used to derive measures of gain or growth. The use of the Rasch model enabled comparison of students’ ability at two time points.
Chapter 4: Methodology and Sample

This chapter presents the participants, research instrument development, data collection procedure, and data analysis procedure for assessing teachers’ inquiry instruction and for measuring students’ learning in chemistry. A brief summary of the methods is found at the end of the chapter.

Assessing Teachers’ Scientific Inquiry Instruction

Development of research instrument

_The Scientific Inquiry Teaching Observation Instrument (SITOI)_

To meet the study’s research objectives, there was a need for an observational tool that could directly assess inquiry instruction by looking at the granular view of scientific inquiry practices of teachers. For this reason, the Scientific Inquiry Teaching Observation Instrument (SITOI) was developed by the author to cater for this need. The SITOI was designed to measure teachers’ implementation of specific inquiry-based instructional practices in science classrooms.

_The SITOI development stage_

The following stages were employed to develop the SITOI. Descriptions of each of the development processes are presented below.

_1. Establishment of the SITOI framework._ In the first process of the SITOI development, an assessment framework that is aligned with scientific inquiry was created. The establishment of the framework involved two primary steps. First, the construct was defined by reviewing relevant literature on the use of scientific inquiry in
the classroom and examining science curricula (especially the new Grade 7 chemistry curriculum in the Philippines) to see the nature of inquiry-based lessons and the associated inquiry skills included in the curriculum. Second, existing and established observation protocols for science teaching at junior secondary level were examined, particularly those that assess inquiry-based classroom teaching in order to build on previous work in the field.

In the first step, the nature of scientific inquiry as a teaching approach in science was explored to identify the general characteristics of scientific inquiry that are useful in chemistry classrooms. The characteristics were derived from inquiry-based science curriculum reform documents in the United States and Europe (e.g., *Benchmarks for Science Literacy* [AAAS, 1993]; *Inquiry and the National Science Education Standards* [NRC, 2000]; *ESTABLISH project* [McLoughlin, 2011]; *Framework in K-12 Science Education* [NRC, 2012]) and some characteristics were provided by science education researchers who worked on the use of scientific inquiry in teaching (e.g., Crawford, 2007; Lederman et al., 2014; Minstrell & van Zee, 2000). Aside from these documents, the Philippine Grade 7 chemistry curriculum was closely examined to determine how scientific inquiry is articulated in the new curriculum materials (e.g., *Science Curriculum Guide* [DepEd, 2016], *Teachers’ Guide, Learners’ Module*). This also offered descriptions and characteristics of scientific inquiry. In addition, the features of inquiry-based teaching were identified through exploring different inquiry-based instructional models developed by various researchers (e.g., 5E instructional model; EIMA model; guided-inquiry model) in order to determine the components of scientific inquiry suitable for basic education. The models suggest that scientific inquiry is a
broad array of approaches with varied teaching components that usually has questions to be answered or problems to be solved.

In the second step, established observation protocols for science teaching (e.g., Reformed Teaching Observation Protocol [Sawada et al., 2002]; Science Teacher Inquiry Rubric [Bodzin & Beerer, 2003]; Electronic Quality of Inquiry Protocol [Marshall et al., 2009]; Inquiry into Science Instruction Observation Protocol [Minner & DeLisi, 2012]) were examined to determine the components as well as the specific indicators commonly used as contents of observational instruments to describe inquiry-based teaching in the science classroom. Although the observational instruments examined in this study (see Chapter 3) did not address all of the needs of the SITOI development, they did provide ideas about the component elements of inquiry-based science teaching.

The emphasis given on scientific inquiry appears to be a universal theme of K to 12 science education documents. However, it is clear that there is no single and fixed method of inquiry teaching in the science classroom. Most of the characteristics of scientific inquiry and key features of the different models of inquiry instruction suggest these commonalities as exemplified in the following six major components of scientific inquiry (Fogleman et al., 2011; Minner et al., 2010; Wilson et al., 2010). These six components are the major practices of scientific inquiry and were used as a framework to develop specific items or indicators of inquiry teaching practices listed in the SITOI.

1. Engaging in questioning (Q)
2. Designing and conducting investigations (DI)
3. Collecting data (CD)
4. Analyzing data (AD)
5. Developing explanations (DE)

6. Communicating information (CI)

It is important to note that the many facets of scientific inquiry reviewed from the instructional models, inquiry science curricula, and observation protocols were not all included in this study. These facets were examined to identify the common aspects of inquiry that the researchers considered most relevant to school science education. Although the models, curricula, and observation protocols reviewed in this study offered different features of inquiry, they all have exhibited commonalities in the aforementioned six components of inquiry relevant to school science education.

2. Development of items for the SITOI Version 1. After establishing this framework, a preliminary version of the SITOI was created using the six components to assess inquiry-based instruction of teachers. To devise items representative of each of the six components, Version 1 of the SITOI was initially developed. This version of the SITOI was composed of 36 items or statements on inquiry practices in classrooms grouped into the six components of inquiry to capture the nature of inquiry instruction of chemistry teachers. This preliminary set of items was developed and patterned according to the items on inquiry teaching practices of the established and research-based inquiry observation instruments reviewed in this study. The items ranged from teacher-centered to student-centered inquiry practices.

3. Content validity of the SITOI Version 1. Two educational experts (one Professor and one Research Fellow) of the Assessment Research Centre (ARC) at the Melbourne Graduate School of Education reviewed the content of the SITOI Version 1. Both of them had extensive experience in educational assessment. One of the experts
had scientific background with secondary school science classroom experience. Independent preliminary feedback from each expert was gathered and used as a means to revise the items. Their feedback suggested grammatical revisions and content clarifications. To address their feedback, revisions of 36 preliminary items were done to make them more clear and more specific. Items were added in some components of inquiry to represent thoroughly the practices of scientific inquiry in classrooms. Unnecessary repeated items in the list were deleted. Rewording or rephrasing the statements was done for clarity and comprehension. One of the suggestions was to rephrase all the statements and begin each statement with the word ‘Teacher’ to emphasize that the SITOI was designed to assess teachers’ inquiry teaching practices. For example, ‘Teacher prompts students to formulate and ask their own questions’. Further, items in each component were reviewed again to make sure that they appropriately represent a particular component of inquiry. With these actions, items of the SITOI Version 1 were revised which resulted in the development of the SITOI Version 2. A copy of SITOI Version 1 can be found in Appendix A.

4. Pilot test of the SITOI Version 2. The SITOI Version 2 with 29 items was piloted in one Year 7 science class and one Year 8 science class in a public secondary school in Victoria, Australia. Two researchers (the author and a research staff member of the ARC) conducted paired observations in each science class using the SITOI Version 2 to clarify the items on inquiry practices listed in the instrument and to identify if the behaviors described by items were observable in the classroom. The pilot test also provided an opportunity to assess the usability of the SITOI in the classroom. A check mark was put next to an item every time it was observed in the classroom. Notes were also taken during the observations. The SITOI Version 2 was piloted in
Australia since the Australian basic education system has been implementing an inquiry-based science curriculum for a number of years (ACARA, 2017). Therefore, at least theoretically, science teachers should be exhibiting a variety of inquiry-based teaching practices in classrooms. Further, the K to 12 science curriculum in Australia and the new K to 12 science curriculum in the Philippines are both student-centered and inquiry-based, emphasizing the teaching and learning of inquiry.

5. Revision of items of the SITOI Version 2. After pilot testing of the SITOI Version 2 in Australia, post-observation reflections and discussion meetings were conducted by the two researchers to compare their observation data gathered using the instrument, consolidate ideas, analyze observation notes, and confirm which items in each component of inquiry listed in the SITOI Version 2 were enacted by teachers and identify which items need improvement. Based on individual observational data gathered using the SITOI, it was found that the two researchers had observed almost the same items on inquiry practices of teachers enacted in classrooms. However, there was a little difference in the total number of check marks put in some of the items observed. With this, some items were refined based on the observed teacher practices implemented in the inquiry-based science classrooms. Additional check boxes in each item were also provided. It was found that some items on inquiry practices could be combined with others that were similar and that, in order to fully capture scientific inquiry practices, it was necessary to refine, revise, and add specific items based on the observed practices enacted by teachers in the classroom. With these actions, items of the SITOI Version 2 were revised which resulted in the development of the SITOI Version 3. A copy of SITOI Version 2 can be found in Appendix B.
6. Content validity of the SITOI Version 3. A science education specialist from the University of the Philippines National Institute for Science and Mathematics Education Development was asked to review the content of the SITOI Version 3 with 31 items. She holds a PhD in Chemistry Education and has extensive experience in secondary school chemistry classroom research in the Philippines. Her feedback in the SITOI Version 3 mainly focused on content clarification. In particular, she suggested that the items in each component of inquiry should be more specific to ensure it could be used effectively with Grade 7 chemistry teachers in the Philippines, one part of the target sample population. For example, she suggested that an example of complex data as specified in this item ‘Teacher asks students to analyze complex data’ be provided. This is because complex data may not be part of the Grade 7 chemistry curriculum in the Philippines. Her feedback provided the basis for item refinement, which resulted in the final version of the SITOI. A copy of SITOI Version 3 can be found in Appendix C.

7. Finalization of the SITOI. The final version of the SITOI used in observations was composed of 31 items on specific classroom practices, grouped into the six major components of scientific inquiry. All items listed in the SITOI were finalized and verified if they appropriately represented the intended scientific inquiry components. Revisions (grammatical and content) from the previous process were made for clarity and comprehension of the items. The items in each component of inquiry were arranged from teacher-centered to student-centered to determine the degree of initiation of inquiry practices in the classroom. The implication is that the more responsibility students have for posing and responding to questions, designing and conducting investigations, and extracting and communicating their learning, the more
open the inquiry. The more responsibility the teacher takes, the more guided or structured the inquiry (NRC, 2000).

The SITOI items

After a series of revisions made in the foregoing process, the resulting instrument includes the following 31 items of specific practices, which were developed according to the six major components of scientific inquiry framework. As mentioned above, the process of developing these items includes the examination and content validation by relevant experts such as chemistry education specialist, scientist, and education assessment specialist. These items were refined based on their critical comments and suggestions.

Component I: Engaging in questioning (Q)

1. Teacher asks students a question about facts previously presented that requires short, specific answer.

2. Teacher asks students a question about facts NOT previously presented which elicit students’ own ideas.

3. Teacher asks students a question that requires them to justify a situation or phenomenon.

4. Teacher prompts students to formulate and ask their own questions.

Component II: Designing and conducting investigations (DI)

1. Teacher demonstrates how to do the activity/experiment.

2. Teacher provides specific procedures to follow for students to do the activity/experiment.
3. Teacher identifies the treatment and control variables for the activity/experiment.
4. Teacher guides students while conducting the activity/experiment.
5. Teacher asks students to identify the treatment and control variables for the activity/experiment.
6. Teacher asks students to design their own procedures for the activity/experiment with assistance of teacher.
7. Teacher asks students to design their own procedures for the activity/experiment.
8. Teacher asks students to formulate their own objectives for the activity/experiment.

**Component III: Collecting data (CD)**

1. Teacher provides data for students.
2. Teacher asks students to make descriptive observations and/or collect data from teacher demonstration.
3. Teacher asks students to make descriptive observations and/or collect data from activity/experiments that students perform.
4. Teacher asks students to make measurements using scientific tools and equipment.
5. Teacher asks students to explore phenomena and collect data outside the classroom.

**Component IV: Analyzing data (AD)**

1. Teacher provides analysis/solution for students.
2. Teacher tells students direction on how data/problem is to be analyzed/solved.
3. Teacher asks students to analyze/solve simple data/problems.

4. Teacher asks students to analyze complex data/problems (e.g., secondary data from existing scientific databases).

5. Teacher prompts students to assess the reliability and/or validity of data/results.

**Component V: Developing explanations (DE)**

1. Teacher gives the explanation without giving students opportunity to explain results.

2. Teacher gives the explanation but students are given opportunities to explain and no one can make an explanation.

3. Teacher gives students pieces of evidence/information/clue they need and then asks students to form their own explanation/conclusion/generalization from results.

4. Teacher asks students to form their own explanations/conclusion from results.

**Component VI: Communicating information (CI)**

1. Teacher asks students to write information using the prescribed format.

2. Teacher asks students to devise and use their own format of writing information.

3. Teacher asks students to describe, illustrate diagram/chart/picture, or graph/table.

4. Teacher asks students to report on data or results of an individual or group activity to the whole class.

5. Teacher asks students to report on data or results of an individual or group activity with teacher-student interaction.
The final version of the SITOI is located in Appendix D. The SITOI was used in the classroom from the start of the instruction period until the end of the instruction period. Every time a teacher enacted the practice listed in the SITOI, a tick was placed in a box provided in the instrument. Hence, the teaching implementation of a specific practice could be recorded as many times as occurred. If a practice was not applicable to the lesson taught by the teacher, ‘NA’ (not applicable) was noted next to a particular item.

**Teacher questionnaire**

A short teacher questionnaire was developed to determine the background characteristics of the sample teachers and their classroom contexts. It consisted of two parts. The first part consisted of eight questions about teacher background information such as education, gender, years of teaching experience, attendance at professional development programs on the new science curriculum, and access to new curriculum materials. The second part consisted of nine questions about the nature of the chemistry classes they taught. Information on class size, student attendance, availability of resource materials in class (e.g., science equipment, glassware, curriculum materials), workspace to conduct experiments, and storage room for science materials was collected. Both parts of the questionnaire included checklists and open-ended questions. A copy of the teacher questionnaire used in this study is located in Appendix E.

**Ethics**

This study was given ethics approval from the University of Melbourne Human Research Ethics Committee. The implementation of this study was also approved by the
Department of Education (DepEd) in the Philippines. The ethics documents for this study (e.g., consent forms, plain language statements) can be found in Appendix F. The plain language statements provided background information to the study, the research focus, and how the participant was going to be involved. Contact information for the ethics committee at the University of Melbourne was provided on this form.

**Sample recruitment**

**Teacher participants**

The data for this study were collected from four public mainstream secondary schools from the National Capital Region (NCR) of the Philippines. These schools were situated in densely populated cities in NCR. They were located quite far apart in three different cities—Quezon City, Pasig City, and Makati City. The schools’ average class size is 41. NCR was selected because of its relatively large population and consequent role as education provider for a relatively large number of students with elementary and secondary education. More characteristics of sample schools are outlined in Table 1 below.

<table>
<thead>
<tr>
<th>School</th>
<th>School Type</th>
<th>School Location</th>
<th>Total Student Population</th>
<th>No. of Sample Teachers</th>
<th>No. of Sample Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Regular, coeducational</td>
<td>Small urban area</td>
<td>7,755</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Regular, coeducational</td>
<td>Small urban area</td>
<td>7,499</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Regular, coeducational</td>
<td>Large urban area</td>
<td>12,348</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Regular, coeducational</td>
<td>Large urban area</td>
<td>6,912</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

*Notes. Regular school is a public school using the regular science curriculum. Student population was recorded during the school year 2015-2016.*
Invitations to schools to participate in this study were mailed out through the ACTRC, which is based in Manila. The school principals were invited to participate upon permission from the DepEd by sending a letter from ACTRC, following formal approval for the research by the DepEd. Consenting principals provided names and contact details of Grade 7 chemistry teachers that enabled the ACTRC to send invitations to participate in the research to relevant staff. The schools where the teachers consented to participate were included in the research.

Based on this procedure, ten Grade 7 chemistry teachers (three males and seven females) from four of the largest public secondary schools in NCR participated in this study. The maximum years of science teaching experience of these teachers was twenty-one and the minimum was four. Of the 10 teachers, nine were science majors and eight participated in the national training for the implementation of the new science curriculum conducted by DepEd. Some of them obtained postgraduate degree in education (e.g., MA Educ). More details on teacher characteristics are presented in Chapter 5.

**Classroom observations**

A series of classroom observations was conducted to identify teachers’ inquiry practices in chemistry. Observation of classes provided opportunities to identify specific teaching practices employed by teachers that were related to the six major components of scientific inquiry. The lesson observations were conducted in twelve Grade 7 chemistry classes in four public secondary schools in NCR. Most of the Grade 7 chemistry classes observed in this study were crowded with students. The highest number of students in a class was 57 and the lowest was 39. Some students were
grouped into homogeneous classes while other students were included in heterogeneous classes. Generally, homogeneous classes in the Philippines are composed mainly of students with similar ability. In contrast, heterogeneous classes are composed of students with a wide range of ability levels, most of whom were not as academically able as students in homogeneous classes. Student attendance in most classes was generally good. Science laboratory room and materials were available in some classes only. More details about each chemistry class observed are presented in Chapter 5.

Inquiry-based lessons in chemistry (Solutions, Substances and Mixtures, Elements and Compounds, Acids and Bases, and Metals and Nonmetals) taught by teachers were included in the new Grade 7 chemistry curriculum for the first quarter of the school year. A total of 10 chemistry teachers were observed in different classroom contexts in order to gather a wide variety of teaching practices related to inquiry while implementing the inquiry-based curriculum. This would give a more detailed and evidence-based documentation of the nature of inquiry teaching in Philippine classrooms. There were two teachers who were observed teaching two different chemistry classes and the remaining eight teachers were observed teaching one chemistry class. Ten chemistry classes were observed for five one-hour lessons, one class was observed for four one-hour lessons, and one remaining class was observed for three one-hour lessons. This variation in the number of observations was a result of class suspensions due to inclement weather conditions affecting the two classes with fewer than five observations. The number of lesson observations per class is presented in Table 2 below.
Table 2. Number of Lesson Observations per Class

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Number of Classes</th>
<th>Number of Observations</th>
<th>Duration (Hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>5 per class</td>
<td>5</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>E</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>F</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>G</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>H</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>I</td>
<td>2</td>
<td>5 in 1&lt;sup&gt;st&lt;/sup&gt; class</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 in 2&lt;sup&gt;nd&lt;/sup&gt; class</td>
<td>3</td>
</tr>
<tr>
<td>J</td>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

All classroom observations were done by the author. However, another person was invited to observe all classes once each week. The rationale for doing this was for validation of what was observed in the classroom using the SITOI, and to ensure that there was no occurrence of bias. The invited observer was a Lecturer at the University of the Philippines who used to teach chemistry to undergraduate students. He also had experience in secondary school chemistry classroom. In order to familiarize the invited observer about the use of the SITOI, the author gave an orientation on its essential features and on how to use the instrument in the classroom.

The SITOI checklist was used in all lesson observations. In addition to using the SITOI, notes of what exactly happened during instruction were written by both observers in all lesson observations. This method produced detailed observation notes in each class, which provide thorough descriptions of the inquiry practices enacted by teachers. This also captured the specific classroom cases or scenarios that showed teachers’ enactment of inquiry practices. Note-taking during instruction was done to ensure that the data gathered from the observation using the SITOI were backed up with specific evidence and thus became solid. This would make the observation data as
precise as possible. The total number of observations made was 57, over a period of six weeks. In Chapter 1, it was mentioned that only in Grade 7 chemistry was scientific inquiry explicitly listed as a conceptual topic to be covered by teachers. Grade 7 students studied chemistry in the first quarter of the school year with six weeks of instruction. With this in mind, the implementation of classroom observations for this study was fitted within this period of instruction. Generally, five one-hour lesson observations were done per class to examine teachers’ implementation of inquiry-based chemistry curriculum in the classrooms. In this duration of observation, teachers taught different inquiry-based lessons in chemistry. The multiple classroom observations per teacher provided the observers with more opportunities to capture the different facets of teachers’ inquiry-based teaching practices, which helped generated sufficient observational data.

After the observation, a debriefing session was conducted every week to compare and discuss the observational data gathered using the SITOI. If discrepancies were observed, these were discussed to determine the source of disagreement. Based on individual observational data gathered, it was found that the author and the invited observer had observed (ticked) almost all the same items on inquiry practices enacted by teachers listed in the checklist.

**Teacher questionnaire administration**

The questionnaires were administered to teachers in order to collect data on their experience in teaching science in secondary school classrooms, on their attendance in training for the new science curriculum, on their confidence to teach the new science curriculum, on their access to new curriculum materials, on their educational background, and on their chemistry classroom settings such as the number of students in
a class and the availability of science facilities and resources. Questionnaires were given to teachers after the lesson observations and then collected by the author as soon as they finished answering. All ten teachers answered the questionnaire efficiently.

**Data analysis procedure**

*Validity of the SITOI*

Validity is an important property of test scores. It is the “degree to which evidence and theory support the interpretations of test scores for proposed uses of test” (AERA, APA, and NCME, 2014, p. 11). In other words, validity tells us whether the scores are measuring the right things for a particular use of the test or instrument. For a newly developed test, it is important to examine whether the test items really measure the latent construct that they are supposed to measure because this determines the appropriateness of the proposed inferences derived from test scores or other instrument indicators. Given the complexity of validity, it is always recommended multiple different types of validity indices be applied in test development practices (Messick, 1990). These widely applied types of validity include content validity, criterion-related validity (predictive and/or concurrent), and construct validity (Messick, 1990; Reeves & Marbach-Ad, 2016), etc. To examine the relevance and representativeness of the content of the instrument in relation to the content of the behavioral or performance domain about which inferences are to be drawn, the exploration of content validity for the SITOI was prioritized in this study. The behavioral domain is the latent construct (scientific inquiry), which is the target domain in this study.

As discussed in Chapter 3, the contents of most observation instruments for science teaching are geared towards describing broader strategies, and are not sufficient
for capturing the specific inquiry practices of teachers in classrooms. They lack specific teaching indicators or items related to scientific inquiry. Since there is a lack of observation instruments containing items with specific inquiry practices, this study explored the development of SITOI that focuses directly on assessing the implementation of specific inquiry-based teaching practices of teachers. Because of this, developing appropriate contents for the SITOI, particularly the relevant items representing components of scientific inquiry, was important in the early formation of the instrument. For this reason, examining the content validity of the newly developed SITOI was a priority. Thus, this study concentrated on exploring the content validity of the instrument given that this involves the specification of the target domain (scientific inquiry) and development of items that reflect this domain specification (Kane, 2006), which was crucial in the SITOI developmental stage process. Compared to other types of validity such as criterion validity and construct validity, content validity mainly focuses on evaluating how well the content of the instrument represents or samples the target domain about which inferences are to be drawn or predictions made (Messick, 1990). This is demonstrated in the suggestion of other researchers (e.g., Goe, Bell, & Little, 2008) that when assessing the validity of classroom observation instruments for teacher evaluation, it is essential to examine how well its content exemplifies teachers’ implementation of standard of practice that are deemed important for the target grade level, subject, and teaching context. Although there is concern about the objectivity of content validity (e.g., construct validity and criterion validity are more objective than content validity), this can be addressed through the making of judgments by content experts who are not involved in the instrument development process (Kane, 2006), which is what was undertaken for the present study.
As described in *The SITOI development stage*, the content validity of the SITOI was established using the judgment of content experts who were not associated with the SITOI development process, using the resultant independent feedback to provide evidence supporting claims of validity. If the expert endorses an item based on relevance and representativeness of the content, it can be considered to have construct validity. If the expert rejects an item, it can be discarded or rewritten. This method aligns with the claim of Messick (1990) that in practice, content validity evidence is usually established through consensual professional judgments about the content relevance of items (presumably construct-valid) to the domain of interest and judgments about the representativeness of content of the instrument that covers the target domain. This method for establishing content validity has also been employed by other researchers who have developed observation instruments for classroom teaching (e.g., Pearl et al., 2018; Smolleck et al., 2006). According to Messick (1990), this process of validating an instrument provides “judgmental evidence in support of the domain relevance and representativeness of the content of the instrument” (p. 11). This description of content validity was crucial in the developmental stage of the SITOI. In validating the content of the SITOI, the experts verified that the all items included in this instrument appropriately represented the target domain, which is the scientific inquiry. The experts recommended these items, which showed relevance to the intended components of scientific inquiry.

Construct validity and criterion validity were not examined in this study because establishing these types of validity for empirical research normally requires a relatively large sample size in order to generate robust findings. The present study explored the development of a new observational tool (SITOI) involving four selected schools in
Manila that had access to training on the implementation of the new inquiry-based science curriculum conducted by the Department of Education. For this reason, the study involved a sample size that was not large enough to conduct robust data analyses for establishing construct validity and criterion validity of the SITOI. Moreover, in establishing the validity of the assessments, convergent validity can be examined particularly when using different measures of construct to develop robust evidence of relationships and effects (Carlson & Herdman, 2012). However, there is a lack of alternative measures for the same construct with the same features like that of the SITOI, that is containing items or indicators on specific practices of scientific inquiry in classrooms, which hinders the examination of convergent validity of the SITOI.

**Inter-rater reliability**

Inter-rater reliability refers to the degree of variation in results between different raters evaluating the same performance; ideally the variation should be very small (Pantzare, 2015). In this study, paired observations were conducted to explore variations of observational results between two observers. A debriefing session between observers was conducted after class observations to check, compare, and discuss the observational data gathered using the SITOI. If discrepancies were observed, these were discussed to determine the source of disagreement in order to achieve consensus on the use of the SITOI. Based on individual observational data gathered, observers had observed almost all the same items on inquiry practices enacted by teachers listed in the SITOI. This initial method of examining inter-rater reliability was based on the process employed by a group of researchers who designed and validated the *Electronic Quality of Inquiry*.

The researcher of this study conducted all the observations to maintain the consistency of interpreting and using of observation protocol in all chemistry classes. The invited observer conducted classroom observations once each week to validate what was observed and to avoid the occurrence of bias. In this case, the invited observer conducted fewer number observations than the researcher, which resulted in fewer number of common observations conducted by both observers (i.e., only 10 observations). Because of this very small number of common observations, it was not possible to conduct robust statistical analysis on inter-rater reliability of the SITOI.

**Classroom observation data analysis**

To determine the components of scientific inquiry enacted by teachers in chemistry classrooms, the mean score (average number) of the implementation of each component was calculated for each lesson observed. The mean score was derived from the total frequency of implementation of each component divided by the total number of lesson observations per class. This provided an average implementation number for each inquiry component per lesson observation in each class. The total frequency of implementation of each of the six components was determined by counting the number of ticks recorded in the SITOI.

To determine the specific practices enacted by teachers under each inquiry component, the mean score (average number) of the implementation of each specific practice under each component was calculated. This provided an average implementation number for each specific practice (under each inquiry component) per
lesson observation in each class. Some examples of specific practices enacted by teachers under the inquiry components were prompting students to formulate and ask their own questions (*engaging in questioning*), asking students to make measurements using tools and equipment (*collecting data*), and prompting students to form their own explanation based on evidence (*developing explanations*). The idea of calculating the mean score (average number) of teachers’ implementation of each scientific inquiry practice in chemistry was derived from the study of O’Dwyer et al. (2015) where they examined Grade 8 teachers’ use of instructional practices that support students’ conceptual understanding in mathematics. They identified six instructional practices implemented by teachers and presented these numerically and graphically.

Furthermore, to determine the degree of initiation of inquiry practices for each chemistry class, the frequency of teacher implementation of teacher-centered and student-centered practices under each inquiry component was identified (e.g., Capps & Crawford, 2013) by counting the number of ticks recorded from all observations. A numerical score of 1 to 5 was assigned to specific practices under each inquiry component (listed in the SITOI) to describe the degree of initiation in the classroom; 1 being the most teacher-centered and 5 being the most student-centered (e.g., Capps & Crawford, 2013). It is important to note that the specific practices under each inquiry component included in the SITOI were listed from the most teacher-centered (top) to the most student-centered (bottom). For example, the inquiry component *collecting data* has five individual practices as listed in the SITOI. A score of 1 was assigned to the first practice (top) as this is the most teacher-centered. Then, a score of 2 was assigned to the second practice, 3 to the third, 4 to the fourth, and 5 to the last practice (bottom) as this is the most student-centered. The identified frequency of teacher implementation (the
recorded number of ticks from all lesson observations for each class) for specific practices (teacher-centered and student-centered) under each inquiry component was multiplied in the assigned scores to get the total score for inquiry initiation of each class (e.g., Capps & Crawford, 2013).

To ascertain the mean score in inquiry initiation for each class, the total score for inquiry initiation was divided by the number of observations. In this study, there is no specified or assigned upper limit number of scientific inquiry practices implemented by teachers. Every time the teacher was observed to enact an inquiry practice in the classroom, it was recorded immediately in the SITOI and observation notes. Thus, each implementation of a specific practice under each inquiry component can be recorded as many times as occurred.

In addition to using the SITOI, observers wrote down notes from each lesson observation in all classes. These observational notes were gathered and analyzed. The collected notes were organized and encoded as soon as the observation was finished to ensure these notes were as accurate as possible. Observation notes mainly consisted of verbatim teacher-student dialogues which showed the following teacher verbal practices that support inquiry environment: (1) gauging or expanding students’ thinking or knowledge through asking various types of questions, (2) providing feedback to students through responding to students’ thinking, and (3) prompting thinking or reducing complexity by letting students form explanations or giving them new ways to consider concepts. Students’ verbatim questions were also captured in the observation notes. Other information included in the notes were identification numbers of schools, teachers, and classes, date of observation, number of students present during observation, lesson topic, start and end time of observation, and observation number.
Observation notes gathered for each lesson were analyzed by identifying teaching practices that aligned with the specific practices under each component of inquiry. A combination of letters and number codes was used for assigning the identified teaching practices. For example, the four practices of *engaging in questioning* listed in the SITOI were coded as Q1 (most teacher-centered, top), Q2, Q3, and Q4 (most student-centered, bottom). These codes were used to identify questioning practices captured from the observation notes that were matched with the engaging in questioning practices listed in the SITOI. This coding procedure was followed to analyze the specific teaching practices in other components of scientific inquiry as well. After analyzing the entire set of observation notes, the frequency of implementation of practices was determined by counting the coded practices in each component of scientific inquiry. Furthermore, the continuum of classroom inquiry proposed by Brown, Abell, Abdulkadir, and Schmidt (2006) was used to characterize the nature of inquiry instruction of teachers (e.g., teacher-centered or student-centered inquiry) in chemistry classrooms. An example of coded lesson observation notes can be found in Appendix G.

**Teacher questionnaire data analysis**

The responses of teachers in the questionnaire were categorized into characteristics of teachers and characteristics of their chemistry classes. These characteristics were uncovered from the analysis of the questionnaire. For instance, teachers who had access to science reform documents and who attended training for the new science curriculum were identified. Classes that had access to a science laboratory, equipment, and new curriculum materials were also identified from the questionnaire.
Measuring Students’ Learning in Chemistry

Development of research instrument

The ACTRC chemistry tests

The ACTRC chemistry tests were designed specifically for Grade 7 junior high school students in the Philippines. The tests were composed of both scientific inquiry and content knowledge items. The pretest composed of 48 items; 29 items for content knowledge and 19 items for scientific inquiry. The posttest had 58 items; 35 items for content knowledge and 23 items for scientific inquiry. A more specific breakdown of test items is presented in the next section.

One key objective of the present study is to investigate the relationship between students’ learning in chemistry and teachers’ scientific inquiry instructional practices. With this, the chemistry tests for Grade 7 students developed through collaboration between the ACTRC and the ARC teams were used in this study to assess student learning in chemistry. In this study, student learning in chemistry refers to the acquisition of both content knowledge and scientific inquiry skills. This is in line with the PISA 2015 Science Framework in that it emphasizes that scientific literacy requires both content knowledge in science and knowledge of the practices associated with scientific inquiry (OECD, 2017). The implementation of the spiral science curriculum for basic education in the Philippines aimed to develop scientific literacy among students such that they are able to make judgments and decision on the applications of scientific knowledge that may have significant impact in everyday life (DepEd, 2016). Thus, this study used tests consisting of items on chemistry content and items on scientific inquiry skills.
The tests assessed students’ knowledge of chemistry concepts and scientific inquiry skills developed through the Grade 7 chemistry curriculum. Specifically, the tests assessed students’ development in the underlying construct of chemistry concepts. In order to assess this, a baseline assessment of what is explicitly taught within the Grade 7 chemistry curriculum and any precursor knowledge or skills that would help a student learn the concepts was necessary. Thus, the pretest assessed some concepts that were outlined from the previous elementary science curriculum of Grades 3 to 6. Similarly, the posttest assessed concepts that were explicitly stated in the Grade 7 chemistry curriculum as well as precursor ideas for chemistry concepts in subsequent grade levels (Grades 8-10). The pretest and posttest were linked by sets of common test items. The use of common items enables the comparison of student acquisition of skills and knowledge on the same scale. In addition to chemistry concepts, scientific inquiry skills specified in the Grade 7 chemistry curriculum were also assessed by both tests. Figure 1 below shows the structure of the chemistry test.
Figure 1. The ACTRC chemistry tests structure.


The ACTRC chemistry tests development process

The following outlines the process undertaken by the test development teams from the ACTRC and the ARC to construct the chemistry tests.

1. Analysis of the new Grade 7 chemistry curriculum. The test development teams analyzed collaboratively the new Grade 7 chemistry curriculum to identify key conceptual themes and key scientific inquiry skills. The focus of this study is the
chemistry component (Matter) of the Grade 7 spiral science curriculum. In junior high school (Grades 7-10), Grade 7 students complete Matter as their first unit of science study (see Table 3). This provides the opportunity for baseline measurement of student understanding of chemistry concepts and skills. It is also important to note that only in the Grade 7 chemistry curriculum is scientific inquiry explicitly listed as a conceptual topic to be covered. After curriculum analysis, the test development teams identified and agreed to work on the three conceptual themes in chemistry: properties of matter, structure of matter, and changes in matter. Key skills were also identified in the curriculum: scientific inquiry skills. The structure of the curriculum is outlined in Table 3 below.

Table 3. Junior High School Science Curriculum Focus by Quarter Across Grades

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Grade 7</th>
<th>Grade 8</th>
<th>Grade 9</th>
<th>Grade 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>Matter</td>
<td>Force, Motion, &amp; Energy</td>
<td>Living Things and Their Environment</td>
<td>Earth &amp; Space</td>
</tr>
<tr>
<td>2nd</td>
<td>Living Things and Their Environment</td>
<td>Earth &amp; Space</td>
<td>Matter</td>
<td>Force, Motion, &amp; Energy</td>
</tr>
<tr>
<td>3rd</td>
<td>Force, Motion, &amp; Energy</td>
<td>Matter</td>
<td>Earth &amp; Space</td>
<td>Living Things and Their Environment</td>
</tr>
<tr>
<td>4th</td>
<td>Earth &amp; Space</td>
<td>Living Things and Their Environment</td>
<td>Force, Motion, &amp; Energy</td>
<td>Matter</td>
</tr>
</tbody>
</table>


2. Creation of a chemistry tests blueprint. To structure the development of items for chemistry pretest and posttest, a blueprint was created using the information from curriculum analysis. This included the concepts and skills that the students need to have in order to learn chemistry. The blueprint took into account the following questions: (1) What chemistry strands run through the different grades? (2) What is the
most communicative terminology to use for these strands? (3) Which strands appear only at one/some grades? and (4) What is the relative importance of the categories/strands at each grade level? (Ferido et al., 2015).

To articulate the skills integral to each grade level of the curriculum, specific behaviors that a student could demonstrate were identified. Behaviors that could be demonstrated in a pen and paper test were written for each statement. Where the same behaviors appear at multiple grade levels, these were noted at each relevant level. The blueprint for the chemistry pretest included the prerequisite concepts and skills considered necessary for students to engage in the Grade 7 chemistry curriculum. These prerequisites were determined from an analysis of Grades 3-6 science curricula. It should be noted that some of the prerequisite concepts and skills were not explicitly stated within these curricula. However, the prerequisites were included in the test blueprint as they were seen as prerequisites for the successful undertaking of the Grade 7 chemistry curriculum. The prerequisite chemistry strands included in the blueprint were states of matter, substances and mixtures, elements and compounds, atomic structure, molecular structure, physical and chemical changes, and chemistry-related inquiry skills. Although the concept that matter consists of elements, atoms, and subatomic particles is not a strict prerequisite for Grade 7 chemistry, this idea was included since students coming into Grade 7 with an understanding of this concept would benefit. The blueprint for chemistry posttest includes the prerequisite concepts and skills considered necessary for students to engage in the Grade 8 chemistry curriculum. This blueprint was derived from the combination of the prerequisite concepts and skills determined by the test development and curriculum expert teams (same chemistry strands as mentioned above) and additional prerequisites added after
the analysis of the chemistry pretest. The blueprint for pretest and posttest indicated the capabilities (what should students to be capable of) for the concepts of properties of matter, structure of matter, and changes in matter as well as for scientific inquiry skills.

3. Construction of chemistry tests items. To inform the construction of test items, a workshop on item writing and item review was conducted by the test development teams, focusing on guidelines for writing test items, appropriate terminology, and on multiple choice item development guidelines. Sample test items were provided to the item writers. The items were constructed to cover a range of difficulties. For example, items that assess chemistry content covered topics such as identifying the properties of mixtures as well as distinguishing the methods of separating components of mixtures. Items that assess scientific inquiry skills covered topics from simple measurement and classification tasks to controlling of variables and interpretation of multivariate data. The constructed items in the pretest and posttest were not exactly the same but they assessed the same construct. With this, common items were selected by a psychometrician to link the pretest and posttest and generate the data from which can be inferred a progression of skills. This method allows for an estimate of student ability to be made independent of the test set or tasks undertaken.

4. Paneling of chemistry tests items. A series of meetings was conducted in Melbourne and Manila by the ARC and the ACTRC teams to panel the constructed chemistry test items. Once each item was written and the skill identified, it underwent a paneling process to review the content of the items and their face validity. Each item was paneled twice by team members in each geographical location. This process drew on the expertise of all team members and ensured items adhered to guidelines for best
practice in objective item writing and contained language and concepts that were appropriate in the Philippines. During the paneling sessions, members of the test development teams were able to discuss important points such as (1) the knowledge and skills required to answer the item correctly, (2) the difficulty of the item, and (3) the quality of the item. The necessity of general consensus on item to be retained or removed from the test was always observed by the test developer during the paneling sessions.

5. **Pilot testing of chemistry test items.** After a series of paneling sessions, 72 chemistry test items for the pretest were pilot tested in a special summer school in NCR. One hundred and ninety-seven Grade 7 students took the pretest for pilot testing. This convenience sample of students was thought to be of approximately similar ability to those beginning junior high school students. The pretest pilot was conducted in May 2015. The purpose of the pilot test was to evaluate the performance of each item and to obtain item characteristics in order to develop a psychometrically sound test. In other words, this process was for test development purposes.

6. **Item calibration.** Test data were calibrated using the Rasch one parameter simple logistic model (Rasch, 1960), through *ConQuest version 2.0* generalized item response modeling software (Wu, Adams, & Wilson, 2007). In calibrating the items, the whole test was analyzed in the software to determine its psychometric properties. After the analysis, the results were examined, including checking the fit indices (Weighted Mean Square) to find out which items fit the Rasch model, checking the observed item characteristic curve, which should be close to theoretical one, and checking the item discrimination and difficulty indices. Based on these results, the test development team
discussed which items should be revised or deleted. Items that did not fit the model were deleted from the test, and the reasons for item deletion were presented in the meeting. After item deletion, the whole test with a new set of items was analyzed using the same software. After analysis, the calibrated items were found to fit the model, showing that they measured the same construct and that the spread of the items was appropriate for the student sample. Test items were examined based on item fit indices and item difficulty estimates, which were determined from the analysis. In addition, the expected a posteriori/plausible value (EAP/PV) item separation and the weighted maximum likelihood estimation (WLE) person separation reliabilities were also identified in the calibration process, and were acceptable for both tests.

7. Finalization of the tests. The output of the item analysis was used to finalize the tests. The final number of chemistry test items in the administered pretest and posttest is shown below. The items on scientific inquiry skills on both tests aligned with the following six components of scientific inquiry: engaging in questioning, designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information. For the pretest, a total of 48 items was chosen for test administration after pilot analysis. There were 29 items on content knowledge and 19 items on scientific inquiry. For the posttest, a total of 58 items was chosen for test administration. There were 35 items on content knowledge and 23 items on scientific inquiry. The content of the administered pretest with samples of key concepts and skills tested is shown in Table 4 and the content of the administered posttest is shown in Table 5.
Table 4. *Content of Administered Pretest*

<table>
<thead>
<tr>
<th>Strand</th>
<th>Number of Items</th>
<th>Key Concepts/Skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Physical states of matter</td>
<td>8</td>
<td>Properties and examples of solids, liquids and gases</td>
</tr>
<tr>
<td>1.2 Properties of substances and mixtures</td>
<td>10</td>
<td>Separation techniques; properties and examples of mixtures; properties and examples of acids and bases</td>
</tr>
<tr>
<td>1.3 Properties of elements and compounds</td>
<td>3</td>
<td>Properties and examples of metals and non-metals</td>
</tr>
<tr>
<td>2.1 Atomic structure</td>
<td>2</td>
<td>Elements and atoms; electrons and electric current</td>
</tr>
<tr>
<td>2.2 Molecular structure</td>
<td>1</td>
<td>Link between physical properties and molecular structure</td>
</tr>
<tr>
<td>3.1 Physical and chemical changes</td>
<td>5</td>
<td>Phase changes; rusting</td>
</tr>
<tr>
<td>3.2 Chemical reactions</td>
<td>0</td>
<td>N/A</td>
</tr>
<tr>
<td>4.1 Scientific inquiry</td>
<td>19</td>
<td>asking/formulating questions that can be investigated</td>
</tr>
<tr>
<td>Engaging in questioning</td>
<td>(2)</td>
<td>recognizing scientific investigation; identifying experimental variables; designing simple investigation</td>
</tr>
<tr>
<td>Designing and conducting investigations</td>
<td>(3)</td>
<td>making measurement using appropriate equipment; reading and recording correct measurement</td>
</tr>
<tr>
<td>Collecting data</td>
<td>(5)</td>
<td>analyzing and interpreting data table</td>
</tr>
<tr>
<td>Analyzing data</td>
<td>(2)</td>
<td>developing explanation based on evidence; drawing conclusion based on results</td>
</tr>
<tr>
<td>Developing explanations</td>
<td>(3)</td>
<td>using graphical representation to illustrate relationship of variables; using graph to present results</td>
</tr>
<tr>
<td>Communicating information</td>
<td>(4)</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>48</td>
<td></td>
</tr>
</tbody>
</table>


Below are some examples of the types of items written by the test development teams (Ferido et al., 2015). Example items on scientific inquiry can be found in Chapter 6. It is important to note that due to the need for test security, the examples below are not the actual items from the chemistry tests.
Strand: Physical states of matter. This item requires students to apply their knowledge about the states of matter. Understanding the differences between solids, liquids, and gases will assist them when they come to learn about Solutions in Grade 7.

Which of the following is a gas?
A. steam
B. soup
C. chalk
D. flowers

Strand: Properties of elements and compounds. This item uses the context of separation of mixtures (taught in Grade 6) to get students to apply their knowledge about metals. They need to recognize that iron is a metal and that magnets attract many metals, then connect these ideas and apply them to the given context. Connecting ideas about metals and their properties will assist them when learning the more detailed properties of metals and non-metals, such as malleability, ductility, and conductivity in Grade 7.

Charles suspects that there are iron filings in a powder sample given to him. To confirm this, he suspended the powder sample in water and stirred it. Which step will help him confirm the presence of iron filings?
A. Allow iron filings to float
B. Allow iron filings to settle at the bottom of the beaker
C. Use magnet to attract iron filings
D. Use magnet to attract other particulates
Table 5. Content of Administered Posttest

<table>
<thead>
<tr>
<th>Strand</th>
<th>Number of Items</th>
<th>Key Concepts/Skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Physical states of matter</td>
<td>4</td>
<td>Properties and examples of solids, liquids and gases</td>
</tr>
<tr>
<td>1.2 Properties of substances and mixtures</td>
<td>16</td>
<td>Separation techniques; properties and examples of mixtures; properties of substances with different pH values, terminology of solutions</td>
</tr>
<tr>
<td>1.3 Properties of elements and compounds</td>
<td>7</td>
<td>Properties and examples of metals and non-metals; macroscopic properties of elements and compounds; graphic representations of compounds</td>
</tr>
<tr>
<td>2.1 Atomic structure</td>
<td>1</td>
<td>Chemical symbols</td>
</tr>
<tr>
<td>2.2 Molecular structure</td>
<td>3</td>
<td>Particulate nature of matter</td>
</tr>
<tr>
<td>3.1 Physical and chemical changes</td>
<td>4</td>
<td>Phase changes; rusting</td>
</tr>
<tr>
<td>3.2 Chemical reactions</td>
<td>0</td>
<td>N/A</td>
</tr>
<tr>
<td>4.1 Scientific inquiry</td>
<td>23</td>
<td>Engaging in questioning (2) asking/formulating questions that can be investigated</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Designing and conducting investigations (7) recognizing scientific investigation; identifying experimental variables; using appropriate procedure/method for experiment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Collecting data (5) making correct measurement using appropriate equipment; reading scales; using appropriate method for correct measurement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Analyzing data (1) analyzing and interpreting data table</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Developing explanations (3) developing explanation based on evidence; drawing conclusion based on results</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Communicating information (5) using graphical representation to illustrate relationship of variables; using graph to present results; interpreting graph of two variables</td>
</tr>
<tr>
<td>Total</td>
<td>58</td>
<td></td>
</tr>
</tbody>
</table>


Data collection procedure

Student participants

To measure chemistry learning, pretest and posttest data were collected from four hundred and ninety-five (495) Grade 7 students in twelve classes from four sample schools. The sample students from these schools consisted of more females than males.
The specific numbers are provided in Table 6 below. The students were taught by ten chemistry teachers participating in this study. Some of the students belong to homogeneous classes while others belong to heterogeneous classes. These students obtained their elementary education from different schools. Because of this, students may have had different learning experiences in science. They belong to a cohort that was exposed to the previous elementary science curriculum (before K to 12 reform) where scientific inquiry was not effectively communicated and a spiral progression of concepts and skills was not emphasized. Students in Grade 7 chemistry classes were chosen because only in this grade level’s chemistry curriculum is scientific inquiry explicitly listed as a conceptual topic to be covered.

Table 6. Details of Sample Students

<table>
<thead>
<tr>
<th>School</th>
<th>Student Age Range (Year)</th>
<th>No. of Female Students</th>
<th>No. of Male Students</th>
<th>Gender Not Specified</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11–14</td>
<td>91</td>
<td>64</td>
<td>0</td>
<td>155</td>
</tr>
<tr>
<td>2</td>
<td>11–14</td>
<td>58</td>
<td>54</td>
<td>3</td>
<td>115</td>
</tr>
<tr>
<td>3</td>
<td>11–14</td>
<td>67</td>
<td>51</td>
<td>0</td>
<td>118</td>
</tr>
<tr>
<td>4</td>
<td>11–14</td>
<td>62</td>
<td>44</td>
<td>1</td>
<td>107</td>
</tr>
</tbody>
</table>

*Chemistry tests administrations*

The pretest was administered to Grade 7 students from 25th to 26th of June 2015 at the start of first quarter of school year 2015-2016 prior to chemistry instruction. After six weeks of instruction, the posttest was administered at the conclusion of the first quarter of the same school year. The posttest was administered from 12th to 13th of August 2015 to the same Grade 7 students who previously took the pretest. The total number of students who took both the pretest and posttest was 495 and this constituted the sample for the analyses. Figure 2 below shows the tests administration scheme.
In each day of test administration, Grade 7 students from three classes in two schools were given the test. Each test was administered in every class for one hour. Each student was given a test booklet, a scannable answer sheet, and a pencil in both pretest and posttest. Test administrators (the researcher and a proctor) were present during test administrations. Before each test started, the researcher briefly discussed the test protocol to the students. The purpose of administering the test was also explained clearly to the students. Table 7 shows the set-up for administering the test in schools.

**Table 7. Set-up for Chemistry Tests Administrations**

<table>
<thead>
<tr>
<th>Pretest</th>
<th>School</th>
<th>Number of Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 June 2015</td>
<td>School 1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>School 2</td>
<td>3</td>
</tr>
<tr>
<td>26 June 2015</td>
<td>School 3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>School 4</td>
<td>3</td>
</tr>
<tr>
<td>Posttest</td>
<td>School</td>
<td>Number of Classes</td>
</tr>
<tr>
<td>12 August 2015</td>
<td>School 1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>School 2</td>
<td>3</td>
</tr>
<tr>
<td>13 August 2015</td>
<td>School 3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>School 4</td>
<td>3</td>
</tr>
</tbody>
</table>
Data analysis procedure

Student ability estimates

Student ability estimates were obtained from the pretest and posttest using the Rasch one parameter simple logistic model (Rasch, 1960). The administered pretest had 48 items and assessed some concepts that were outlined from the previous Grades 3 to 6 science curricula. The administered posttest had 58 items and assessed concepts specified in the Grade 7 chemistry curriculum as well as precursor ideas for chemistry concepts in subsequent grade levels. The person-separation reliability of pretest and posttest were 0.86 and 0.71 respectively. It is important to note that these indices are comparable to alpha reliability and are well within the acceptable range.

Common items equating

Although the majority of the items in the pretest and posttest were different, both tests measured the same constructs, student learning of chemistry concepts and scientific inquiry skills. To measure these constructs, both tests were developed in such a way that common items were included in them. There were 12 common items included in both pretest and posttest. The common items were used to equate the posttest to the scale established by the pretest, which enables the comparison of student results obtained by the tests.

Equating is a process of putting the two tests on the same scale for comparison (Wu, Hak, & Tsung-Hau, 2016). It enables matching the scores on different tests and interpreting them on the same scale. This enables all the items in an item pool, and the students who took them, to be described with the same units of measurement. With this, student performances can then be interpreted in the same levels on a construct, regardless of the subset of items or different tests they took. This is the goal of test
equating, and the use of the Rasch model is what makes it possible (Griffin, 1999). In this study, tests were equated using an approach in which both pretest and posttest responses were merged and analyzed together. This procedure resulted in one file of students’ data on chemistry tests. In this study, all students who took the tests and all pretest and posttest items, including the 12 common items, were combined. After merging the tests, the whole set of tests was run for analysis in ConQuest software using Rasch modeling. This analysis provided the ability estimates or the Weighted-Likelihood Estimates (WLE) of students’ ability in the pretest and posttest.

**Determining students’ gain score in chemistry**

For a better interpretation, the WLE score of students in the tests were standardized using a mean of 50 and a standard deviation (SD) of 10. For posttest WLE score, the pretest mean of 50 and SD of 10 were used to obtain the standardized posttest WLE score. Thereafter, the gain score (estimate of ability) of each student in chemistry was determined by taking the difference between standardized posttest WLE score and standardized pretest WLE score. There were 495 students who have both pretest and posttest WLE scores and they constituted the study sample for analysis. The obtained student gain score in chemistry was used in the next analysis—Multilevel Modeling.

**Multilevel modeling of the relationship between students’ learning in chemistry and teachers’ scientific inquiry practices**

To address the second research question, the relationship between students’ learning in chemistry and teachers’ scientific inquiry practices was examined using multilevel modeling. Multilevel models for each of the six practices of scientific inquiry (engaging in questioning, designing and conducting investigations, collecting data,
analyzing data, developing explanations, and communicating information) were generated via *Mplus* 7.4 version software (Muthén & Muthén, 2016) using Bayesian estimation. The process of multilevel modeling was chosen for this study to ensure that the statistical dependence among students within classes was accounted for by the complex residual structure thereby producing correct estimates of the standard errors associated with the regression coefficients (O’Dwyer et al., 2015; Raudenbush & Bryk, 2002). One major advantage of multilevel modeling is that it is possible to simultaneously relate outcome variables to predictors at the individual and group levels (Goldstein, 2011; Raudenbush & Bryk, 2002; Snijders & Bosker, 2012). In this study, Bayesian estimation was used due to its suitability for a small number of groups, which is the case of the present study. Several researchers have argued that Bayesian estimation offers a promising approach for estimating multilevel models, particularly when sample sizes are small and the estimation of variance components is crucial (Gelman & Hill, 2007; Hamaker & Klugkist, 2011; Jackman, 2009; Swaminathan & Rogers, 2008; Zitzmann, Ludtke, & Robitzsch, 2015). Recently, Zitzmann et al. (2015) conducted a simulation study that compares the Bayesian estimation approach with the Maximum Likelihood estimation approach using *Mplus* software. They found that Bayesian estimation gives more accurate estimates of the group-level effect under problematic conditions (i.e., small number of groups, predictor variable with small intraclass correlation coefficient [ICC]) than the Maximum Likelihood estimation.  

In this study, students’ chemistry learning (represented by posttest score) was regressed on teachers’ scientific inquiry practices along with the student covariate (pretest score). In the first step, an unconditional (or null) two-level regression model was established. This model consists only of the outcome variable (student posttest score),
score in chemistry) and without independent variables. It gives information on partitioning the total variability in student posttest score into within-class and between-class variance components. These unconditional variance components were used to estimate the degree of statistical dependence (nesting) among students within classes, as indicated by the *intraclass correlation coefficient (ICC)* and served as a comparison for subsequent models that included teachers’ scientific inquiry practices as well as the student covariate (pretest score). The ICC is the proportion of variation in the student posttest score in chemistry that is due to differences between classes. The equation for the unconditional model in this study is as follows:

\[
\text{chemistry posttest score} = \beta_{0j} + r_{ij} \quad \text{and} \quad \beta_{0j} = \gamma_{00} + u_{0j}
\]

In the second step, the within-class (level 1) model was created to explore whether the student covariate (pretest score) is associated with students’ chemistry learning. It gives information on how much of the total unexplained individual level variance for student chemistry posttest score is explained by student covariate. The equation for the level-1 model is as follows:

\[
\text{chemistry posttest score} = \beta_{0j} + \beta_{1j} (\text{pretest score}) + r_{ij}
\]

In the level 1 model, \(\beta_{0j}\) is the chemistry posttest score when all other variables are constant. The effect of pretest on students’ chemistry posttest score is represented by \(\beta_{1j}\). The \(r_{ij}\) is a random student effect. The level-1 predictor variable was entered into the model centered at the grand mean. Centering level 1 predictors appropriately is vital to the interpretation of intercept and slope parameters in multilevel models (Enders & Tofghi, 2007).
Aside from the within-class (level 1) model, the between-class (level 2) model was created to determine if students’ chemistry learning was impacted by each practice of scientific inquiry implemented by teachers, holding a student covariate in the model constant. Thus, in level 2 model, each practice of scientific inquiry was tested separately and six models were established. The equation for the level 2 model is as follows:

$$\beta_{0j} = \gamma_{00} + \gamma_{01} \text{ (each practice of scientific inquiry)} + u_{0j}$$

In this model, the $\gamma_{01}$ is the regression coefficient, which represents the association between teachers’ scientific inquiry practice and students’ chemistry posttest score, holding the pretest in the model constant. Each level 2 predictor (each practice of scientific inquiry) was added in the model uncentered. This model gives information on how much of the total unexplained individual level variance for students’ chemistry posttest score was explained by teachers’ scientific inquiry practices.

**The process of multilevel modeling**

The following outlines the steps of multilevel modeling employed in this study.

1. **Performing descriptive analysis of the variables.** In order to describe the variables investigated in this study, descriptive statistics of posttest score (outcome variable), pretest score (within-class [level 1] variable), and each scientific inquiry practice (between-class [level 2] variable)—engaging in questioning, designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information—were calculated. Specifically, the mean and standard deviations (SD) for these variables were determined using the results of the student chemistry tests and classroom observations.
2. **Performing correlation analyses of the variables.** This step would give preliminary ideas on which predictor variables are highly associated with student learning, and if predictor variables are independent from each other. In addition, the correlations of the six scientific inquiry practices was determined to explore the possibility of creating a composite variable across all six scientific inquiry practices as this may provide a more comprehensive measure of construct than a single variable (O’Dwer et al., 2015), which can be used in the model analysis. This study used the suggestions of Cohen (1988) on interpreting the strength of correlation coefficient values \((r)\): 0.10 to 0.29—small; 0.30 to 0.49—medium; and 0.50 to 1.0—large.

3. **Creating two-level unconditional model (null model).** A model consists only of outcome variable (posttest score) and no predictor variables was created and analyzed to partition the variability in the outcome variable into within-class and between-class variance components, and testing whether the variance of the between-class component is significantly different from zero. The equation for this model was presented in the previous section. Based on this model, the value of the **intra class correlation coefficient** (ICC) was determined, which reflects the portion of total variance of a variable at the between-class model and can be considered as an index of the degree of non-independence or the clustering effect of the data (Hox, 2010; Raudenbush & Bryk, 2002; Zhang & Lee, 2017). In this study, the value of ICC was used as a basis of determining whether running a multilevel modeling is appropriate. The common criterion applied in this study was that if the value of ICC is greater than 0.05, multilevel modeling is appropriate to use (Muthen & Satorra, 1995; Zhang & Lee, 2017).
4. Creating two-level model with predictors. This study used the pretest score as the only predictor variable at the within-class model. The within-class model was created to determine the total unexplained variance for posttest score explained by the level 1 predictor, which was the pretest score. The equation for this model was presented in the previous section. For the between-class model, each of the six scientific inquiry practices of teachers was used as a predictor variable. The between-class model was created to determine the total unexplained variance for posttest score explained by each scientific inquiry practice of teachers (level 2 predictor), holding a pretest constant. The equation for level 2 model was also discussed in the previous section. Each of the six scientific inquiry practices was analyzed separately, thus six level 2 models were created. The established two-level model with predictors were then analyzed.

5. Creating multivariate multilevel model. Since the two-level model with predictors was created and analyzed in step 4, the results of this analysis were reviewed before running the multivariate multilevel analysis to determine whether the predictor variables in the within-class and between-class show statistically significant relationship with the outcome variable. This information could be useful in identifying the variables to be included in the multivariate analysis. It can be noted that the variables that are significant have contributions to the explanation of the variance in the outcome variable (posttest score).

If all predictor variables in the models specified in step 4 are significant, all variables can be included in the multivariate analysis, where the level 1 predictor (pretest score) and all level 2 predictors (six scientific inquiry practices) were put in a single two-level model with posttest score as outcome variable. The equations for this multivariate multilevel model are illustrated below:
Level 1: \[ \text{chemistry posttest score} = \beta_{0j} + \beta_{1j} (\text{pretest score}) + r_{ij} \]

Level 2: \[ \beta_{0j} = \gamma_{00} + \gamma_{01} (\text{engaging in questioning}) + \gamma_{02} (\text{designing and conducting investigations}) + \gamma_{03} (\text{collecting data}) + \gamma_{04} (\text{analyzing data}) + \gamma_{05} (\text{developing explanations}) + \gamma_{06} (\text{communicating information}) + u_{0j} \]

The description for the level 1 model is the same as discussed in the previous section. However, the level 2 model here is different from what was discussed previously. In this new level 2 model, student chemistry posttest score \((\beta_{0j})\) was predicted by the linear combination of the six scientific inquiry practices of teachers. The \(\gamma_{01}\) through \(\gamma_{06}\) are the regression coefficients, which represents the association between each practice of scientific inquiry and chemistry posttest score, holding the pretest in the model constant. Here, each level 2 predictor (each scientific inquiry practice) was added in the model uncentered.

On the one hand, it is also important to note that if the analysis described in step 4 would give a result that show some predictor variables in the within-class and between-class models are not statistically significant, these predictor variables may be removed from the multivariate analysis (e.g., Nguyen & Griffin, 2010). This is because these variables do not contribute to explain the variability in students’ learning in chemistry (posttest score). In this study, any predictor variables that were found statistically insignificant in the analysis described in step 4 were removed from the multivariate analysis.
Chapter Summary

A series of lesson observations in twelve chemistry classes was conducted to explore the inquiry practices of teachers observed in the Philippines. Using the observational checklist (the SITOI) developed by the author, a total of 57 one-hour observations (alongside with observational notes) assessed the nature of inquiry teaching practices of teachers as they implemented the new Grade 7 chemistry curriculum. The SITOI was composed of 31 items grouped into the six components of scientific inquiry: engaging in questioning, designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information. All observations were performed by the author during the first quarter of the school year (six weeks) in which the chemistry component of the curriculum was studied by the students. A teacher questionnaire was also used to gather information on the characteristics of teachers and of their chemistry classes. To determine the nature of inquiry implemented in classrooms, the observational data were analyzed by calculating the average number of implementations of each inquiry component per lesson observation. This was calculated from the total frequency of implementation of each inquiry component divided by the total number of lesson observations per class. The frequency of implementation of each of the six components of inquiry was determined by counting the number of ticks recorded in the SITOI. The degree of initiation of inquiry (teacher-centered or student-centered) was also determined using the SITOI. Observational notes were coded to identify the inquiry practices listed in the SITOI.

To measure the learning of 495 Grade 7 students in chemistry, the ACTRC chemistry tests (pretest and posttest) were used in this study. The tests were administered before and after chemistry instruction. The ACTRC chemistry tests were
designed in accordance with the Philippine Grade 7 chemistry curriculum, and
developed and scored based on the Rasch (1960) model, to measure the growth of
students in chemistry. In this study, Rasch modeling was used to calibrate chemistry test
data to produced students’ ability estimates. Since the pretest and posttest in chemistry
contained different items, test equating (common items equating) in Rasch analysis was
employed, which was an effective means to enable matching the scores on these tests
and interpreting them on the same scale. This calibration provided the Weighted
Likelihood Estimate (WLE) of ability scores of students (growth score). Multilevel
analysis (two-level with Bayesian estimation) was used to analyze the relationship
between teacher practices and student learning since it takes into account the statistical
dependence among students within classes. Bayesian estimation offers the present study
a promising approach for estimating multilevel models with small number of groups.
Chapter 5: Assessing Teachers’ Inquiry Instruction in Chemistry

Classrooms

This chapter reports on the results of the classroom observation analysis. It is divided into five parts. The first part presents the background characteristics of teachers as participants and their classroom contexts. The second part presents the amount (mean implementation number) of each component of scientific inquiry enacted by teachers. The third part identifies and focuses on the specific classroom practices enacted by teachers related to each component of scientific inquiry. The fourth part presents the characteristics of the nature of inquiry instruction of teachers through comparing the amount of inquiry practices enacted by teachers with the degree of initiation in the classroom—teacher-centered or student-centered inquiry instruction. Finally, part five presents the summary of the chapter.

Characteristics of Teachers and their Classroom Settings

Before describing the details of teachers’ implementation of inquiry-based teaching in chemistry classrooms, this part presents the background characteristics of teachers and the descriptions of their classes, to show the scenario of each chemistry classroom observed at the time this study was conducted.

The background characteristics of teachers involved in this study, gathered by teacher questionnaires are shown in Table 8. The responses were consolidated according to teacher characteristics and information on the nature of their classes. The mean of science teaching experience of teachers was 12.1 years (minimum=4 years; maximum=21 years).
Table 8. *Background Characteristics of Teachers*

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Gender</th>
<th>Major</th>
<th>Science Teaching Experience (Years)</th>
<th>Number of Students</th>
<th>Participated in National Training for New Science Curriculum</th>
<th>Availability of Science Laboratory</th>
<th>Access to Basic Laboratory Apparatus</th>
<th>Availability of New Teachers’ Guide</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>M</td>
<td>General Science</td>
<td>15</td>
<td>41</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>B</td>
<td>F</td>
<td>General Science</td>
<td>21</td>
<td>55 (c1) 39 (c2)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>C</td>
<td>F</td>
<td>Biology-Chemistry</td>
<td>16</td>
<td>40</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>D</td>
<td>M</td>
<td>Physical Science</td>
<td>4</td>
<td>41</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>E</td>
<td>F</td>
<td>Chemistry</td>
<td>19</td>
<td>40</td>
<td>Yes</td>
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*Notes.* M is male and F is female.

(c1) is class 1 and (c2) is class 2.

Teacher A

At the time of the study, Teacher A taught five Grade 7 chemistry classes in a large public secondary school (School 3) with a total student population of 12,348. He held a bachelor’s degree in secondary education and a master’s degree in general science education. He had 15 years’ experience in science teaching at basic education level. Before the implementation of the new K to 12 education in the Philippines, he was teaching chemistry at third year high school (Grade 9) and physics at fourth year high school (Grade 10) in the same secondary school. When the K to 12 curriculum was implemented, he reported that he was confident to teach the content of the new science curriculum.

Teacher A was observed teaching chemistry in one of his Grade 7 classes. This class was composed of 41 students with a wide range of ability levels. His classroom was located on the second floor of five-story building. It was small, one-half of the size.
of a regular classroom. Ideally, a regular classroom in public schools in the Philippines can accommodate a maximum of 40 students. So, his classroom could accommodate a maximum of 20 students only. The classroom was well-lit but hot inside because the two ceiling fans in the room were not enough for the class. There was not enough space inside the classroom for the teacher and students to move conveniently. The classroom was crowded with students, seated in chairs with no space in between. Despite these challenging conditions, Teacher A seemed to be patient in teaching chemistry and interacting with his students.

It was observed that the new inquiry-based science curriculum documents such as the *Teachers’ Guide* and the *Learners’ Module* developed by the Philippine Department of Education were available in his class. Students used the Learners’ Module most of the time and each of them had a copy of this document. Teacher A had a copy of the Teachers’ Guide but he used this irregularly in delivering the lesson. During the period of class observation, Teacher A mostly used non-experimental activities to teach chemistry lessons. Non-experimental activities were mostly hands-on activities that had no testing of variables and hypotheses like games, demonstration activities, etc. He did not use the available laboratory even if there was a laboratory-based activity in the lesson. The chemistry laboratory in the school was small. Inside the laboratory, there were some scientific apparatus, storage cabinets, sinks, working tables, and chairs. Teacher A allowed his students to work along the corridor outside the classroom. In this case, there were no working tables or chairs in the corridor. Students worked in teams and each team formed a circle, sat down on the floor, and worked on their activity. Teacher A provided each team with a plastic tray containing science
materials for them to use. He brought some basic apparatus like beakers and test tubes into the classroom only when needed. Most students in this class were cooperative.

**Teacher B**

Teacher B taught chemistry in the same school as Teacher A. She had four Grade 7 chemistry classes. Two of her classes were involved in this study (see class details below). Teacher B had an undergraduate degree in secondary education. She was an experienced teacher with 21 years in science teaching. She taught third year high school chemistry (Grade 9) before the K to 12 education reform. She reported that her confidence in teaching the new science curriculum would depend on the topic. During the observation period, Teacher B used non-experimental activities in both classes.

**Teacher B’s class 1**

Class 1 was a large class with 55 students of similar ability. This class was the ‘star class’ (high-achieving class) for Grade 7 in her school. For this class, she taught chemistry in a regular classroom. Her classroom was well-lit and well-ventilated. However, there was not enough space inside the classroom for the students. The Teachers’ Guide and Learners’ Module were available in Teacher B’s class. All students had copies of the Learners’ Module but they seldom used them in the classroom. Teacher B was not observed using the Teachers’ Guide in this class. She used the chemistry laboratory to teach a non-experimental activity in one lesson. She brought her students into the laboratory to work on the activity. The students worked in teams, and each team had a working table. She let her students use some equipment and materials inside the laboratory. In other chemistry activities, Teacher B allowed students to work inside the classroom and in the corridor. Students worked in teams in a
circular formation; some teams sat down on the floor while others were seated at their chairs.

**Teacher B’s class 2**

Class 2 was composed of 39 students with a wide range of ability levels. These students stayed in a small classroom (the same size as Teacher A’s classroom) located also on the second floor. This classroom was well-lit but had no air-conditioning. Due to lack of space, the classroom was very crowded. Most students used the Learners’ Module. Teacher B was not observed using the Teachers’ Guide. In this class, Teacher B also used the laboratory to deliver the lesson using a non-experimental activity. She allowed her students to work in the laboratory and most of them appeared enthusiastic. The students worked in teams and each team had a working table. The students used the equipment and materials inside the laboratory. Teacher B also allowed her students to work in the corridor outside the classroom for other chemistry activities. Students sat down on the floor and worked in teams in a circular formation.

**Teacher C**

Teacher C taught chemistry in another large public secondary school (School 4) with student population of 6,912 at the time of the study. She had three Grade 7 chemistry classes. She held a bachelor’s degree in secondary education, and at the time this study was conducted, she was working on her doctoral degree in education. Teacher C was an experienced chemistry teacher who had been teaching for 16 years. She was teaching chemistry in third year high school (Grade 9) before the implementation of K to 12 curriculum. She reported that she had the confidence to deliver the content of the new science curriculum.
Teacher C was observed teaching chemistry in one of her Grade 7 classes. This class was one of the high-achieving classes in Grade 7 in her school. She had 40 students with similar ability. Teacher C was the person in charge of taking care of the chemistry laboratory. She always used the laboratory in every teaching session. She used experimental and non-experimental activities to deliver the lesson. The chemistry laboratory in the school was small. There were working tables, stools, storage cabinets, and laboratory apparatus available for student use. However, there was little space inside the laboratory, thus students worked very closely together. Students worked in teams on chemistry activities. During the observation period, it was noticed that Teacher C always reminded her students to practice discipline and orderliness inside the laboratory. All students had the Learners’ Module and they used this document in every session. Teacher C sometimes used the Teachers’ Guide in her class.

**Teacher D**

During the time of the study, Teacher D was in the early stage of his teaching career. He was the youngest among the teacher-participants, with four years of teaching. He had an undergraduate degree in secondary education. Teacher D worked at the same school as Teacher C. He used to teach chemistry in third year high school (Grade 9) and physics in fourth year high school (Grade 10) before the curriculum reform. He reported that he was confident to teach the content of the new science curriculum.

Teacher D taught chemistry in a Grade 7 class that consisted of 41 students with a wide range of ability levels. In the whole period of observation, it was noticed that student attendance in this class was low. Teacher D’s classroom was spacious for students to work on chemistry activities, however the classroom had no air-
conditioning. Each student had a copy of the Learners’ Module and they used it in every lesson. Teacher D had a copy of the Teachers’ Guide but he was not observed using this in the classroom. Teacher D taught chemistry without using the laboratory. During the observation period, he mostly used non-experimental chemistry activities to teach the lessons. In one lesson observation, there was a laboratory-based activity, but he allowed the students to work inside the classroom using their modules. Students in this class were not observed using the laboratory apparatus or equipment.

**Teacher E**

Teacher E was an experienced chemistry teacher, with 19 years of teaching. She was teaching chemistry in third year high school (Grade 9) before the curriculum reform. Teacher E’s content knowledge and chemistry laboratory experience were strong, as she had an undergraduate degree in chemistry. She also obtained a certificate in teaching chemistry and physics. She worked at the same school as Teachers C and D. When the reform was implemented, she reported that she was confident to teach the content of the new science curriculum. During the observation period, she used experimental activities to teach the lesson in every class. At the time of the study, Teacher E had four Grade 7 chemistry classes.

One Grade 7 chemistry class of Teacher E was observed for this study. This class had 40 students with a wide range of ability levels. Teacher E used the biology laboratory as her classroom. The biology laboratory was bigger than the chemistry laboratory with four large working tables with stools. The room was well-lit and well-ventilated. Inside the laboratory, there were scientific apparatus and equipment, storage cabinets with science materials, sinks, and science teaching models. Students used the
necessary apparatus and materials for their chemistry activities. All students had copies of the Learners’ Module and they used them in most of the lessons. However, Teacher E had no copy of the Teachers’ Guide thus she was not observed using this in any sessions. Students worked in teams on the activities. There were two teams working on one big table. Each team had laboratory apparatus and materials to use in the activity. It was observed that most students in this class were enthusiastic in performing the activities.

**Teacher F**

Teacher F was teaching Grade 7 chemistry in another large public secondary school (School 2) with a total student population of 7,499. She held a bachelor’s degree in secondary education. She had three Grade 7 chemistry classes. Teacher F had a long experience in teaching Grade 7 science since she had been teaching first year high school (Grade 7) students for some years before the science curriculum reform. When the new curriculum was implemented, Teacher F reported that she was confident in delivering the new science curriculum but this would depend on the topic.

In this study, Teacher F was observed teaching chemistry to a high-achieving Grade 7 class. This class had 43 students with similar ability. She had a copy of the Teachers’ Guide. She delivered the chemistry lessons based on the sequence of topics specified in the Teachers’ Guide. Students sometimes used the Learners’ Module through sharing since not all students had a copy. Teacher F taught chemistry in a regular classroom that was well-lit and well-ventilated. She used experimental and non-experimental activities to teach the lesson. There was no science laboratory in the school. The space inside the classroom was not large enough for students to perform
chemistry activities. Thus, some students worked inside the classroom while others worked in the corridor outside the classroom. There was no working table available for students; most of them sat down on the floor while performing their activities. The school had some basic laboratory apparatus (e.g., beakers, graduated cylinders) available for student use. Storage cabinets for these and other science materials were not available inside the classroom. Teacher F brought the apparatus from the faculty office to the classroom whenever materials were needed in the lesson. In some cases, materials needed for chemistry activities were provided by Teacher F and her students from resources in their homes. It was observed that each team of students with six to seven members had one plastic storage bin where they put their own materials for chemistry activities. Most students in this class were cooperative.

**Teacher G**

Teacher G taught chemistry in Grade 7 at the same school as Teacher F. She had five chemistry classes. She taught chemistry in third year high school (Grade 9) before the implementation of the new curriculum. She had an undergraduate degree in secondary education. She reported that her confidence in teaching the new science curriculum depended on the nature of the topic.

Teacher G’s Grade 7 chemistry class had 52 students with a wide range of ability levels. Like Teacher F, she had a copy of the Teachers’ Guide. In the delivery of the lesson, she followed the sequence of chemistry topics as specified in the Teachers’ Guide. Most of the time, students shared the Learners’ Module since not all students had a copy. Teacher G’s chemistry classroom was well-lit but had no air-conditioning. She taught chemistry with experimental and non-experimental activities. Since Teacher
G’s school had no science laboratory, students performed chemistry activities inside the classroom. Students worked in teams with seven to eight members. Due to the lack of space in the classroom, Teacher G allowed some teams to perform activities in the corridor while other teams stayed inside the classroom. There were no available storage cabinet and working tables for students. However, basic science materials (e.g., beakers, graduated cylinders) were available for student use. Teacher G brought the materials into the classroom when needed. Some materials for chemistry activities were provided by Teacher G. In this class, students had no storage bin for their science materials.

**Teacher H**

Teacher H was in early stage of her teaching career at the time of the study, having been teaching for five years. She taught general science in first year high school (Grade 7) before the K to 12 curriculum reform. When the new science curriculum was implemented, she taught Grade 7 chemistry at the same school as Teachers F and G. She had a total of four Grade 7 chemistry classes. Teacher H reported that her confidence in teaching the content of the new curriculum would depend on the topic. She had a bachelor’s degree in secondary education.

In this study, Teacher H’s Grade 7 chemistry class was composed of 52 students with a wide range of ability levels. These students sometimes used the Learners’ Module and few of them had copies of this material. Teacher H had a copy of the Teachers’ Guide. Like Teachers F and G, she also followed the sequence of topics as specified in the Teachers’ Guide when she delivered lessons in her class. She used experimental and non-experimental activities in the class. Students performed these activities in the classroom since the school had no science laboratory. The classroom
was small, thus some students worked in the corridor outside the classroom. There were no working tables inside or outside the classroom, so most students sat down on the floor while performing the activities. Students worked in teams with ten to eleven members. Some basic laboratory apparatus and science materials were available, however there was no storage cabinet to keep these resources. They were brought by Teacher H into the classroom when needed. Teacher H provided each team of students with a big cardboard box for storing materials for chemistry activities.

**Teacher I**

Teacher I taught chemistry in another public secondary school (School 1) with a student population of 7,755 at the time of the study. She had an undergraduate degree in secondary education with a major in a non-science subject. She had long experience in teaching Grade 7 science since she taught this level before the curriculum reform. Teacher I had three Grade 7 chemistry classes, two of which were involved in this study as described below. She reported that her confidence in teaching the new science curriculum would depend on the topic. During the time of class observation, Teacher I used experimental and non-experimental chemistry activities in the lessons.

**Teacher I’s class 1**

This class was one of the high-achieving classes in Grade 7. It was a large class with 57 students with similar ability. Due to lack of space, Teacher I’s classroom was very crowded. A little space was provided inside the classroom for Teacher I’s table. The classroom was clean and well-lit but there was no air-conditioning. In this class, the Learners’ Module was used by students in most teaching sessions. However, each team of students with ten to eleven members had only one copy of the Learners’ Module,
which necessitated sharing. The leader in each team was responsible for taking care of the Learners’ Module. At the end of the session, students needed to return the module to the teacher. Teacher I had a copy of the Teachers’ Guide but she used this irregularly.

The school had no science laboratory. Whenever Teacher I used hands-on activities to teach the lesson, she allowed students to work inside and outside the classroom. Some teams worked in the corridor outside the classroom. Since there were no working tables, students in each team sat down on the floor in circular formation while doing their activities. Storage cabinets for science materials were not available in the classroom, so each team had a plastic storage bin where they put their materials for chemistry activities. The team leader was in-charge of keeping the plastic storage bin safe. Some basic laboratory apparatus (e.g., beakers, test tubes) were available in this class and the students used these for activities. If the apparatus needed for an activity was not available in the school, it was observed in this class that Teacher I provided improvised laboratory apparatus for the students.

**Teacher I’s class 2**

Class 2 was also a high-achieving class in Grade 7. It was also a large class with 54 students of similar ability. These students stayed in a clean and well-lit classroom. However, the classroom was small for 54 students (like the room for class 1) and there was lack of space for everyone to move and work conveniently. The room had no air-conditioning. In this class, there was also a lack of copies of the Learners’ Module, and each team of ten to eleven students shared one copy of the Learners’ Module. It was observed that students used the module in every session. After the session, Teacher I collected the Learners’ Module from each team. Teacher I used non-experimental activities to teach the lessons with this class. She allowed student teamwork to carry out
these activities. Due to lack of space inside the classroom, some teams worked in the corridor outside the room. There were no working tables available for students, so the members in each team sat down on the floor in a circular formation while doing their activities. Each team had a plastic storage bin to keep their materials for chemistry activities since storage cabinets were not available in school. The team leader was in-charge of taking care of the plastic storage bin.

**Teacher J**

Teacher J was teaching at the same school as Teacher I. Before the implementation of K to 12 curriculum, Teacher J taught general science in first year high school (Grade 7). When the new science curriculum was implemented, he taught Grade 7 chemistry. He had four Grade 7 chemistry classes. Teacher J reported that he was confident to teach the content of the new curriculum, but this would depend on the topic. He had a bachelor’s degree in secondary education.

In this study, Teacher J’s class had 55 students with a wide range of ability levels. This large class was accommodated in a small classroom. The classroom was clean and well-lit but had no air-conditioning. In this class, each student had a copy of the Learners’ Module, however they rarely used it during the sessions observed. The students needed to return the module to Teacher J after use. Teacher J had a copy of the Teachers’ Guide, but he was not observed using it. Teacher J rarely used chemistry activities in the sessions observed. He only once gave students a non-experimental activity. Since there was no science laboratory, the students worked in teams inside and outside the classroom. Like in the classes of Teacher I, students sat down on the floor while working on their activity. Each team had one plastic storage bin with science
materials for the activity. In this class, students were not observed using laboratory apparatus.

**Components of Scientific Inquiry Enacted by Teachers in Chemistry Teaching**

Based on 57 lesson observations, the six components of scientific inquiry (engaging in questioning [Q], designing and conducting investigations [DI], collecting data [CD], analyzing data [AD], developing explanations [DE], and communicating information [CI]) were employed to some extent by teachers in their chemistry instruction. Comparing across the six components of inquiry enacted by teachers (refer to Figure 3), a large portion of chemistry instruction was comprised of engaging in questioning practices (39%). Out of 12 chemistry classes, this pattern was observed in 11 classes. Generally, teachers were accustomed to using questioning as this was a more familiar and common classroom practice compared to other components of scientific inquiry (e.g., designing and conducting investigations, collecting data). Engaging in questioning practices may be more suitable for their classrooms, given the context, as this could be an easier and more convenient way of delivering the content rather than setting up chemistry activities each time. Further, teachers’ questioning practices may foster students’ higher order thinking skills even with a lack of chemistry activities, especially considering science facilities and resources were not always available. Different teaching practices related to engaging in questioning, from teacher-centered to student-centered, were observed from all the teachers who implemented questioning in chemistry classrooms. More details on specific questioning practices of teachers are identified in the next part of this chapter. The mean number of implementation for each
of the six components of scientific inquiry per observation is illustrated in Figure 3 below.

![Chart showing mean scores of inquiry component with standard error bars per observation]

Figure 3. Mean scores of inquiry component with standard error bars per observation.

The smallest portion of chemistry instruction was comprised of analyzing data practices (8%). In this study, analyzing data practices were usually observed whenever there was experimentation. Despite the experimental activities present in the new Grade 7 chemistry curriculum, some teachers chose to use non-experimental activities in chemistry teaching. This situation may give teachers less opportunity to provide students with the chance to analyze data in chemistry classrooms. The other components of scientific inquiry incorporated into chemistry instruction less often than questioning.
were: designing and conducting investigations (12%), collecting data (10%), developing explanations (13%), and communicating information (18%).

Furthermore, analysis of the observations revealed that some teachers incorporated particular components of scientific inquiry into their chemistry instruction more frequently than others. The amount (mean implementation number) of scientific inquiry component enacted by teachers in their classrooms is shown in Figure 4. It is important to note that teachers taught the same inquiry-based lessons in chemistry as outlined in the Grade 7 chemistry curriculum documents. These inquiry-based lessons were *Solutions, Substances and Mixtures, Elements and Compounds, Acids and Bases,* and *Metals and Nonmetals.*

![Figure 4. Inquiry practices enacted by each teacher per observation.](image)

As evident in Figure 4, each teacher incorporated all of the six components of scientific inquiry into their teaching of Grade 7 chemistry using the new science
curriculum. Each teacher tended to enact more practices related to engaging in questioning and communicating information than practices related to analyzing data, collecting data, designing and conducting investigations, and developing explanations. Generally, the practices of analyzing data, collecting data, designing and conducting investigations were observed in teaching with experimental activities, which could be challenging practices for most teachers to incorporate due to extrinsic factors such as large class sizes and the availability of science facilities (e.g., access to a laboratory) and resources. In looking at individual teachers’ enactment of inquiry component per observation, Teacher F had the largest number of practices related to inquiry implemented in the classroom. Despite the challenging conditions of school resources and facilities, Teacher F still managed to implement inquiry-based practices in chemistry instruction. Conversely, Teacher J had the smallest number of practices related to inquiry enacted in the classroom. It is also interesting to determine the practices enacted by teachers with two chemistry classes (class 1 and class 2) each such as Teachers B and I. It can be noticed in Figure 4 that some components of inquiry were given more emphasis by Teachers B and I in one class than in the other class.

Below are the details of their implementation of scientific inquiry components supported with actual classroom scenarios captured during observations. These were presented to understand: (1) how Teacher F implemented more inquiry practices in her classroom, (2) why Teacher J implemented less inquiry in his classroom, and (3) what was the nature of inquiry teaching in two chemistry classes of Teachers B and I—did they implement the same approach to inquiry teaching in their two classes and did they give the same emphasis on using inquiry to both of their classes? It is important to note that in all observations, the researcher moved from one place to another in the
classroom and in the corridor (if there was a student activity), which was beside the classroom, to observe closely what the teachers and the students were doing and to capture efficiently the inquiry practices occurred during the instruction. The researcher made sure that this process of observation did not cause any class disruptions or delays in the instructional activities.

**Teacher F: Teacher with most enacted practices related to inquiry**

Comparing across teachers, Teacher F had the highest mean score (M=21.60, SD=9.15) in implementing practices related to inquiry per chemistry lesson observation. Based on a series of observations, Teacher F usually taught chemistry lessons using different components of scientific inquiry, which could give her more opportunities to implement inquiry practices in the classroom. Some of the inquiry components that she used were evident in the following teaching scenarios as observed in her classroom. It is important to note that the words of students and teachers in the scenarios were quoted verbatim so may include grammatical errors.

**Scenario 1**

To teach and help students distinguish the type of Solutions, Teacher F showed two setups: (1) To a beaker that contained water, she added a small amount of sugar, then she stirred the contents; (2) To a beaker that contained water, she added a large amount of sugar, then she stirred the contents. She asked the students to observe. Then, she asked the students the question, “What will happen to the sugar?” The students answered, “The sugar dissolves easily in setup 1.” Teacher F asked, “Why?” The students answered, “Because the water has a greater amount than sugar which helps the sugar to dissolve easily.” Then the teacher asked more questions, “What do you call this solution in setup 1?” “Which solution is unsaturated? Saturated?” “Why did you say so?” (Teacher F, Lesson Observation 1, 29-06-2015)

In this scenario, Teacher F engaged her students in the lesson cognitively through asking questions about the demonstration. It was evident in the scenario that
while doing the demonstration, Teacher F asked a question that elicited students’ own ideas about the topic. After the demonstration, she asked the students again but this time she asked a question that required them to justify their answers. These practices of Teacher F were relevant to the engaging in questioning component of inquiry. In addition, the approach of Teacher F in this scenario could also give her the opportunity to implement inquiry practices related to developing explanations.

**Scenario 2**

Teacher F discussed the features of the periodic table of elements and the important information that students can get from it. She also discussed the guidelines of writing the correct symbol of the elements as shown in the periodic table. After discussing the guidelines, she conducted a short game that required students to form a word by combining the symbol of the elements. For example, the symbol for Cobalt is Co and the symbol for Neon is Ne. Combining the symbols of these two elements, the word “CoNe” is formed. This game required students to be familiar with the elements and their correct symbols. After the game, the teacher asked the students to explain their work. She also asked them to explain the uses and importance of the elements, “What is the use of oxygen?” “What is the importance of iron?” (Teacher F, Lesson Observation 4, 23-07-2015)

In the second scenario, Teacher F used a non-experimental activity to teach the concepts related to the periodic table of elements. In this activity, she let her students analyze or solve problems when she asked them to form a word from the given list of elements by combining the correct symbols of the elements. This practice was related to the inquiry component of analyzing data. The activity also allowed Teacher F to implement practices that encouraged students to develop their own explanations when she asked them to explain the use and importance of the elements after they performed the activity. This practice was related to developing explanations.

**Scenario 3**

Teacher F provided students with an experiment about factors affecting solubility. Before the students performed the experiment, she discussed first some
safety reminders to consider in performing the experiment. She instructed the students what to do in the activity by discussing the procedures. After conducting the experiment, the whole class discussed the results. The teacher asked one group of students to report the data collected from the experiment. The students explained the procedures and results of the task assigned to them. Two students reported in front of the class. After presentation, the teacher asked the students, “Why do you think it is dissolved?” team 1 answered, “The water and vinegar attracted [to] each other.” “Based on your results, what is the factor that affects solubility, team 1?” The students answered, “The nature of solute and solvent.” (Teacher F, Lesson Observation 1, 29-06-2015)

In the third scenario, Teacher F used experimentation to engage students in conducting investigation on the factors that affect the solubility of a substance. She asked the students to perform an investigation in teams. After conducting the experiment, Teacher F asked the students to communicate the results of the investigation through a group presentation in class. It was observed that it was not just a one-way communication of results. It was a presentation with interactions between teacher and students. This was evident when Teacher F asked the students a series of questions and then the students responded to the questions being asked. This gave Teacher F an opportunity to use practices that allowed students to work out an explanation about what they have discovered from their experiment. In this scenario, Teacher F enacted practices related to conducting investigation, communicating information, and developing explanations.

Despite the challenges in the teaching environment, Teacher F still managed to use available opportunities to implement inquiry-based teaching practices as much as possible. As shown in Figure 4, Teacher F enacted more of engaging in questioning practices and less of analyzing data practices. Analysis of lesson observations revealed that Teacher F always used chemistry activities (experimental and non-experimental) to teach the content of the lesson. Due to the large class size, students performed these
activities in teams. Teacher F was observed to use more non-experimental activities than experimental activities. This is likely due to the non-availability of space for conducting science experiment in her school and the lack of science equipment and materials. Because of this situation, Teacher F implemented inquiry practices suitable for her school and classroom contexts using non-experimental activities.

The use of non-experimental activities provided Teacher F with the opportunities to implement inquiry practices that do not necessarily require science facilities and equipment. Most of these practices were related to engaging in questioning. She frequently used questioning practices to deliver the content in the activity and to engage students cognitively in the lesson. Further, since using non-experimental activities usually consumed shorter teaching time (as in the case of Teacher F) than using experimental activities, Teacher F was observed to use the available time to implement other inquiry teaching practices after students performed non-experimental activities. These practices were related to communicating information and developing explanations. These findings from Teacher F’s class suggest that it is important to consider the context of teaching and learning environment in implementing inquiry-based teaching as this may provide the key for teachers to implement a variety of inquiry practices in classrooms.

**Teacher J: Teacher with fewest enacted practices related to inquiry**

On the one hand, Teacher J had the lowest mean score (M=7.75, SD=1.71) in implementing inquiry practices per chemistry lesson observation. It was observed that in his class, there were available opportunities to implement inquiry practices in the
classroom. However, he did not use these opportunities fully in class. This situation is illustrated in the following scenario of Teacher J’s class:

Teacher J’s chemistry class was observed for four one-hour lessons. In three of the lessons, he used the first thirty minutes in doing teaching activities such as checking of test papers, assignments, and student portfolios. Teacher J asked the students to check their own papers while he announced the correct answers in front of the class. Students had folders where they compiled their own test papers, quizzes, assignments, and activity sheets. (Teacher J, Lesson Observations 2-4, 13, 29, 31-07-2015)

This scenario shows that the available time of Teacher J to teach chemistry as inquiry was compromised due to his application of other teaching activities other than inquiry. Although Teacher J did use inquiry-based teaching, he seemed to prioritize more the implementation of other teaching activities than the implementation of inquiry teaching practices. Specifically, the activity that he implemented was asking students to mark their own test papers, past quizzes, and assignments while he announced the correct answers in front of the class. In this approach, students were just listening to Teacher J without interaction. This consumed most of his teaching time.

Teacher J was observed using a non-experimental activity only once to teach a lesson. Students performed this activity in teams. During this session the teacher was observed implementing inquiry practices related to conducting investigations and communicating information. However, this approach was not sustained in his class as noticed during the period of observation. He delivered Grade 7 chemistry lessons without incorporating activities in most of his teaching sessions. He focused more on lecturing in front of the class to deliver the content of the lesson. In this approach, Teacher J enacted some inquiry practices related to engaging in questioning. However, this approach did not offer him wide opportunities to use other components of scientific inquiry, which resulted in less implementation of inquiry practices in teaching
chemistry. However, there are reasons that could explain this situation. Teacher J had a large class size (55 students), and a lecturing mode of instruction could be a convenient way for him to teach the lesson in his big group of students. Further, the challenges of Teacher J’s school environment (e.g., lack of science resources, unavailable space for conducting science activities) were another factor that may reduce his capacity to include chemistry activities in teaching most of the lessons. This may have caused him to implement less inquiry-based teaching practices. Based on these explanations, it is arguable that Teacher J used other approaches to teaching chemistry, which may be convenient for his own classroom settings. However, this may inhibit him from enacting varied inquiry practices. Findings from Teacher J’s class suggest incongruency between the new curriculum emphasis, which is inquiry-based teaching, and classroom practices due to some extrinsic factors.

**Teachers B and I: How did they implement inquiry in their two chemistry classes? Did they apply the same teaching approach in their two classes?**

Two of the teachers in this study taught two chemistry classes each. Figure 4 shows the amount of inquiry practices enacted by Teachers B and I in their two classes. There was no big variation in the amount of enacted inquiry practices in both classes of Teacher B. In fact, the amount of practices related to conducting investigations, analyzing data, and communicating information enacted by Teacher B was the same in both classes. However, observations revealed that Teacher B gave more emphasis on implementing other components of inquiry in class 2 than class 1. One inquiry component was collecting data. This is because demonstration activities employed by Teacher B were more visible in class 2 than class 1. Teacher B used demonstrations in
class 2 to explicitly show the difference between pure substance and mixture as presented in the scenario below. Through this strategy, Teacher B had the opportunity to engage students in demonstrations that required them to make and write descriptive observations, which is a specific practice of collecting data. Consider the scenario below:

Teacher B demonstrated mixture in class 2 by adding salt into a test tube containing water, and then she shook it. She asked the students to describe what they observed. She also asked them if salt could be separated from water. After this, Teacher B demonstrated substance by mixing iron filings and sulfur into the test tube, and then she heated it. She asked the students to describe what they observed and if sulfur and iron filings could be separated. (Teacher B, Lesson Observation 1 [class 2], 30-06-2015)

In class 1, Teacher B used other approaches to teach the lesson. She used traditional lecture to deliver the concepts of pure substance and mixture. Teacher B was delivering the lecture in front of the class using chalkboard and the students were listening to her. Teacher B’s class 1 was a high-achieving class and composed of 55 students with similar ability. With this, it may be easier for Teacher B to facilitate the lesson in a large class with academically good students using lecture mode of teaching than setting up demonstration activities. However, the lecturing approach may not offer him opportunities to use practices related to collecting data. Conversely, class 2 had smaller number of students than class 1. It was composed of 39 students with a wide range of ability levels. Most of these students were not as good as students in class 1. Because of this, Teacher B explicitly discussed the lesson through demonstration so that students may easily understand the concepts.

When it comes to Teacher I’s inquiry teaching, lesson observations revealed that there was a variation in the amount of scientific inquiry practices enacted in her two classes. The mean score of inquiry implementation per lesson observation for class 1
(M=17.00; SD=9.67) was greater than class 2 (M=11.67; SD=7.64). This shows that Teacher I enacted more inquiry practices in class 1 than class 2. The variation was evident particularly in the enactment of practices related to communicating information, analyzing data, and engaging in questioning.

For communicating information, Teacher I enacted more practices in class 1 than class 2 as previously shown in Figure 4. This finding was explained by her application of different approach in teaching the same lesson in class 1 and class 2. Specifically, the lesson was about “Acids and Bases”. In class 1, Teacher I used a chemistry activity entitled “How Can You Tell if a Mixture is Acidic or Basic?” to deliver the concepts of acids and bases. This activity was performed by her students in teams. In this activity, each team was asked to determine if the given household materials were acidic or basic using an eggplant indicator. While doing the activity, Teacher I asked each team to write the results in the data table (communicating information). After the activity, she asked each team to report their results in class through presentations (communicating information). Specifically, she asked them to present the acidic or basic nature of the household materials using the color scheme for eggplant indicator. After reporting, Teacher I discussed the concepts on acids and bases using the results of the activity. The practices related to communicating information enacted in this class were not observed in class 2.

Teacher I used another approach to teach acids and bases in class 2. She discussed the importance of knowing about the acidity and basicity of some substances through traditional lecture. She used a visual material showing a pH scale, posted on the chalkboard, to determine the acidity and basicity of sample substances. There was no hands-on activity for the students. After the lecture, Teacher I gave a short quiz for the
students. This approach of teaching in class 2 may not provide opportunities for Teacher I to employ practices related to communicating information. As a result, Teacher I enacted less communicating information in class 2 than class 1. It was observed that during this time, Teacher I was not on track in class 2 in terms of teaching the required chemistry lessons for the first marking period. Thus, class 2 was behind class 1 in terms of the number of lessons taught during that period. In this case, Teacher B used lecturing approach in class 2 because this may be the fastest way to teach the lesson so that class 2 could move on to the remaining lessons. It may be important for Teacher I to teach the required lessons as specified in the new curriculum in both classes since this could have an impact on student assessment.

When it comes to analyzing data, Teacher I’s practices were more visible in class 2 than class 1. This variation was specifically evident in the lesson that involves activities about the “Concentration of Solutions” wherein Teacher I asked the students to analyze the concentrations of solid solution quantitatively. Observations revealed that in class 2, students were more engaged with Teacher I’s practices on analyzing and solving problems about the concentration of solutions than students in class 1. The reason for this is that there was a difference in the strategy that the teacher used to teach this lesson. In class 2, Teacher I taught the lesson by letting students perform the activity in the classroom. She asked the students to analyze the existing data needed for determining the exact ratio of solute to solvent in a solid solution, which specifies the concentration of a solution. Then, she asked the students to solve the problem related to concentration of solid solution below. After this, Teacher I asked them to explain how they analyze and solve the problem. Consider the following problem:
A one peso coin has a mass of 5.5 grams. How many grams of copper are in a one peso coin containing 75% copper by mass?

In class 1, Teacher I asked the students to solve this problem at home. Then in the next session, the first teaching activity that she performed was to discuss how to analyze and solve the problem. She discussed the solution for this problem in front of the class by writing on the chalkboard the complete steps of solving the problem. Students were listening to Teacher I and checking their own work based on the solution written on the board. Then, she asked the students if they got the correct solution and if they understood the process. Because of this approach, where Teacher I provided the solution to the problem outright, there were some practices in class 2 that were not implemented in class 1. This approach may limit her to employ other teaching practices related to problem solving and analysis.

These findings show that the reason why Teachers B and I enacted more inquiry in one class and less inquiry in another class was that they used different teaching approach to deliver the same lesson in both classes. It seemed that they consider their own classroom contexts and their efficiency in covering the content of the new curriculum when using a particular teaching approach in chemistry.

**Specific Classroom Practices Related to Each Component of Inquiry Enacted by Teachers**

To provide an evidence-based documentation of specific teacher behaviors in using the major practices of scientific inquiry as a teaching approach in developing country, this part presents the specific classroom practices of teachers for each component of scientific inquiry. It includes and describes selected teaching scenarios.
from the chemistry classroom of individual teachers to show how the specific practices in each component of inquiry were employed in their own teaching. This will provide a granular view of teachers’ instruction to better understand their enactment of inquiry teaching. Some specific practices under each component of inquiry listed in the SITOI were implemented by the teachers in chemistry teaching during observed lessons. Furthermore, information on which class implemented the most or the least of specific practices in a particular component of inquiry will be described as this may be useful and relevant for understanding the relationship between scientific inquiry and learning, which is discussed in the later chapters of this thesis.

**Component 1: Engaging in questioning**

Generally, the results show that throughout the 57 lesson observations all teachers used an engaging in questioning practice that specifically asked questions about facts that were not previously presented, which elicited students’ own ideas and required short specific answers. This type of engaging in questioning practice was the most dominant in the classes observed. It comprised 58% of the total engaging in questioning practices. Teachers also asked questions that required students to give a justification for a phenomenon. These comprised 33% of the total engaging in questioning practices. The least used practice related to engaging in questioning was prompting students to ask or formulate their own questions (9%). Figure 5 below shows the mean implementation number of implementing engaging in questioning practices by individual teachers per lesson observation.
Comparing across teachers, Teacher F had the highest mean number of engaging in questioning practices (M=9.20). Based on observations, Teacher F frequently asked her students a question that elicited their own ideas, requiring short specific answers. She enacted this engaging in questioning practice the most compared with other teachers. Consider the scenario below:

To introduce the new lesson which was the properties of metals and non-metals, Teacher F showed pictures of coins, plastic bottles, and electrical wires to the students. Then, she asked the students, “What do you think are the properties of these materials?” One student answered, “Coins are hard.” Afterwards, Teacher F provided some properties of materials and asked the students to identify if these properties were for metals or non-metals. One property that has been mentioned was high melting point. Teacher F asked the students, “What does it mean by high melting point?” One student answered, “It needs a very high temperature to melt.” (Teacher F, Lesson Observation 5, 27-06-2015)
In this scenario, Teacher F asked questions to probe the background knowledge of the students about the properties of metals and non-metals. She also asked the students about their ideas on a specific terminology that is commonly used in science (*melting point*). This specific practice was also observed in the class of Teacher H as follows:

Teacher H started to discuss the new lesson, *Solutions*. She asked the students this question, “Class, what do you mean by miscible?” Then she asked another question, “What do you mean by immiscible?” (Teacher H, Lesson Observation 1, 29-06-2015)

In this case, to start a new lesson about *Solutions*, Teacher H asked questions that elicited students’ own ideas about the meaning of scientific terminologies used to describe *Solutions* such as *miscible* and *immiscible*.

The questions asked by Teacher F encouraged students to give short specific answers. However, she rarely prompted her students to develop and ask their own questions about the phenomena. This situation was also observed in other chemistry classes. Teacher J was not observed prompting students to ask their own questions at all even when there were opportunities to implement this engaging in questioning practice in the lessons. Focusing only on this practice, prompting students to develop and ask their own questions, Teacher I enacted this practice the most compared with other teachers. Specifically, Teacher I used this practice more frequently in class 2 than in class 1. This is because in class 2, she implemented more student engagement activities that required individual analysis of the *Concentrations of Solutions* than in class 1. Because of this, she encouraged her students to ask questions for analysis. Next to Teacher I, Teacher B and Teacher H also prompt students to ask questions frequently. Consider the following scenario from Teacher B’s class 1:
After the students performed the activity on metals and non-metals, Teacher B started to process the results. First, she asked the students to share different properties of metals that they discovered from the activity. Then, properties like malleability, conductivity, and luster were discussed. Next, she asked questions about properties of non-metals. Some students answered “Non-metals cannot conduct electricity” while others said “They are dull”. Before proceeding to detailed discussions, Teacher B asked the students, “Do you have any questions?” “What is your question in the activity?” Teacher B called students for questions. One student asked, “Are there non-metals that conduct electricity?” Another student asked, “Why diamonds are made of Carbon but they are solid?” (Teacher B, Lesson Observation 2, 16-07-2015)

It is evident from this scenario that students were given opportunity to think and ask their own questions. Teacher B was observed to be patient in soliciting questions from students and giving them time to formulate questions about their activity on metals and non-metals. This was evident when Teacher B engaged students in questions that asked them to formulate questions twice, which goes like this, “Do you have any questions?... (wait time)” “What is your question in the activity?” When she asked the first question, no students responded. In this case she gave a wait time after asking a question for students to think and raise their own questions. Then, she asked the second question that encouraged students again to formulate questions. After this, two students formulated and asked their own questions about the activity. This type of practice may be important in science instruction where teachers are aiming to foster higher-cognitive level learning in their students. Waiting more than a second for a student answer to a teacher question is one well-known practice that has been shown to have a significant positive effect on student learning (Osborne et al., 2013). However, compared to the high mean scores of teachers for implementing the other two engaging in questioning practices, this practice had low mean scores. This implies that even if teachers have opportunities to use an inquiry-based curriculum to teach chemistry most of them who were observed were not prioritizing this type of engaging in questioning practice where
students’ questioning ability is considered fundamental to develop critical reasoning, and to the process of scientific inquiry. A practice of engaging in questioning that was not observed during teachers’ instruction was asking students a question about facts previously presented. This may imply that the teachers observed in this study did not prioritize the use of teacher-centered questions that could lead to a simple recall of facts.

**Component 2: Designing and conducting investigations**

In designing and conducting investigations, there were four major practices enacted by teachers in chemistry classrooms. Comparing across these four investigation practices, the most enacted practice was providing specific procedures for students to follow to conduct an investigation activity. This practice comprised 63% of the total practices related to investigation. This practice was observed in all chemistry classrooms where teachers provided students with an activity sheet that listed the procedures or posted a diagram that outlined the specific procedures. Figure 6 outlines the frequency of investigation practices, and shows that most teachers implemented this practice (red bar) more than other investigation practices in their chemistry classrooms.
Another practice enacted by teachers was guiding students while conducting their own investigation. Twenty-one percent (21%) of the total inquiry practices related to investigation enacted by teachers were composed of this practice. This practice was observed in 11 chemistry classes. Teachers assisted students in setting up the apparatus for investigation and in using scientific tools and equipment for measurement. Teachers also monitored and checked the students to see if they had properly followed the investigation procedures.

In some classes, teachers demonstrated how to do investigations. This practice comprised 13% of the total teachers’ inquiry practices related to investigation. This practice was observed in five classes. Some teachers performed full demonstration of the investigation activity in front of the class before letting the students conduct the
activity. Students were asked to carefully watch each step of the teacher in demonstrating how the investigation should be done. Furthermore, observations revealed that the least enacted practice of teachers related to investigation was asking students to design their own procedures for investigation (3%). Only two teachers enacted this practice (see Figure 6).

Requiring students to “evaluate the design, practices, and conduct of scientific enquiry” (Osborne, 2014, p. 589) is one of the PISA’s three key competencies of the scientifically literate individual (OECD, 2012). According to Osborne (2014), this competency is best developed by engaging students in the practice of designing empirical investigations to test hypotheses. However, from the four major investigation practices observed in classrooms, this practice was the least implemented by teachers. It was noted that whenever there was an experiment, most teachers had “recipe-type” procedures for the students to follow. It was very rare to observe teachers letting students design their own procedures for an experiment. It may be that the year level observed influences the findings here. Designing experiments with the scarce science resources available in Philippine schools may be a challenging task for Grade 7 students, so most teachers assisted them or created the experimental procedure for students. This could also be due to the challenges of teaching environment (e.g., unavailable space for conducting experiments), which may deter most teachers from employing this type of investigative practice.

Teacher E was one of the two teachers who encouraged students to design their own investigation, which is evident in the following scenario:
Teacher E gave each group of students a sample mixture for them to separate. The mixtures were salt solution; oil and water; sulfur and iron filings; starch and water; and ink. Teacher E instructed the students, “Given the sample mixture and materials on each table, set up the materials and think of ways or procedures in which you can separate the components of a mixture. Discuss within your group the method that you will use. Answer the questions and present your results.” (Teacher E, Lesson Observation 2, 14-07-2015)

In this scenario, Teacher E used an investigative activity about *Separating Components of a Mixture* to allow students to explore different separation techniques such as distillation, filtration, and decantation. She gave her students the freedom to choose the necessary materials that they needed in designing their own methods to separate the components of a mixture. Observations showed that Teacher E had the highest mean score in implementing inquiry practices related to investigation per chemistry lesson observation (M=4.00). Based on observations, Teacher E enacted all the aforementioned investigation practices in her chemistry class. Since she had an undergraduate degree in chemistry, her knowledge and experience in conducting scientific research may have helped her to implement these investigation practices in the classroom. She frequently used the practice of guiding students while conducting investigations. She was observed using chemistry activities in all lessons that she taught. These activities were (1) preparation of solutions, (2) separating components of mixtures, (3) electrolysis of water, (4) identifying acidic and basic substances, and (5) determining the pH of substances. These activities were included in and suggested by the new chemistry curriculum for Grade 7. This strategy provided her with opportunities to enact varied practices related to designing and conducting investigations in the classroom. The following is another scenario from Teacher E’s class where three investigation practices were exhibited:
Teacher E asked the students to perform an experiment on expressing concentration of a solution quantitatively by preparing a 70% alcohol. Before doing the experiment, Teacher E reviewed different laboratory apparatus placed on the table by asking, “Which is graduated cylinder? Which is Erlenmeyer flask?” After this, she asked the students, “How do you prepare a 70% alcohol?” She provided a list of steps on preparing 70% alcohol (practice 1). A demonstration of the experiment was shown by Teacher E before students performed it. She demonstrated how to measure and read the volume of a liquid using graduated cylinder (practice 2). Students were divided into five groups. Each group was asked to measure the volume of an alcohol using graduated cylinder. While students work, Teacher E moved around and instructed each group to measure the volume of alcohol and water (practice 3). The teacher also checked if each group prepared the right concentration of an alcohol. (Teacher E, Lesson Observation 1, 02-07-2015)

Throughout the lesson observations, no teachers were observed explicitly teaching the concept of fair testing in investigation activities with experimental variables (e.g., dependent and independent variables). Teachers were not observed identifying the treatment and control variables for the activity. Although scientific inquiry skills such as testing variables were indicated in the Grade 7 chemistry curriculum documents, teachers in this study were not observed teaching this in class discussions. In the same way, teachers were not observed asking students to identify the treatment and control variables for experimental activities. The other practice that was not observed in classrooms was asking students to formulate their own objectives for the activity.

**Component 3: Collecting data**

Generally, inquiry practices related to collecting data were rarely implemented by teachers. Based on observations, only 10% of the total inquiry practices implemented by teachers were related to collecting data. From this small percentage, there were four major practices related to collecting data enacted by teachers. The first was the most implemented practice of teachers, which was asking students to collect data from an
individual or a group activity. This practice comprised 50% of the total collecting data practices implemented by teachers. Teachers asked students to collect data through making descriptive observations from chemistry activity the students performed in the classroom. The second practice was asking students to collect data from teacher demonstrations. This comprised 34% of the total collecting data practices. Teachers asked students to collect data through making descriptive observations from a simple demonstration related to the lesson conducted by the teacher. These first two collecting data practices were observed in ten classes. The third inquiry practice of teachers related to collecting data was asking students to make measurements using scientific tools and equipment. Fifteen percent (15%) of the total collecting data practices enacted by teachers was composed of this practice. Generally, this practice was observed whenever students conducted experimental activities. These collecting data practices of teachers also involved students in organizing data through recording into the activity sheets that the teachers provided for them, or through writing into their notebooks. Finally, the fourth practice of teachers was providing data for students (1%). This practice was observed only in one class when the teacher asked the students to perform an activity on What are the Properties of Solutions. The teacher posted a visual material on the chalkboard that showed a data table containing different properties of solutions to present to the class the correct data needed for the activity. Figure 7 shows the specific classroom practices related to collecting data enacted by teachers.
Comparing across teachers, Teacher I (I1) had enacted the four collecting data practices. She implemented these practices in one of her chemistry classes (class 1). Based on observations, Teacher I was the only teacher who provided data for the students to use in their chemistry activity about the properties of solutions. This practice was observed only once when she provided correct data after the students performed the activity to help them figure out the properties of solutions. This practice shows that “occasionally teachers need to intervene and provide explicit teaching during inquiry-based lessons for instructional efficiency, reduced chances of errant learning, and increased productive interactions between teachers and students” (Holliday, 2004, p. 201). Although Teacher I enacted the four practices related to collecting data, her mean scores for collecting data practices per observation were still low (M=1.40 for class 1;
M=1.00 for class 2). This means that collecting data was not extensively used in her classrooms. The lack of school resources may have affected Teacher I’s capacity to implement this component of inquiry in the classroom.

In contrast with Teacher I, Teacher C had the highest mean score in implementing collecting data practices in chemistry classroom per lesson observation (M=3.00). Teacher C had relatively extensive science facilities and resources which may help her to implement collecting data practices. Based on observations, Teacher C implemented two practices related to collecting data: (1) asking students to collect data through making descriptive observations from the students’ investigation activity; and (2) asking students to make measurements using scientific tools and equipment. Observations revealed that Teacher C used experimental activities where she frequently required students to make observations and measurements. These activities were related to factors affecting solubility, properties of solutions, and using acid-base indicators in determining acidic and basic substances. The following is a scenario from Teacher C’s class, which shows her implementation of a practice related to collecting data.

Specifically, Teacher C asked students to collect data from an individual activity through making descriptive observations.

Teacher C gave students an activity about determining the acidity or basicity of some common household items using indicators. She provided an activity sheet for each student. Common household items like vinegar, shampoo, baking soda, etc., were also provided. She explained each procedure, for example how to use the litmus paper. The teacher asked the students to observe and describe what they observed by recording in their activity sheet. She distributed litmus paper to each group of students and asked them to observe the changes in color of litmus paper. She asked the students what were their observations when the indicator reacted to the sample substances. (Teacher C, Lesson Observation 5, 03-08-2015)
Moreover, Teachers E, F, and G had the same amount of collecting data practices implemented in classrooms. However, Teacher E enacted varied practices related to collecting data compared to Teachers F and G. This is because experimental activities for students were more visible in Teacher E’s class than the classes of Teachers F and G, which gave Teacher E more opportunities to employ collecting data practices. On the one hand, Teacher J implemented only one specific practice related to collecting data. Recall that Teacher J had the fewest enacted practices related to inquiry, which may be attributed to a different approach that he used to deliver the lessons. This may inhibit him from enacting inquiry including practices related to collecting data. The teachers in this study were not observed using investigation activities that require students to explore and collect data outside. For this reason, the practice of asking students to explore phenomena and collect data outside was not seen in chemistry classrooms.

Component 4: Analyzing data

This component of scientific inquiry occurred least in teachers’ chemistry instruction. Teachers’ practices related to analyzing data comprised only 8% of the total inquiry practices in chemistry instruction. There were four practices related to analyzing data implemented by teachers in the classroom. First, the most frequently implemented practice was asking students to do the analysis. This practice comprised 69% of the total implemented practices related to analyzing data. Teachers encouraged students to create their own data analysis procedure and way of solving problems. Generally, teachers asked students to analyze data gathered from investigation activities they conducted in the classroom. Teachers also asked students to analyze quantitative problems (e.g., expressing concentration of solutions quantitatively) in chemistry and provide necessary
solutions to the problem. Second, teachers provided students with specific direction for analysis, which comprised 20% of the total implemented practices on analyzing data. Before the students analyzed or solved the problem, some teachers explicitly discussed the procedures for solving quantitative problems and for analyzing experimental data for students to follow. Third, some teachers provided a prepared analysis and solution for the students (6% on analyzing data practices). A small portion of Teacher I’s chemistry instruction was composed of this practice. This practice was only observed in Teacher I’s classes. Last, teachers prompted students to assess the reliability or validity of data resulting from investigation activities (5%). This practice was observed in two chemistry classes only. The practice of analyzing data that was not observed in classrooms was asking students to analyze complex data. Teachers did not teach chemistry lessons involving analysis of complicated data for investigations.

Comparing across teachers, Teacher I had the highest mean score in the implementation of inquiry practices related to analyzing data (M=3.67). This was evident in class 2 (I2) (see Figure 8), where a large portion of chemistry instruction was composed of practices that asked students to analyze and solve problems. This practice was mostly observed when Teacher I discussed the lesson on the Concentration of Solutions that required students to describe quantitatively the exact ratio of solute to solvent, which specifies the concentration of a solution. The mean implementation number of analyzing data practices per lesson observed is presented in Figure 8.
Teacher I provided the students in class 2 with problems on expressing the concentration of solutions. She asked the students to analyze and solve the problem below:

How [much is the] many volume of isopropyl alcohol in a 60 mL bottle of alcohol?

In this scenario, she encouraged students to devise their own procedure for analyzing and solving this problem. She asked the students to write the complete solution for the problem in their notebooks. Afterwards, she called one student to explain the analysis procedure to the class. The problem above was also given to students in class 1 however, Teacher I used a different approach to deliver this lesson. In class 1, Teacher I provided the solution to the problem for the students, which limits her to employ other

![Figure 8. Analyzing data practices.](image_url)

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<th>Class</th>
<th>Providing prepared analysis/solution for students</th>
<th>Providing students specific direction for analysis</th>
<th>Asking students to do the analysis</th>
<th>Prompting students to assess the reliability and validity of data/results</th>
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Mean per lesson observation
inquiry practices related to problem solving and analysis. Thus, Teacher I enacted more practices related to problem and data analysis in class 2 than in class 1.

In another teaching scenario below, an inquiry practice related to analyzing data was implemented in a different chemistry topic taught in the classroom.

Teacher A prepared a blank periodic table. Hypothetical elements like Xy, G, Ab, Z, A, X and their properties were also given. He then asked students to analyze the properties of these elements and to identify their location in the periodic table based on their properties. (Teacher A, Lesson Observation 4, 24-07-2015)

In this scenario, Teacher A encouraged students to perform data analysis on their own. She provided the data (properties of hypothetical elements) that they analyzed in order to determine the correct location of the elements in the blank periodic table.

In very rare cases, Teachers B and H prompted students to assess the reliability or validity of the data they developed from investigation activities. This practice was observed after the students conducted their experiment and the teacher started to process the results. Consider the following scenario from Teacher H’s class, which shows this practice:

After the students performed an experiment on distinguishing substances and mixtures in terms of how temperature changes during boiling, Teacher H asked them to report their temperature readings for distilled water and seawater after 30 seconds (s), 60 s, 90 s, 120 s and 150 s. Student data were presented on the board. Then the teacher asked, “What does the data mean? Are the data based on temperature readings correct? Based on data, what can you say about the boiling temperature of distilled water and seawater?” (Teacher H, Lesson Observation 3, 24-07-2015)

In this scenario, Teacher H provided students with the opportunities to examine the data (temperature readings) that they collected by reflecting on the method they used in doing the experiment (e.g., recording temperature in 30 second time interval). She asked each team of students to describe how they measured the temperature. She also asked
them to examine if there were any differences between the collected data for substances and mixtures. After examining the data, she asked students to form descriptions about the boiling points of seawater and distilled water.

**Component 5: Developing explanations**

Thirteen percent (13%) of the total inquiry practices implemented by teachers in chemistry classrooms were related to developing explanations. There were four practices related to developing explanations observed in teachers’ chemistry instruction outlined in Figure 9 below.

![Mean per lesson observation graph](image)

**Figure 9.** Developing explanations practices.

The first practice was prompting students to form their own explanations based on results. Among the four developing explanations practices observed, this practice was the most enacted by teachers. This practice comprised 38% of the total
implemented practices related to developing explanations. This was implemented in ten
classes, and Teacher F’s class had the highest mean score for implementing this practice
per lesson observation (M = 2.60). Generally, this practice was implemented by
teachers after the students conducted an experiment like the one shown in the following
scenario from Teacher F’s class. In this scenario, Teacher F discussed a lesson on

*Factors Affecting How Fast a Solid Solute Dissolves.*

Teacher F gave students an experiment about the factors affecting solubility. After conducting the experiment, the whole class discussed the results. Teacher F asked
one team of students to report on the data collected from investigating the effects of hot
water and cold water on dissolving salt and sugar. The students explained the procedure
of their investigation. Two students were reporting the results in front of class. After
presentation, Teacher F asked students, “Why do you think salt dissolved faster than
sugar in hot water?” Students from team 1 answered, “The water and salt attracted with
each other.” “Based on your results, what is the factor that affect[s] solubility, team 1?”
The students answered, “[The] Nature of [the] solute.” (Teacher F, Lesson Observation
1, 29-06-2015)

In this lesson, Teacher F divided the students into five teams with six to seven
members to investigate the factors that affect how fast a solid solute dissolves in a given
volume of water. Each team was assigned to investigate one factor only. The students
investigated factors such as stirring, particle size, temperature, nature of solute, and
pressure. In the scenario above, students investigated the effect of the nature of solute
on solubility. It was observed that Teacher F gave students the opportunity to formulate
their own explanations based on results of their work. Teacher F asked students to
provide an account of why something happens based on their results. It was observed in
this class that students could readily give their own explanations to Teacher F.

Observations also revealed that students from other classes had difficulty in
giving explanations or formulating conclusion from results. According to Treagust and
Tsui (2014), this is very common in science teaching when students have difficulties
identifying explanations that involve cause-effect relationships in phenomena.

However, in a situation like this, Teacher G used evidence of the occurrence of phenomena to scaffold students in giving explanations. This strategy is shown in the next scenario from Teacher G’s class where she used a familiar example to help students understand the possible factors that affect solubility.

Teacher G asked team 2 to explain the procedure and results of the experiment assigned to them. One student from team 2 read the procedure and showed the results in front of class. After presenting the results, Teacher G asked team 2, “What is the factor that affects solubility? From your results, what is the relationship of temperature and rate of solubility?” It was observed that students were having difficulty in giving answers to teacher. In this situation, Teacher G gave an example that could help students figure out the relationship between temperature and rate of solubility. The teacher said, “By using hot water the solubility is faster while using cold water the solubility is slower.” [Note: This is not always the case for all solutes.] After giving this information, the teacher asked the original question again to let students form their own explanations. (Teacher G, Lesson Observation 1, 29-06-2015)

The second practice that was part of the developing explanations component was providing evidence for students to develop their own explanations, which comprised 9% of the total implemented developing explanations practices. For example, Teacher G also asked students to perform an experimental activity on Factors Affecting How Fast a Solid Solute Dissolves. Unlike in Teacher F’s class where students could readily explain their results, the students in Teacher G’s class could not provide an explanation, thus she gave an example that described solubility in hot and cold systems to help students form an explanation. This situation is related to the report of some researchers (e.g., Gilbert & Treagust, 2009; Treagust & Tsui, 2014) that in today’s science classrooms, teachers are using examples, models, simulations, actions, and gestures to show evidence for scientific phenomena in order to deliver better explanations, and to help students understand the science behind these phenomena.
The third practice of teachers observed in chemistry instruction was providing explanations for students without giving them the opportunity to explain results. These comprised 36% of the total developing explanations component. Most teachers explicitly discussed the results of investigation activities and connected these to the main concepts of the lesson. This practice was also frequently observed during chemistry instruction. This practice was implemented in eleven classes, and Teacher E’s class had the highest mean score for implementing this practice per lesson observation. Finally, the fourth practice was providing explanations with student opportunity to explain results. During discussion or processing the results of investigation activity, some teachers encouraged students to make explanations about a particular topic or about the activity they performed. However, there were times that students could not provide explanations. Since no one could form an explanation, the teacher provided the explanation to them (17%). This practice was implemented in nine classes.

Comparing across teachers, Teachers C (M=3.20) and F (M=3.20) had the highest mean scores in implementing inquiry practices related to developing explanations per lesson observation. Observations revealed that they frequently engaged their students to make explanations about the results of their chemistry activities. The results also revealed that inquiry practices related to developing explanations implemented in two chemistry classes (I1 and I2) of Teacher I were different. In class 1, Teacher I enacted developing explanation practices such as providing evidence then asking students to form an explanation, and prompting students to form their own explanations. In class 2, she enacted different practices such as providing explanations for students, and providing explanation with student opportunity to explain. This difference in developing explanations practices of Teacher I in class 1 and class 2 may
be a result of the different approach of teaching that she used in both classes. Teacher I used approaches in class 1 that were more inquiry in nature than class 2 to deliver the same lessons, which could give her opportunities to engage students in making their own explanations. In class 2, she employed a traditional lecture mode of teaching, which may encourage her to explain everything for students.

Component 6: Communicating information

Practices related to communicating information comprised 18% of the total inquiry practices implemented by teachers in chemistry instruction. Five practices related to communicating information were observed during instruction and the most frequent practice was asking students to report the results of their experiment or activity to the whole class. This practice comprised 46% of the total communicating information practices implemented by teachers in classrooms. It was enacted the most by Teacher H and implemented in ten classes. Figure 10 shows the communicating information practices implemented by teachers.
The aforementioned practice was typically observed when chemistry activities (experimental or non-experimental) were given to students to work on. A typical implementation of this practice was observed in the class of Teacher E when she discussed the lesson on *Separating Components of a Mixture*. Consider the following teaching scenario from Teacher E’s class:

After the students performed an experiment on separating components of a mixture, Teacher E asked team 1 to present the results of their work in class. Two members of team 1 discussed the evaporation method in separating the components of the salt solution. After this, the teacher explained why evaporation was used and the process involved during evaporation. Next, Teacher E asked team 2 to present their results. Two members of team 2 explained the method called *floation*, and then the teacher mentioned another method called *scooping*. She discussed this by using the sample mixture of oil and water. She also mentioned the difference between the density of oil and water. After team 2, team 3 was called to present their work. Two members
discussed what they did in paper chromatography. (Teacher E, Lesson Observation 2, 14-07-2015)

In this scenario, Teacher E gave students with opportunities to communicate the results of their work through oral presentations in class. However, it was noted that during students’ presentations, more useful classroom dialogues (e.g., student-teacher and student-questioning dialogues) were not manifested. Based on observations, students in this class were just reading visuals with results posted on the chalkboard in front of their classmates with a short elaboration. After students presented their results, Teacher E immediately continued to discuss results and introduced science concepts involved in the activity without probing or giving them opportunity to ask questions, make comments or suggestions. This scenario was observed in other classes as well. Unfortunately, this type of teacher practice may not encourage deep classroom conversations, particularly with respect to reflecting scientific discourse.

However, there were a few classes that encouraged a simple interaction between students and teachers during presentations. Some teachers asked students to report results of experiment or activity to whole class with interaction. This is another communicating information practice implemented by teachers in classrooms. Fifteen percent (15%) of the total practices related to communicating information were composed of this practice. This practice was observed in seven classes and mostly implemented in the class of Teacher F like the one shown in the following scenario:

After performing the experiment on factors affecting how fast a solid solute dissolves, Teacher F asked each team to report their results in front of the class. She called team 1 to present their results on investigating the effect of the nature of solute and solvent on solubility of a substance. Two students were reporting in the class. After reporting, Teacher F asked the students, “What is the factor that affects solubility, team 1” The students answered, “The Nature of [the] solute and [the] solvent” Then, Teacher F asked a follow-up question, “Why [did] is the substance dissolve?” The students
answered, “Because water and vinegar [are] attracted [to] with each other.” (Teacher F, Lesson Observation 1, 29-06-2015)

It is important that the process of communicating shown in the aforementioned practices should be accomplished effectively through a dialogic way of communication, which may promote scientific discourse in the classroom. However, it can be noticed that the captured student-teacher dialogues presented in some scenarios is limited. It could be patterned to the initiation (teacher asks a question), response (student responds with an answer), and evaluation (teacher evaluates student response) (IRE) model, which according to Skamp (2018) does not encourage “student-negotiated meaning making” (p. 53). In addition to these practices, other practices related to communicating information enacted by teachers were asking students to write information using the prescribed format (21%), asking students to make and use their own format of writing information (3%), and asking students to make and describe diagram, graph, or table (15%).

Comparing across teachers, Teacher H had the highest mean score in implementing practices related to communicating information (M=5.60). She frequently asked her students to present the results of activity (experimental or non-experimental) in the class. The presentation was usually done by each team of students. After the students communicated their results, the next practice of Teacher H was to process the results reported by each team and connect the results to the lesson being discussed. Observations also revealed that Teachers D, F, and G enacted varied communicating information practices in their classrooms. Recall also that Teacher I enacted more communicating information practices in class 1 than class 2 due to differences in the teaching approaches that she used in each of these classes.
Characterization of Inquiry in Chemistry Classrooms

In this study, to characterize inquiry in chemistry classrooms, mean scores for the degree of initiation of inquiry (teacher-centered or student-centered) in each class and mean scores for the amount of inquiry practices implemented in each class were plotted in the graph as shown in Figure 11 below.

![Graph showing amount of inquiry practices versus who initiated the inquiry in the classroom.](image)

*Figure 11. Amount of inquiry practices versus who initiated the inquiry in the classroom.*

The calculated mean scores for the degree of initiation of inquiry by each teacher ranged from zero to 105 and plotted in the x-axis of the graph. The mean scores were calculated by dividing the total score for inquiry initiation in each class by the number of observations. The total score for inquiry initiation was calculated by multiplying the number of implementation for each practice to the scores ranging from 1 (for most teacher-centered practice) to 5 (for most student-centered practice) (Capps
& Crawford, 2013). The calculated mean scores for the amount of inquiry implemented by each teacher ranged from zero to 25 and were plotted against the y-axis of the graph. The mean scores were calculated by dividing the total frequency of implementation of each inquiry component by the total number of lesson observations per class.

The graph of the degree of inquiry initiation versus the amount of inquiry practices shown in Figure 11 created a modified version of the inquiry continuum, which was based on the continuum of classroom inquiry proposed by Brown et al. (2006). Using this continuum, teachers’ inquiry-based instruction in chemistry classrooms were characterized based on their location on the continuum. Teachers could be located in the upper quadrant (more inquiry) or lower quadrant (less inquiry). They could also be located at the right side (student-centered) or left side (teacher-centered). Teachers’ location in the continuum was based on their mean scores in the degree of inquiry initiation and amount of inquiry practices. The higher the mean score in the degree of inquiry initiation, the more student-centered the inquiry was in the classroom. The higher the mean score in the amount of inquiry, the more inquiry was implemented in the classroom. In this study, all teachers observed scored less than 52, which suggests that inquiry practices observed in the classrooms were largely teacher-centered. The highest mean score was 51 (Teacher F) and the lowest mean score was 12 (Teacher J). It is important to note that the focus of this study is not on investigating the relationship between the amount of inquiry or the degree of inquiry initiation in classrooms and student learning. This study investigated which specific practice or component of inquiry implemented in classrooms is related to learning, which is discussed later in the thesis. Details of teacher-centered and student-centered inquiry practices enacted by teachers are discussed below.
Teacher-centered inquiry practices

As noted, teacher-centered scientific inquiry was more evident in the chemistry classes observed in this study than student-centered scientific inquiry. In examining the chemistry lessons that the teachers taught, hands-on or group activity-based lessons (usually non-experimental activities) were characterized as having more teacher-centered scientific inquiry. Usually, most parts of these lessons were teacher-driven and highly structured. Thus, these lessons provided little opportunity for student autonomy. The most common teacher-centered inquiry practices that occurred were: teachers provided specific procedures to follow in the activity (*designing and conducting investigations*), teachers demonstrated how to do the activity (*designing and conducting investigations*), teachers asked questions about facts not previously presented which elicited students’ own ideas (*engaging in questioning*), teachers assisted students while performing the activity (*designing and conducting investigations*), and teachers gave the explanation without giving students the opportunity to explain the results (*developing explanations*). Below are some teaching scenarios captured from classroom observations that illustrated teacher-centered inquiry practices:

**Providing specific procedures for group activity**

Teacher G presented an activity on separating the components of mixtures. Before commencing the activity, she divided the students into three teams. She assigned each team a specific activity to perform. Team 1 performed activity A (separating a mixture of rice powder and sulfur), team 2 performed activity B (separating a mixture of oil and water), and team 3 performed activity C (separating a mixture of salt and water). Teacher G provided each team with a set of procedures that they needed to follow and then explained the procedure to each team. She moved around each group station and guided the students in performing the procedure of the activity. (Teacher G, Lesson Observation 3, 15-07-2015)
Demonstrating how to perform the activity

As part of the activity on Electrolysis of Water, Teacher II demonstrated the procedure in front of the class for the students. She demonstrated how to use the improvised electrolysis apparatus. She showed how to fill each “electrolysis syringe” with five percent (5%) sodium hydroxide solution. She also showed how to collect gases using a syringe from the apparatus. While Teacher II was demonstrating the procedure and explaining what to do in the activity, students were gathered in front to observe the demonstration. Based on demonstration, Teacher II asked students, “What happens to the water?” After the demonstration, she repeated the explanation of the procedures for the activity. (Teacher II, Lesson Observation 4, 21-07-2015)

Making explanations for students

Teacher C presented an activity on distinguishing substances and mixtures based on how temperature changes during boiling. In this activity, distilled water was used as a sample substance and seawater was used as a sample mixture. Each team performed boiling of distilled water first, then followed by boiling of seawater. After performing the activity, Teacher C asked the students, “What can you say about the boiling temperature of distilled water and seawater?” After asking this question, she immediately explained the results of the experiment using the data of each team. She explained first the boiling of distilled water followed by the boiling of seawater. Then, she asked again a follow-up question, “What do you mean by distilled water?” After this, she immediately told the class that 100 degrees Celsius is the boiling point of distilled water. (Teacher C, Lesson Observation 3, 24-07-2015)

Student-centered inquiry practices

Chemistry lessons with investigative or experimental components like collecting data, analyzing data, and communicating results of investigation that provided students with at least some autonomy or intellectual ownership could be classified as mostly student-directed. The most common specific inquiry practices that occurred in these lessons were: the teacher asked students to collect data through making descriptive observations from the activity or experiment (individual or group) the students performed in the class (collecting data), teacher asked students to analyze data and/or solve problems (analyzing data), and teacher asked students to report out data or results of an individual or group experiment to the whole class (communicating information).
The following are some teaching scenarios captured from classroom observations that illustrated student-centered inquiry practices:

**Collecting data through observations**

Teacher C presented an activity on determining the acidity or basicity of some substances and mixtures using indicators. She asked students to use common household materials like vinegar, shampoo, and baking soda as sample substances and mixtures. Students used an acid-base indicator (*litmus paper*) to identify which of these materials are acids and bases. Students observed the reaction of the litmus paper with the common household materials. Specifically, they observed the changes in color of litmus paper once it reacted to household materials. The descriptive data that they collected were recorded in their data table. (Teacher C, Lesson Observation 5, 03-08-2015)

**Analyzing and solving problems**

After the students prepared the solution of 70% alcohol, Teacher E engaged them in quantitative methods for expressing the concentration of solutions. In doing so, she provided students with problems on expressing the correct concentration of solutions. Each team of students devised their own procedure for analyzing and solving problems. They wrote the complete solution for the problem in their notebooks. Afterwards, Teacher E called each team to explain their analysis procedure in the class. (Teacher E, Lesson Observation 1, 02-07-2015)

**Reporting out data or investigation results**

After the students performed an experiment on factors affecting how fast a solid solute dissolves, Teacher F asked each team to report their results in front of the class. Team 1 reported the results of investigation on the effect of nature of solute and solvent part on solubility of a substance. After reporting, Teacher F asked the students, “What is the factor that affects solubility, team 1.” The students answered, “The nature of [the] solute and [the] solvent” Then, Teacher F asked a follow-up question, “Why [did] is the substance dissolve?” The students answered, “Because water and vinegar [are] attracted [to] each other.” After this, other teams also reported their data and results in the class. (Teacher F, Lesson Observation 1, 29-06-2015)

In Figure 11, most teachers plotted in the upper left quadrant and few teachers plotted in the lower left quadrant. Teachers in the upper left quadrant were found to demonstrate multiple practices related to the six components of scientific inquiry. However, there was not much evidence of inquiry-based instruction in the two
chemistry classes in the lower left quadrant. The lack of inquiry in these two classes does not necessarily mean that the teachers did not teach chemistry as inquiry at all but inquiry practices were less frequent. It can be noted that in most classes observed, students were involved in inquiry that was guided by teachers. Overall, the evidence collected from classroom observations suggest that most teachers demonstrated the potential to teach chemistry as inquiry.

Chapter Summary

The findings from this chapter suggest that teachers tended to enact more inquiry teaching practices related to engaging in questioning and communicating information than the practices of analyzing data, collecting data, designing and conducting investigations, and developing explanations. Because of the challenges in the teaching and learning environments (e.g., lack of science laboratories, lack of resources, large class sizes) encountered by most teachers, proper implementation of inquiry-based teaching approaches may be challenging for them. As a result, inquiry practices, particularly teaching experimentation that involved fair testing, were not typically implemented by the teachers in their chemistry instruction. However, some teachers used improvised teaching materials and equipment to implement inquiry in their classrooms. Other teachers chose to use different approaches (e.g., traditional lecture) other than inquiry to deliver the lesson, which could be suitable to their own classroom contexts.

The six components of scientific inquiry were enacted by teachers in varying degrees in their classrooms. The variation in inquiry practices was not surprising given the different backgrounds of the teachers and different classroom contexts. Of the 10
teachers who demonstrated different inquiry instructional practices, there was no single factor that could account for this. One might expect that chemistry classes in a school with more facilities and equipment (e.g., working space for experiments, storage for science materials, laboratory apparatus) would be able to demonstrate more inquiry in the classroom, yet six of the 12 classes belong to schools with no available science facilities and equipment and in some of these there was a greater use of inquiry practices than in better-equipped schools. In fact, the class that demonstrated the highest amount of inquiry in the classroom (Teacher F) was from a school with no science laboratory to conduct experiments. This would suggest that teachers may remain the central factor influencing creation of an inquiry-based classroom, and that a highly capable teacher may be able to implement inquiry-based practices in spite of a lack of facilities. Even where carefully designed and specified curriculum materials are provided, teachers may play the key role in determining how the inquiry-based instructional materials are enacted. However, this is not to suggest that the degree of implementation of inquiry practices is immutable. In this study, most teachers who had greater implementation of inquiry in classrooms had participated in a week-long intensive inquiry-based national training program conducted by DepEd and UP NISMED, which suggests that appropriate professional learning can have an impact on the degree to which practices are implemented in classrooms. Although all teachers in this study showed the potential to implement inquiry practices in the classroom, teacher-centered scientific inquiry instruction was more evident than student-centered scientific inquiry instruction, which suggests that inquiry in most chemistry classrooms was structured.
However, the findings from the study also suggest that the capacity of most teachers to implement inquiry-based teaching practices may be seriously constrained by the available resources; while highly capable teachers may be able to implement science inquiry practices in situations where there are limited or no laboratory access and learning resources, the majority of teachers may struggle to do this. This further suggests that there may be limits to translating pedagogies such as inquiry practices that have largely been developed in first-world countries, into countries where high levels of resourcing and facilities cannot be taken for granted.
Chapter 6: Investigating the Relationship Between Teachers’ Inquiry Practices and Students’ Learning in Chemistry

This chapter is divided into three parts. The first part presents the results of the Rasch analysis of the ACTRC chemistry tests (pretest and posttest). The second part presents the results of the student chemistry tests. The third part presents the results of the multilevel analysis of the relationship between the specific practices of scientific inquiry implemented by teachers and students’ learning in chemistry. The multilevel analysis is presented in two-level unconditional model, two-level model with predictor variables, and multivariate multilevel model.

Results of the Rasch Analysis of the ACTRC Chemistry Tests

The summaries of item statistics for the pretest and posttest are presented in Table 9 and Table 10, respectively. Test items were examined for item difficulty (item delta) and item fit (weighted mean squared [MNSQ] fit). The item fit indices for all items of the ACTRC chemistry pretest and posttest were within the acceptable range of 0.8-1.2 logits (Wright & Linacre, 1994). Based on the ACTRC’s Science Curriculum Project Report for Stages 1 and 2, the items for both tests were found to fit the model, showing that they measure the same construct. (Ferido et al., 2015; Ferido et al., 2016).
Table 9. Chemistry Pretest Item Statistics

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<th>Item Difficulty (Item Delta)</th>
<th>Error</th>
<th>Item Fit (Weighted MNSQ)</th>
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Table 10. Chemistry Posttest Item Statistics

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<td>0.84</td>
<td>0.11</td>
<td>1.04</td>
</tr>
<tr>
<td>18</td>
<td>-0.06</td>
<td>0.09</td>
<td>1.03</td>
</tr>
<tr>
<td>19</td>
<td>-0.15</td>
<td>0.09</td>
<td>1.00</td>
</tr>
<tr>
<td>20</td>
<td>-0.06</td>
<td>0.09</td>
<td>0.99</td>
</tr>
<tr>
<td>21</td>
<td>-1.03</td>
<td>0.09</td>
<td>0.90</td>
</tr>
<tr>
<td>22</td>
<td>-0.28</td>
<td>0.09</td>
<td>1.00</td>
</tr>
<tr>
<td>23</td>
<td>-1.05</td>
<td>0.09</td>
<td>1.01</td>
</tr>
<tr>
<td>24</td>
<td>0.12</td>
<td>0.10</td>
<td>0.97</td>
</tr>
<tr>
<td>25</td>
<td>-0.52</td>
<td>0.09</td>
<td>1.04</td>
</tr>
<tr>
<td>26</td>
<td>-1.20</td>
<td>0.09</td>
<td>0.91</td>
</tr>
<tr>
<td>27</td>
<td>-1.62</td>
<td>0.10</td>
<td>0.94</td>
</tr>
<tr>
<td>28</td>
<td>0.16</td>
<td>0.10</td>
<td>1.02</td>
</tr>
<tr>
<td>29</td>
<td>1.08</td>
<td>0.12</td>
<td>1.00</td>
</tr>
<tr>
<td>30</td>
<td>-0.47</td>
<td>0.09</td>
<td>0.90</td>
</tr>
<tr>
<td>31</td>
<td>-0.53</td>
<td>0.09</td>
<td>1.06</td>
</tr>
<tr>
<td>32</td>
<td>1.46</td>
<td>0.14</td>
<td>1.01</td>
</tr>
<tr>
<td>33</td>
<td>0.81</td>
<td>0.11</td>
<td>1.00</td>
</tr>
<tr>
<td>34</td>
<td>-0.93</td>
<td>0.09</td>
<td>0.98</td>
</tr>
<tr>
<td>35</td>
<td>0.03</td>
<td>0.09</td>
<td>0.99</td>
</tr>
</tbody>
</table>
The expected a posteriori/plausible value (EAP/PV) item separation and the weighted maximum likelihood estimation (WLE) person separation reliabilities were acceptable for both tests as shown in Table 11. Values greater than 0.70 are considered acceptable (Grigg & Manderson, 2016; Yang, He, & Liu, 2017). This means that the tests performed well in having items with different levels of difficulty to discriminate between students with different levels, providing support for the reliability of the two tests.

Table 11. Item and Person Separation Reliabilities for the ACTRC Chemistry Tests

<table>
<thead>
<tr>
<th>ACTRC Chemistry Tests</th>
<th>EAP/PV Item Separation Reliability</th>
<th>WLE Person Separation Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>0.863</td>
<td>0.857</td>
</tr>
<tr>
<td>Posttest</td>
<td>0.713</td>
<td>0.705</td>
</tr>
<tr>
<td>Note. Each ‘X’ represents 0.8 cases.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Figure 12.</em> Variable map of student and item distribution for the pretest.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 13. Variable map of student and item distribution for the posttest.

Variable map or wright map can provide visual information about how the items and persons are distributed along the latent continuum. Given that the Rasch model places item difficulties and person abilities on the same scale, the distribution of item difficulties can then be compared against the distribution of the person abilities, which

Note. Each ‘X’ represents 0.8 cases.
provides us how well the students at various levels of the latent ability could be assessed. The variable maps for the pretest and posttest are shown in Figure 12 and Figure 13, respectively. The distribution of students is shown on the left side with students represented by ‘X’. The items are shown on the right side and each item is shown as a number according to the test order. For the pretest, the logit scale extends from -3 to 3 logits. The most difficult item on the pretest is shown to be Item 41, and the easiest is shown to be Item 6. Generally, the items in the pretest widely spread along the latent continuum, ensuring that there are available items with different difficulty levels to measure the students who are located at different positions at the latent continuum. For the posttest, the logit scale extends from -2 to 1 logits. The most difficult items on the posttest are shown to be Items 4, 8, 32, and 36, and the easiest is shown to be Item 11. Although the items in the posttest appear to be a little hard for the students, there are still relatively enough available items along the latent continuum to measure the students widely located at different position at the latent continuum. In summary, all the results of the psychometric analyses provide initial support for the construct validity of the two chemistry tests.

**Results of the Student Chemistry Tests**

The results of the student chemistry tests are shown in Table 12. Specifically, the mean score of each class in the pretest and posttest, and the mean gain score in chemistry are presented in the table. The associated standard deviations (SD) are also shown.
### Table 12. Mean Pretest, Posttest, and Gain Scores per Class

<table>
<thead>
<tr>
<th>School</th>
<th>Teacher</th>
<th>N&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Pretest&lt;sup&gt;b&lt;/sup&gt;</th>
<th>SD</th>
<th>Posttest&lt;sup&gt;b&lt;/sup&gt;</th>
<th>SD</th>
<th>Gain&lt;sup&gt;c&lt;/sup&gt;</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>A</td>
<td>35</td>
<td>42.70</td>
<td>7.71</td>
<td>48.32</td>
<td>6.28</td>
<td>5.62</td>
<td>5.66</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>53</td>
<td>59.42</td>
<td>5.49</td>
<td>58.24</td>
<td>5.66</td>
<td>-1.17</td>
<td>5.56</td>
</tr>
<tr>
<td></td>
<td>c2</td>
<td>30</td>
<td>44.78</td>
<td>6.81</td>
<td>49.18</td>
<td>5.85</td>
<td>4.40</td>
<td>4.96</td>
</tr>
<tr>
<td>4</td>
<td>C</td>
<td>38</td>
<td>55.35</td>
<td>6.34</td>
<td>54.44</td>
<td>5.40</td>
<td>-0.91</td>
<td>4.85</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>32</td>
<td>41.83</td>
<td>8.35</td>
<td>48.19</td>
<td>4.69</td>
<td>6.35</td>
<td>7.59</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>37</td>
<td>47.58</td>
<td>7.78</td>
<td>49.02</td>
<td>5.61</td>
<td>1.44</td>
<td>5.38</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>40</td>
<td>57.29</td>
<td>7.49</td>
<td>59.64</td>
<td>5.40</td>
<td>2.35</td>
<td>6.03</td>
</tr>
<tr>
<td></td>
<td>G</td>
<td>42</td>
<td>38.55</td>
<td>4.91</td>
<td>45.35</td>
<td>4.49</td>
<td>6.80</td>
<td>4.65</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>33</td>
<td>39.79</td>
<td>7.32</td>
<td>48.42</td>
<td>4.85</td>
<td>8.63</td>
<td>5.31</td>
</tr>
<tr>
<td>1</td>
<td>I</td>
<td>54</td>
<td>56.34</td>
<td>6.64</td>
<td>55.50</td>
<td>5.70</td>
<td>-0.84</td>
<td>4.74</td>
</tr>
<tr>
<td></td>
<td>c2</td>
<td>49</td>
<td>55.50</td>
<td>7.77</td>
<td>54.24</td>
<td>5.57</td>
<td>-1.25</td>
<td>5.60</td>
</tr>
<tr>
<td></td>
<td>J</td>
<td>52</td>
<td>54.57</td>
<td>5.14</td>
<td>53.09</td>
<td>4.26</td>
<td>-1.47</td>
<td>4.97</td>
</tr>
</tbody>
</table>

*Note:* c1 is class 1 and c2 is class 2.

<sup>a</sup>Number of students.

<sup>b</sup>Standardized score where mean=50 and standard deviation=10.

<sup>c</sup>Difference between posttest and pretest scores.

The pretest scores in Table 12 suggest that there is a variation in student abilities in chemistry at the start of Grade 7. These students obtained their elementary education from different schools. They had different elementary school background and may have had different learning experiences in the science classroom.

Figure 14 below shows the relationship between the pretest and gain scores in chemistry.
Figure 14 shows that there is a strong negative relationship between the pretest score and gain score \((r = 0.53)\). This indicates that students with low pretest scores had high gain scores in chemistry while students with high pretest scores had low gain scores in chemistry. It can be inferred from this result that students with high pretest scores may have encountered, to some extent, the lessons specified in the new Grade 7 chemistry curriculum prior to entering junior high school. They may have already learned some concepts being taught by the teacher, and so there was no further capacity for them to demonstrate learning growth. Thus, students with high mean pretest scores seemed to have low or negative gain scores. This may also signify the presence of test ceiling effect, which may limit the interpretation of students’ progress in chemistry. The ceiling effect is “a measurement limitation that occurs when the highest possible score or close to the highest score on a test is reached, thereby decreasing the likelihood that the
testing instrument has accurately measured the intended domain” (Taylor, 2012, p. 133). It can be inferred that students with high pretest scores may have needed an enriched chemistry curriculum, which could contribute for further learning. By contrast, the Grade 7 chemistry lessons may have been new for students with low pretest scores, and when they encountered these lessons in class there may have been space for them to accommodate new conceptual learning. Thus, their gain scores were relatively high.

Since there was a strong relationship between students’ pretest scores (prior abilities) and gain scores, further analysis was conducted by controlling the influence of pretest score using the one-way analysis of covariance (ANCOVA) to obtain the adjusted mean gain score in chemistry of each class as shown in Table 13. 

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Adjusted Gain Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.613</td>
</tr>
<tr>
<td>B c1</td>
<td>3.376</td>
</tr>
<tr>
<td>c2</td>
<td>1.459</td>
</tr>
<tr>
<td>C</td>
<td>1.558</td>
</tr>
<tr>
<td>D</td>
<td>1.904</td>
</tr>
<tr>
<td>E</td>
<td>-0.072</td>
</tr>
<tr>
<td>F</td>
<td>5.815</td>
</tr>
<tr>
<td>G</td>
<td>0.672</td>
</tr>
<tr>
<td>H</td>
<td>3.134</td>
</tr>
<tr>
<td>I c1</td>
<td>2.131</td>
</tr>
<tr>
<td>c2</td>
<td>1.290</td>
</tr>
<tr>
<td>J</td>
<td>0.591</td>
</tr>
</tbody>
</table>

*Note. c1 is class 1 and c2 is class 2.*

After controlling for the influence of pretest on gain score, Table 13 shows that Teacher F’s class obtained the highest mean gain score in chemistry while Teacher J’s class had the lowest mean gain score. The students of Teacher E did not demonstrate progress. The adjusted mean gain score with standard error bars are plotted in Figure 15 from the class with highest mean gain to the class with lowest mean gain.
Figure 15. Adjusted mean gain score with standard error bars per class.

The difference between the mean gain score of Teacher F’s class and the mean gain score of all other classes was significant. The mean difference between Teacher B’s class 1 and the classes of Teachers C, I (class 2), G, J and E was also significant. To further explore for other differences in adjusted mean gain score between classes, a post hoc test for one-way ANCOVA was employed in the analysis. Table 14 presents the mean difference of adjusted gain score between classes with significance values. The gray-shaded part of the table implies that the mean difference in the chemistry gain score between two classes was significant at 0.05 level.
Due to the strong relationship between the pretest and gain scores, the pretest score was controlled as a student covariate in the multilevel modeling of the relationship between teachers’ scientific inquiry practices and students’ learning in chemistry as presented in the next section. This is to account for student-to-student differences in prior abilities that were unrelated to teacher instructional practices.

Results of the Multilevel Modeling

**Descriptive statistics of the variables**

The descriptive statistics (mean [M] and standard deviation [SD]) of the outcome, within-class, and between-class variables are presented in Table 15. The mean posttest score of students in chemistry was relatively higher than the mean pretest score.
The specific inquiry practice that implemented the most was engaging in questioning and the practice that implemented the least was analyzing data.

Table 15. *Descriptive Statistics of the Outcome, Student-Level, and Teacher-Level Variables*

<table>
<thead>
<tr>
<th>Variable</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outcome variable</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemistry posttest</td>
<td>52.49&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.82</td>
</tr>
<tr>
<td><strong>Student-level variable</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemistry pretest</td>
<td>50.53&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.93</td>
</tr>
<tr>
<td><strong>Teacher-level variable</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scientific inquiry practices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engaging in questioning</td>
<td>6.42</td>
<td>4.05</td>
</tr>
<tr>
<td>Designing and conducting investigations</td>
<td>2.00</td>
<td>1.53</td>
</tr>
<tr>
<td>Collecting data</td>
<td>1.65</td>
<td>1.78</td>
</tr>
<tr>
<td>Analyzing data</td>
<td>1.25</td>
<td>1.96</td>
</tr>
<tr>
<td>Developing explanations</td>
<td>2.16</td>
<td>1.85</td>
</tr>
<tr>
<td>Communicating information</td>
<td>2.98</td>
<td>2.54</td>
</tr>
</tbody>
</table>

*Note.* The mean for each scientific inquiry practice is the mean number of implementation per lesson observation.

<sup>a</sup>Standardized score where mean=50 and standard deviation=10.

**Correlations of the variables**

**Correlations between predictor variable and student learning in chemistry**

Initially, an exploration of which among the predictor variables involved in this study have high associations with student learning in chemistry (posttest score) was conducted through a series of correlation analyses. The results of correlation analyses between predictor variable and outcome variable are shown in Table 16.
Table 16. Correlations Between Predictor Variable and Student Chemistry Posttest Score

<table>
<thead>
<tr>
<th>Variable</th>
<th>Student Chemistry Posttest Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Student-level variable</strong></td>
<td></td>
</tr>
<tr>
<td>Pretest score</td>
<td>0.767&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Teacher-level variables</strong></td>
<td></td>
</tr>
<tr>
<td>Engaging in questioning</td>
<td>0.098&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Designing and conducting investigations</td>
<td>−0.132&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Collecting data</td>
<td>−0.192&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Analyzing data</td>
<td>0.217&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Developing explanations</td>
<td>0.092&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Communicating information</td>
<td>−0.232&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>Coefficients are statistically significant at $p < 0.01$.

<sup>b</sup>Coefficients are statistically significant at $p < 0.05$.

Based on Cohen’s (1988) suggestions on interpreting the strength of the value of correlation coefficients ($r$) (discussed in Chapter 4), it can be noticed that the pretest score of students was highly associated with their learning in chemistry (posttest score). This means that student prior abilities may have influenced their learning; thus it is important to control the pretest in the analysis of the relationship between student learning and teacher practices. The correlations between teacher-level variables (each scientific inquiry practice) and student learning in chemistry were relatively small; ranging from $r=0.09$ to $r=0.23$.

Since the literature (discussed in earlier chapters) suggested that scientific inquiry practices as a teaching approach could possibly lead to greater student achievement in science (e.g., Fogleman et al., 2011; Minner et al., 2010; Wilson et al., 2010), it is important to further investigates on the degree to which specific practice of scientific inquiry teaching approach could help students improve their achievement. With this, it is important to consider the six specific practices of scientific inquiry as factors for student learning in chemistry despite their small coefficient values resulting from this initial correlation analyses.
Correlations between predictor variables

In looking at the relationship between predictor variables, most scientific inquiry practices were not significantly related (engaging in questioning, analyzing data, developing explanations, and communicating information) and two practices had weak relationship (designing and conducting investigations and collecting data). Also, the pretest was not significantly related with engaging in questioning and developing explanations and had weak relationship with designing and conducting investigations, collecting data, analyzing data, and communicating information. The results of correlation analyses between predictor variables are shown in Table 17.

Table 17. Results of Correlation Analyses Between Predictor Variables

<table>
<thead>
<tr>
<th>Predictor Variables</th>
<th>Pretest</th>
<th>Q</th>
<th>DI</th>
<th>CD</th>
<th>AD</th>
<th>DE</th>
<th>CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td>-0.056</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(p=0.217)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DI</td>
<td>-0.136&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.103</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(p=0.002)</td>
<td>(p=0.444)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CD</td>
<td>-0.284&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.223</td>
<td>0.332&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(p=0.000)</td>
<td>(p=0.096)</td>
<td>(p=0.012)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AD</td>
<td>0.335&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.085</td>
<td>0.047</td>
<td>0.102</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(p=0.000)</td>
<td>(p=0.528)</td>
<td>(p=0.727)</td>
<td>(p=0.450)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE</td>
<td>0.085</td>
<td>0.136</td>
<td>0.031</td>
<td>0.141</td>
<td>0.019</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(p=0.058)</td>
<td>(p=0.312)</td>
<td>(p=0.816)</td>
<td>(p=0.295)</td>
<td>(p=0.891)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CI</td>
<td>-0.416&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.253</td>
<td>0.128</td>
<td>-0.037</td>
<td>-0.006</td>
<td>0.088</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(p=0.000)</td>
<td>(p=0.057)</td>
<td>(p=0.343)</td>
<td>(p=0.786)</td>
<td>(p=0.963)</td>
<td>(p=0.516)</td>
<td></td>
</tr>
</tbody>
</table>

Note. Q=engaging in questioning; DI=designing and conducting investigations; CD=collecting data; AD=analyzing data; DE=developing explanations; CI=communicating information
<sup>a</sup>Correlation coefficient is statistically significant.

In addition, determining the relationship of the six inquiry practices may be important in exploring the creation of a composite variable across all six practices since this may have the advantage of providing a more comprehensive measure of the construct when compared to a single variable (O’Dwyer et al., 2015). However,
correlation analyses failed to indicate a relationship between most scientific inquiry practices. This may suggest that a composite variable could not be created, and the six practices of inquiry were used individually to represent teachers’ specific practices related to inquiry-based teaching.

Two-level unconditional model: No predictor variable

A multilevel analysis was conducted using the Mplus 7.4 version software (Muthén & Muthén, 2016). The analysis began with a two-level unconditional regression model, which consisted only of the outcome variable (posttest score in chemistry) and no independent variable. This model provides the results of partitioning the outcome variable into within-class and between-class components, and testing whether the variance of the between-class component is significantly different from zero. The unconditional model can be used to determine whether there are statistically significant differences in student learning across 12 classes. From these measures, the intraclass correlation coefficient (ICC) was obtained, which is the proportion of variation in the student posttest score in chemistry that is due to differences between classes. As discussed in Chapter 4, the equation for the two-level unconditional model is as follows:

\[
\text{chemistry posttest score} = \beta_{0j} + r_{ij} \quad \text{(level 1)} \quad \text{and} \quad \beta_{0j} = \gamma_{00} + u_{0j} \quad \text{(level 2)}
\]

In this equation, \(\beta_{0j}\) is the random intercept at level 1, \(r_{ij}\) is the residual score at level 1, \(\gamma_{00}\) is the grand mean/intercept for random intercept coefficient at level 2, and \(u_{0j}\) is the residual score for the random intercept at level 2.
This equation indicates that at level 1, the chemistry posttest score of an individual student \((i)\) who belongs to a particular class or group \((j)\) was decomposed into a class or group mean \((\beta_{0j})\) plus the deviation of an individual student’s chemistry posttest score from the class or group mean (or residual score, \(r_{ij}\)). At level 2, the class or group means were decomposed into the grand mean across all classes or groups \((\gamma_{00})\) plus the deviations of the class or group means from the grand mean (or residual score \(u_{0j}\)).

Table 18 below provides the results from the unconditional model.

<table>
<thead>
<tr>
<th></th>
<th>Estimate</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within-class</td>
<td></td>
<td></td>
</tr>
<tr>
<td>posttest score variance ((w))</td>
<td>29.44</td>
<td>(p &lt; 0.001)</td>
</tr>
<tr>
<td>Between-class</td>
<td></td>
<td></td>
</tr>
<tr>
<td>posttest score variance ((b))</td>
<td>23.84</td>
<td>(p &lt; 0.001)</td>
</tr>
<tr>
<td>Intraclass correlation coefficient (ICC)(^a)</td>
<td>0.45</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\text{ICC} = \frac{b}{w+b}\)

The ICC indicates that around 45% of the variance in students’ chemistry posttest score was explained by the class or group level. If the value of ICC is greater than 0.05 multilevel modeling may be appropriate to use (Muthén & Satorra, 1995; Zhang & Lee, 2017). Table 18 shows that the value of ICC is greater than 0.05 and the posttest score variance between classes was significant. With this, the result of ICC justified the requirement of multilevel modeling.
Two-level model with predictor variables: Pretest score (level 1 predictor) and scientific inquiry practices (level 2 predictors)

The within-class (level-1) model explored whether the student covariate (pretest score) is associated with student chemistry learning. This model provided information on how much of the total unexplained individual level variance for students’ chemistry posttest score was explained by the student covariate. The equation for level 1 model is as follows:

\[
\text{chemistry posttest score} = \beta_{0j} + \beta_{1j} (\text{pretest score}) + r_{ij}
\]

In the level 1 model, \( \beta_{0j} \) is the chemistry posttest score when all other variables are constant. The effect of pretest on students’ chemistry gain score is represented by the regression coefficient \( \beta_{1j} \). The \( r_{ij} \) is a random student effect. The level-1 predictor variable (pretest score) was entered into the model centered at the grand mean.

The between-class (level-2) model determined if student learning in chemistry was impacted by the practices of scientific inquiry implemented by teachers, holding a student covariate in the model constant. It provided information on how much of the total unexplained individual level variance for students’ posttest score was explained by teachers’ scientific inquiry practices. In this model, each practice of scientific inquiry enacted by teachers was tested separately. Thus, six level 2 models were created. The equation for level 2 model is as follows:

\[
\beta_{0j} = \gamma_{00} + \gamma_{01} (\text{each practice of scientific inquiry}) + u_{0j}
\]

In the level 2 model, \( \gamma_{01} \) is the regression coefficient, which represents the association between each practice of scientific inquiry and students’ chemistry posttest score,
holding the pretest in the model constant. Each level 2 predictor (each scientific inquiry practice) was added in the model uncentered.

In Table 19, the within-class and between-class models of students’ chemistry learning and teachers’ scientific inquiry practices were presented. It shows the estimated regression coefficients for each scientific inquiry practice of teachers (Models 1 through 6) for predicting students’ learning in chemistry. It also shows the estimated regression coefficient for student covariate (pretest) since this is included in all models.

Table 19. Relationship Between Teachers’ Scientific Inquiry Practices and Students’ Learning in Chemistry

<table>
<thead>
<tr>
<th>Model description</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
<th>Model 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1 predictor (Student-level)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest</td>
<td>0.484(^a)</td>
<td>0.489(^a)</td>
<td>0.467(^a)</td>
<td>0.510(^a)</td>
<td>0.479(^a)</td>
<td>0.488(^a)</td>
</tr>
<tr>
<td>Level 2 predictors (Teacher-level)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scientific inquiry practices</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Engaging in questioning (Q)</td>
<td>0.551(^b)</td>
<td>-0.336(^c)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.08)(^c)</td>
<td>(0.04)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Designing and conducting investigations (DI)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Collecting data (CD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.081(^c)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.01)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Analyzing data (AD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.033(^c)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.004)</td>
<td></td>
</tr>
<tr>
<td>5. Developing explanations (DE)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.102(^c)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.01)</td>
<td></td>
</tr>
<tr>
<td>6. Communicating information (CI)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.359(^c)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.05)</td>
</tr>
</tbody>
</table>

\(^a\)Coefficients are statistically significant at \(p < 0.001\).
\(^b\)Coefficient is statistically significant at \(p < 0.05\).
\(^c\)Standardized difference which is equal to the coefficient divided by the standard deviation of the outcome variable.

Patterns were observed in the estimated regression coefficients associated with student covariate (pretest score) across the six models as shown in Table 19. The coefficient values for the pretest were significantly associated with the posttest in
Models 1 through 6 ($p < 0.001$). In addition, all estimated regression coefficients associated with pretest were positive; between 0.46 and 0.51. This means that students who had high score in the pretest were predicted to have high score in the posttest as expected. Due to significant association between pretest and posttest scores, student covariate was controlled to see whether teachers’ scientific inquiry practices are associated with students’ learning in chemistry.

**Multivariate multilevel model**

The results of analysis of the two-level model with predictor variables (Models 1-6) shown in Table 19 revealed that the pretest score was statistically significant and positively related with the posttest score. This was observed in all models. In addition, out of six scientific inquiry practices of teachers, only engaging in questioning was statistically significant and positively related with the posttest score after controlling for the pretest. This was observed in Model 1. These results suggested that the other predictor variables, specifically other inquiry practices, that were not significant such as designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information could not be included in the multivariate analysis. Thus, in this study, these variables were removed from the multivariate model. As a result, only one predictor variable (engaging in questioning) was left at the level 2 model and the pretest score remained as predictor variable at the level 1 model. This resulting model was now exactly the same with Model 1, which was already analyzed. Thus, in this case, performing a multivariate analysis was not necessary since only one predictor variable was found significant at level 2 model.
Engaging in questioning and student posttest score

Based on Table 19, engaging in questioning was the practice of scientific inquiry of teachers that was significantly and positively associated with posttest score in chemistry (coefficient=0.55, \( p < 0.05 \)) after controlling for the student covariate included in the model. Using the standard deviation (SD) of students’ posttest score in the sample, the regression coefficients were transformed into predicted standardized differences through dividing the coefficient by the standard deviation of the outcome variable (posttest scores, SD = 6.83). For example, if an independent variable \( A \) is associated with a regression coefficient \( x \) for predicting the outcome variable \( B \), the standardized regression coefficient is interpreted as the predicted standard deviation change in \( B \) for a one unit increase in \( A \), holding all else constant (O’Dwyer et al., 2015). In this case, for every one point increase in teachers’ engaging in questioning practice, for example, employing this practice more frequently from teaching some lessons to teaching most lessons in chemistry, students’ chemistry scores were predicted to increase by 0.08 standard deviations. Generally, teachers observed in this study used this specific practice of scientific inquiry (engaging in questioning) the most in chemistry classrooms. The specific practices of engaging in questioning implemented by teachers were:

1. Teacher asked students a question about facts not previously presented which elicited students’ own ideas (required short, specific answer).
2. Teacher asked students a question that required them to justify a situation or phenomenon.
3. Teacher prompted students to formulate and ask their own questions.
A more detailed discussion of the relationship between the practice of engaging in questioning and student learning in chemistry is presented in Chapter 7.

**Designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information and student posttest score**

Table 19 shows that the estimated regression coefficients associated with the remaining five practices of scientific inquiry implemented by teachers (Models 2-6) were not significant. Based on a series of observations, the practices of designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information were implemented by teachers, however, most of these practices had low mean implementation in classrooms. Specifically, the practices of designing and conducting investigations, collecting data, analyzing data, and developing explanations were not commonly observed in classrooms. It is possible that the contextual conditions in Philippine classrooms limit the capacity of teachers to implement these kinds of inquiry practices extensively. Teachers were not frequently observed explicitly teaching the concepts or skills related to these practices of scientific inquiry in their classes. This may have been reflected in the results of chemistry posttest. For instance, examining the item characteristics for posttest items on designing and conducting investigations showed that most students did not seem familiar with the concepts or skills related to this inquiry practice. It seems likely that the low percentage of students who selected the correct answer in these items indicates that the practice of designing and conducting investigations implemented in classrooms was not explicitly discussed by teachers with their students. It can be inferred from the following posttest items that most students were not familiar with identifying the right variable for
investigation and selecting a suitable method for an experiment. Items 1 and 2 below show the actual posttest items on designing and conducting investigations.

**Item 1**
Angelo tests the ability of different stoves to boil 2 liters of water in a pot. What is the dependent variable?
- A. temperature of water
- B. time
- C. heat source
- D. pot

**Item 2**
Pablo wanted to compare the energy value of different foods. He burned different food samples for 10 minutes under a test tube containing a fixed amount of water as shown below. He used the increase in water temperature as a measure of the relative energy value. Which of the following variables must be kept the same, to ensure validity of results?
- A. mass of food sample
- B. angle of test tube
- C. type of food tested
- D. final temperature of water

Results of Rasch (1960) analyses of posttest items 1 and 2, presented in the shaded part of Tables 20 and 21, showed that the percentage of students who selected the incorrect response for these items was high; 88% for item 1 and 80% for item 2. Only 12% selected the correct response for item 1 (B. time) and 20% for item 2 (A. mass of food sample). These results may suggest that teachers implemented investigation
activities in chemistry without an explicit discussion of how a fair test with experimental variables is conducted in scientific investigations.

Table 20. Chemistry Posttest Item 1 Statistics

<table>
<thead>
<tr>
<th>Label</th>
<th>Score</th>
<th>Count</th>
<th>% of tot</th>
<th>Pt Bis</th>
<th>t</th>
<th>sig. p</th>
<th>PV1Avg:1</th>
<th>PV1 SD:1</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>276</td>
<td>52.47</td>
<td>-0.14</td>
<td>-3.22</td>
<td>0.001</td>
<td>-0.080</td>
<td>0.630</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>65</td>
<td>12.36</td>
<td>0.09</td>
<td>2.12</td>
<td>0.034</td>
<td>0.210</td>
<td>0.620</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>140</td>
<td>26.62</td>
<td>0.09</td>
<td>2.03</td>
<td>0.043</td>
<td>0.130</td>
<td>0.550</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>45</td>
<td>8.56</td>
<td>0</td>
<td>0.01</td>
<td>0.990</td>
<td>0.010</td>
<td>0.640</td>
</tr>
</tbody>
</table>

Table 21. Chemistry Posttest Item 2 Statistics

<table>
<thead>
<tr>
<th>Label</th>
<th>Score</th>
<th>Count</th>
<th>% of tot</th>
<th>Pt Bis</th>
<th>t</th>
<th>sig. p</th>
<th>PV1Avg:1</th>
<th>PV1 SD:1</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>103</td>
<td>19.58</td>
<td>0.05</td>
<td>1.19</td>
<td>0.233</td>
<td>0.160</td>
<td>0.630</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>56</td>
<td>10.65</td>
<td>0.01</td>
<td>0.31</td>
<td>0.753</td>
<td>0.010</td>
<td>0.700</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>90</td>
<td>17.11</td>
<td>0.01</td>
<td>0.29</td>
<td>0.775</td>
<td>0.070</td>
<td>0.530</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>277</td>
<td>52.66</td>
<td>-0.06</td>
<td>-1.36</td>
<td>0.174</td>
<td>-0.040</td>
<td>0.620</td>
</tr>
</tbody>
</table>

In Tables 20 and 21, the heading Label shows the four response categories in the posttest items. Under the heading Score, zero (0) was the score assigned for incorrect response and one (1) was the score assigned for correct response. The Count shows the number of students who responded with each of the response category. The % of total shows the percentage of students who responded with each of the response categories.

Item 3 below shows another posttest item that asked students to choose a suitable experimental method based on the objective of an investigation. Table 22 indicates that 75% of the students who took this item selected the incorrect response.
More detailed explanations about the relationship of these inquiry practices to student chemistry learning are presented in the next chapter.

**Item 3**
Seawater is mainly sodium chloride (table salt) dissolved in water. If you wish to recover ONLY the salt, which of the following methods will you choose?

A. decantation  
B. distillation  
C. evaporation  
D. filtration

**Table 22. Chemistry Posttest Item 3 Statistics**

<table>
<thead>
<tr>
<th>Label</th>
<th>Score</th>
<th>Count</th>
<th>% of tot</th>
<th>Pt Bis</th>
<th>t</th>
<th>sig. p</th>
<th>PV1Avg:1</th>
<th>PV1SD:1</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>76</td>
<td>14.45</td>
<td>-0.02</td>
<td>-0.37</td>
<td>0.715</td>
<td>-0.040</td>
<td>0.530</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>134</td>
<td>25.48</td>
<td>0.04</td>
<td>0.92</td>
<td>0.358</td>
<td>0.120</td>
<td>0.610</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>200</td>
<td>38.02</td>
<td>0.1</td>
<td>2.35</td>
<td>0.019</td>
<td>0.070</td>
<td>0.670</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>116</td>
<td>22.05</td>
<td>-0.15</td>
<td>-3.44</td>
<td>0.001</td>
<td>-0.130</td>
<td>0.580</td>
</tr>
</tbody>
</table>

Table 23 shows the percentage of variance explained (within and between classes, and in total) by each practice of scientific inquiry and the student covariate. The student covariate explained 38% of the total variance in scores. Despite being significantly associated with chemistry posttest score, teacher implementation of the practice of engaging in questioning (Model 1) in classrooms explained only a modest percentage of the total variance in students’ gain score after controlling for the covariate in the model (35%). This suggests that the inquiry practice of engaging in questioning may have had only a small impact on student chemistry learning.
Table 23. Variance in Chemistry Posttest Score Explained by Student Covariate and Teachers’ Scientific Inquiry Practices

<table>
<thead>
<tr>
<th></th>
<th>Student Covariate- only Model (Pretest)</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
<th>Model 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Variance explained:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within class</td>
<td>60.04%</td>
<td>59.76%</td>
<td>59.73%</td>
<td>58.81%</td>
<td>59.71%</td>
<td>59.39%</td>
<td>59.89%</td>
</tr>
<tr>
<td>Between class</td>
<td>11.06%</td>
<td>4.51%</td>
<td>12.37%</td>
<td>10.94%</td>
<td>9.42%</td>
<td>11.66%</td>
<td>6.31%</td>
</tr>
<tr>
<td>Total§</td>
<td>38.13%</td>
<td>35.04%</td>
<td>38.54%</td>
<td>37.39%</td>
<td>37.21%</td>
<td>38.03%</td>
<td>35.91%</td>
</tr>
</tbody>
</table>

Note. Q=engaging in questioning; DI=designing and conducting investigations; CD=collecting data; AD=analyzing data; DE=developing explanations; CI=communicating information

§The total variance is the percentage of the sum of explained variance in within and between classes and the sum of variance available in within and between classes.

Chapter Summary

The student pretest score in chemistry had a strong negative relationship with gain score. Because of this, the pretest was controlled using the one-way analysis of covariance (ANCOVA) to determine the adjusted mean gain score in chemistry of each class. After controlling the influence of pretest on gain score, Teacher F’s class obtained the highest gain in chemistry while Teacher J’s class had the lowest gain score.

Using the Mplus 7.4 version software (Muthén & Muthén, 2016), multilevel analysis was conducted to determine the relationship between each specific practice of scientific inquiry of teachers and student learning in chemistry. The first model in the analysis was the two-level unconditional regression model, which consists only of posttest score and no predictors. This model gave an intraclass correlation coefficient (ICC) of 0.45. This indicates that around 45% of the variance in students’ posttest score was explained by class level. This value of ICC justified the requirement of multilevel modeling that ICC should be greater than 0.05 (Muthén & Satorra, 1995; Zhang & Lee,
In the second model, the pretest score was controlled in the multilevel modeling of the relationship between teachers’ inquiry practices and students’ posttest score. Six models were created because each specific practice of inquiry enacted by teachers was tested separately. The third model, the multivariate multilevel model, was also considered in the analysis.

The results of multilevel analysis showed that the specific practice of scientific inquiry that was significantly and positively associated with posttest score (coefficient=0.55, \( p < 0.05 \)) after controlling for the pretest was engaging in questioning. Conversely, the estimated regression coefficients associated with the practices of designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information implemented by teachers were not significant. The variables that were not significant were removed from the multivariate multilevel model. As a result, only one significant variable remained at the level 2 model. Because of this, performing multivariate analysis was not necessary.
Chapter 7: Conclusions and Implications

This chapter is divided into four parts. The first part reviews the research questions for the study. The second part discusses the results and addresses the research questions. The third part presents the implications of the study. The fourth part presents the limitations of the study.

A Review of the Research Questions of the Study

Several studies have suggested that inquiry-based teaching can lead to greater student achievement in science (Fogleman et al., 2011; Jiang & McComas, 2015; Minner et al., 2010; Mupira & Ramnarain, 2018; Sadeh & Zion, 2009; Tuan et al., 2005; Wilson et al., 2010; Wu & Hsieh, 2006). However, little emphasis had been placed on investigating which specific practices of inquiry-based teaching can lead to greater achievement (Minner & DeLisi, 2012). Because of this, a need for a fine-grained research on the impact of specific inquiry practices to student learning in science was identified in this study. This is important to identify which practices of inquiry teaching has the potential to improve student learning since scientific inquiry has been increasingly used as a teaching approach and as one of the essential features of curriculum documents in pre-tertiary science education worldwide. Furthermore, the overwhelming majority of research on scientific inquiry and its relationship with student learning to date has been conducted in developed countries. It is not yet known whether and how teaching through scientific inquiry, which is advocated by most developed countries, translates to less developed countries and if it is able to positively impact on student learning in these contexts.
With these reasons, this study was conducted to investigate the inquiry-based teaching practices of sample teachers from a less developed country, the Philippines, as they implemented the new Grade 7 chemistry curriculum and how these practices, as promoted by the new curriculum, have impacted student learning in chemistry. Specifically, this study addressed the following research questions:

1. How have teachers implemented inquiry teaching in Philippine junior high school chemistry classrooms? Which specific practices of teachers in junior high school chemistry classrooms exhibited components of scientific inquiry? To what extent are these practices translated to Philippine junior high school chemistry classrooms observed in this study?

2. What is the relationship between the practices of scientific inquiry implemented by teachers (engaging in questioning, designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information) and students’ learning in chemistry?

**Key Findings and Conclusions**

This study has made several contributions to our knowledge in this field. It has provided a critical understanding of teachers’ way of implementing scientific inquiry as a teaching approach in the challenging teaching and learning environments. It has provided an evidence-based documentation of specific practices of scientific inquiry implemented by teachers in teaching chemistry in less developed country. This study has also examined how the specific inquiry practices impacted on student learning, and has shown the potential of a specific practice of scientific inquiry (engaging in
questioning) implemented by teachers to enhance student learning in chemistry. In addition, this study has made a contribution to our knowledge through the rigorous development of a validated instrument, the Scientific Inquiry Teaching Observation Instrument (SITOI), for the observational measurement of specific scientific inquiry teaching practices in the classroom that will contribute to further and more nuanced research in the field. Detailed discussions are presented below.

Towards an understanding of teachers’ implementation of inquiry in the challenging teaching and learning environments

Teachers may tend to prioritize certain practices of inquiry more than others in chemistry teaching

In Chapter 3, a review of inquiry-based instructional models and inquiry-based science curriculum documents showed that there is no fixed approach to inquiry teaching; however, there were commonalities in the following six major components of scientific inquiry that are likely useful in classroom teaching: engaging in questioning, designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information. In this study, each teacher implemented some of these components of inquiry more frequently than others in teaching Grade 7 chemistry. This finding supports the outcome of a study by Kang et al. (2008) who reported that sample teachers in the U.S. placed more emphasis on some of the essential features of classroom inquiry than others. Specifically, they reported that teachers consistently implemented the features of giving priority to evidence, and formulating explanations based on evidence in teaching science, than of engaging in scientifically oriented questions. However, in the present study, teachers seemed to prioritize the
implementation of two components of scientific inquiry in chemistry teaching: engaging in questioning and communicating information. Based on classroom observations conducted in the sample schools in the National Capital Region of the Philippines, most teachers used non-experimental activities which provided them with opportunities to implement teaching practices related to engaging in questioning and communicating information. Generally, teachers implemented these activities without requiring them to use special facilities or many resources.

For engaging in questioning, the most frequently used practice of teachers was asking questions that elicited students’ own ideas about the lesson, which may stimulate and expand their thinking. This differs from the work of Keys and Kennedy (1999), who found that contextual-based questions from science activities were usually explored in class. However, the present study confirmed the findings of ACTRC (2014) particularly on the questioning component of inquiry. When the researchers of ACTRC investigated the delivery of scientific inquiry skills specified in the new Grade 8 science curriculum in the Philippines, they found that classroom teachers frequently asked questions about the content of the lesson, and to some extent, about the inquiry process involved in the lesson, which was also observed in this study.

For communicating information, the most commonly used practice of teachers was allowing students to report the results of chemistry activities through presentations in class. Although students in this practice were actively involved in the planning and delivery of presentation of results to the class, it was observed that an authoritative way of communication seemed to be more strongly manifested in most chemistry classrooms rather than a dialogic way of communication. According to Treagust and Tsui (2014), in science teaching, it is important for a teacher to shift from authoritative to dialogic ways.
of communication through discursive moves and turns of utterances like teachers’ or students’ questions, answers, comments or suggestions. This is because using a dialogic way of communication in the classroom is thought to help students become more enthusiastically involved and to learn well (Mercer & Howe, 2012). Dialogic ways of communication in science through scientific discourse can promote inquiry in the classroom (Quigley, Marshall, Deaton, Cook, & Padilla, 2011). However, dialogic communication was not commonly seen in the classrooms observed in this study. One recommendation arising from this finding is that science teachers may need to be explicitly trained to implement dialogic way of communication in inquiry teaching. It can be important for them to be more open in practicing dialogues with students as part of their inquiry teaching, which may promote learning.

Generally, teachers observed in this study seemed to give less priority to using teaching practices related to designing and conducting investigations, collecting data, analyzing data, and developing explanations. This is supported by the findings of ACTRC (2014) that teaching practices related to these inquiry components such as the use of scientific instruments, the tabulation of results, and the testing of variables, were seldom seen in classrooms. It can be argued that the context of the teaching and learning environment (e.g., class size, availability of facilities and resources) observed in this study is a contributing factor for most teachers to decide to give less priority to these inquiry practices. Detailed discussions of this can be found in the next section. In looking from another perspective, a scientific culture may not be well-established yet in pre-tertiary science education in the Philippines. Thus, the teachers observed in this study may not be culturally attuned to these inquiry practices. In this case, traditional practices in the science classroom may still exist, which according to Williams (1973)
can result in teaching traditions in schools that are difficult to change. He argued that teaching traditions in the classroom are difficult to change, even if modifications are made in curriculum documents. In this case, most of the aspects of the nature of scientific inquiry for pre-tertiary science education suggested by Schwartz et al. (2008) and Lederman et al. (2014) in Chapter 3 (e.g., scientific data are not the same as scientific evidence; multiple methods of scientific investigation; inquiry procedures can influence results) were not explicitly delivered in chemistry classrooms.

It is acknowledged that the implementation of inquiry-based teaching involved a broad array of approaches and needed the support of facilities and resources, but it may be important for teachers to consider implementing a broad range of scientific inquiry processes so that students know how scientific knowledge is generated. If a teacher is focusing only on implementing some practices of inquiry in classrooms, other important aspects of scientific inquiry may be missed, and the necessary understanding about the nature of scientific inquiry may not be achieved by the students.

**Teachers may shift from inquiry to another teaching approach depending on school and classroom contexts**

In this study, teachers were observed using inquiry practices but at some point their implementation was not sustained in their teaching. Teachers tended to shift to a traditional teaching approach even if the lessons required an inquiry-based approach. There are many reasons that could explain this situation. The SEI-DOST & UP NISMED (2011a) reported that the lack of content and pedagogical skills suitable for science teaching was the reason why many Filipino teachers turned to a traditional teaching approach instead of using inquiry. However, this reason was not supported by
this study since most of the teachers were observed to be knowledgeable about the subject matter. It is important to note that most of them were science majors, with extensive learning of science content and concepts in college. In addition, most of them had extensive experience in science teaching and had the potential to use inquiry in classrooms. The present study offered an explanation in the aspect of school and classroom contexts, which could be a deciding factor in teachers’ implementation of inquiry in classrooms. This supports the findings of a study by Ramnarain (2016) when he argued that teachers’ implementation of inquiry in rural schools in South Africa was inextricably context-dependent, and interacted with a number of factors such as school culture and governance. For this study, some features of the school and classroom environment may have significantly constrained the implementation of inquiry practices by the teachers working in the Philippines. The findings highlight the problems in assuming that pedagogical practices that have been found to be successful in more developed countries can and will translate easily to countries in which the context and resourcing are fundamentally different.

Based on observations, Teacher J implemented the inquiry practices related to conducting investigation and communicating information. However, an inquiry approach to teaching was not sustained in his class. He shifted from using inquiry to using a traditional lecture to deliver the lesson. The traditional lecture approach may be a more convenient way to deliver the lesson in his class since he had a big group of students (55 students), rather than conducting inquiry activities. In addition, the lack of available space and resources in the school may have discouraged him from using chemistry investigation activities in his teaching; instead, he used a traditional lecturing format even if the lesson was intended to be inquiry-based. The lack of spacious rooms
for inquiry activities was also observed by the ACTRC researchers when they explored the implementation of the new science curriculum in the Philippines (ACTRC, 2014). Furthermore, the findings of other researchers (e.g., Davis, 2003; Kang & Keinonen, 2016; Kim et al., 2010) that class size and school resources could influence teachers’ use of inquiry practices in classrooms was supported by this study.

Aside from the class size, school facilities and resources, another factor that may influence teachers’ implementation of inquiry practices could be the academic ability of students in a class. Teacher B was observed teaching the same lesson in her two chemistry classes. In class 2, she engaged students in collecting data practices through demonstration activities. In class 1, she used a traditional lecture format. This raises the question of why Teacher B used different approaches in delivering the same lesson in two classes. Class 1 was the top Grade 7 class composed of students of similar ability. In this case, a traditional lecture format may facilitate the lesson with academically able students. By contrast, class 2 was composed of students with a wide range of ability levels, most of whom were not as academically able as students in class 1. Teacher B used demonstration in this class to explicitly discuss the lesson, which may support and help students understand the lesson easily. This observation suggests that teachers may take students’ learning ability into consideration when deciding whether to use inquiry in the classroom, although there is a need for further research in this area. This finding aligns with the work of Wang et al. (2014) who found that the learning abilities of students was a factor that affected teachers’ implementation of inquiry instruction in vocational schools in Taiwan.

Moreover, considerations of how to efficiently cover the content of the curriculum could be another factor in the implementation of scientific inquiry practices
in classrooms. For example, Teacher I taught the same lesson in her two chemistry classes. In class 1, she asked her students to perform a group activity which required them to communicate results through presentations. In class 2, she discussed the activity using traditional lecture without asking students for presentation of results. It was observed that in class 2, Teacher I was not on track in teaching the lessons specified in the curriculum and traditional lecture may be the faster way to cover the remaining content of the curriculum. This finding confirmed Gutierez’s (2015) claim that, although the new science curriculum is inquiry-based, teachers observed in the Philippines tended to use traditional didactic approaches so as to deliver all mandated content. According to Saad and BouJaoude (2012) the importance of efficiency in covering the content of the curriculum had a powerful influence on impeding inquiry practices of teachers in the classroom. This was observed in this study.

This study showed that the implementation of inquiry in classrooms could depend on the features of school and classroom environment such as class size, student learning abilities, covering curriculum content, and availability of facilities and resources. It can be inferred that if these features were problematic they could become barriers to implementing inquiry in classrooms, which may cause teachers to rely on more traditional teaching approaches. This was evident in the cases of the aforementioned teachers. This study showed that the school and classroom contexts affect the capacity of teachers to implement reform-based teaching practices developed in first-world countries (e.g., inquiry-based practices) to other settings. This suggests that inquiry-based teaching practices are more challenging for teachers to translate effectively in the classrooms of less developed countries where the contexts and resources are not as good as in developed countries. Because of this, teachers in less
developed countries may shift from inquiry to traditional approach, or they may tend to implement selected inquiry teaching practices that can fit in to their classroom contexts. This study supported the report of Lim and Prudente (2013) and Sanosa (2013) that the insufficiency of resources and school facilities was one of the factors that affected Filipino teachers in implementing the curriculum the way it was intended to be implemented in the classroom. This study also confirmed the claim of Hume and Coll (2010) and Sherin and Drake (2009) that curriculum misalignment is usually observed during periods of major reform, which is the case of Philippine basic education.

**Teachers may implement inquiry in classrooms with scarce resources using improvisation.**

A review of studies on implementation of inquiry in pre-tertiary science education presented in Chapter 1 reported that one of the barriers to implementing inquiry in classrooms was the lack of resources and facilities (e.g., Davis, 2003; Kang & Keinonen, 2016). This barrier was also observed in the present study. However, some teachers observed in this study, specifically Teachers F and I, showed that to some extent they could still manage to implement inquiry-based teaching practices in their classrooms even if there was a scarcity of science teaching materials and facilities in their schools. How did these teachers implement inquiry while facing the challenges of limited school resources and facilities? This study uncovered a potential solution, which may address this challenge and may support teachers in implementing inquiry in their classrooms.

**Improvisation of instructional materials.** In this study, creative approaches by some teachers in spite of limited resources allowed for the implementation of scientific
inquiry practices. Improvisation of scientific equipment using locally available resources was observed in this study as a means to teach an inquiry-based lesson in chemistry. Based on classroom observation, Teacher I constructed an improvised electrolysis apparatus since the expensive chemistry laboratory equipment and glassware, which are normally used to set up the standard electrolysis apparatus, were not available in her school. Teacher I constructed the improvised electrolysis apparatus using common materials like plastic bottles, plastic syringes, plastic straws, paper clips, and dry cells. The improvised apparatus was used by Teacher I to deliver the lesson and to engage her students in inquiry activities. She allowed her students to carry out an experiment on electrolysis of water using this apparatus to investigate how water decomposed into its elemental components. This scenario suggests a potential solution for the lack of laboratory equipment in schools. Moreover, Teacher F used readily available household materials as substitutes for imported chemicals and scientific materials in teaching chemistry investigation. Based on observation, Teacher F and her students brought locally available resources to use for chemistry activities since their school had inadequate resources and no laboratory. For instance, she used salt, sugar, and water to demonstrate the types of Solutions. Furthermore, since pH meters and litmus paper were not available in school, Teacher I prepared an acid-base indicator using eggplant for students to use in their investigation.

In the foregoing practices of improvisation, cheap locally available materials were used to teach the concepts in chemistry through inquiry teaching. These practices of improvisation are important particularly in schools with insufficient resources, which may not have sufficient funds to provide for producing costly scientific materials and equipment needed for inquiry-based science teaching. In a situation like this,
improvisation of instructional materials could be an alternative solution. The teaching and learning of science without depending too much on the use of imported scientific equipment and materials from Western countries was proven effective in developing countries like Kenya and Nigeria through the practice of improvisation in science teaching (DomNwachukwu & DomNwachukwu, 2006; Ndirangu, Kathuri, & Mungai, 2003). For the present study, the observed improvisation in the Philippine classrooms provided a way for implementation of inquiry in the absence of standard scientific equipment and materials. This is supported by Poppe, Markic, and Eilks (2010) who reported that locally available resources can be used for creative inquiry activities. If policymakers wish to implement inquiry practices in developing countries, it will be important for curriculum developers in these countries to include sections in science teaching documents that can offer advice or procedures on how to make improvised instructional materials using locally available resources for a particular inquiry-based lesson. With this type of support, teachers may be able to make inquiry teaching happen in their classrooms through improvisation.

*Teachers’ implementation of inquiry may be supported by inquiry-based professional development (PD) programs*

In this study, teachers who implemented more inquiry teaching practices in classrooms had previously attended an intensive week-long national training for the new science curriculum. These teachers, specifically Teachers F, G, E, C, and H, were located in the upper left quadrant of the inquiry continuum (Figure 11) presented in Chapter 5. The intensive week-long national training is an inquiry-based professional development (PD) program for science teachers conducted by DepEd in cooperation
with UP NISMED, which focused on the implementation of the new inquiry-based science curriculum for basic education in the Philippines. One of the salient features of the inquiry-based PD was the emphasis on how to implement the new curriculum in their classrooms using scientific inquiry. Teachers who attended the national training program were introduced to inquiry-based classroom activities, inquiry-based teaching approaches, and assessment procedures specifically designed for pre-tertiary science education. By contrast, teachers with fewer inquiry teaching practices, located in the lower left quadrant of inquiry continuum (e.g., Teacher J), did not attend the national training program. This suggests that the intensive week-long national training program conducted by DepEd may have helped those teachers in the upper left quadrant to become familiar with the implementation of inquiry-based science curriculum. Based on this finding, this study does not support the claims of other studies conducted in the Philippines (e.g., Montebon, 2014; SEI-DOST & UP NISMED, 2011a) that an inquiry-based PD program was deemed not effective in promoting the effective implementation of inquiry-based teaching in classrooms. Research studies have proven that a relatively short, yet intensive and well-designed PD program that models inquiry-based practices and provides teachers with opportunities to experience scientific inquiry aligned with school content objectives can effectively enhance teachers’ capacities to implement inquiry in the classroom (Capps & Crawford, 2013; Kazempour, 2009).

According to Ramnarain (2014), if inquiry is to be implemented in the science classroom, teachers will need to be adept at doing the processes of scientific inquiry so that they can guide their students in performing inquiry in the classroom. In this case, inquiry-based PD may be a promising approach to support teachers in carrying out scientific inquiry. It can be important for inquiry-based PD, especially for teachers in
less developed countries, to include information about improvisation in science teaching and to provide teachers with opportunities to share ideas on innovative ways to improvise when resources are scarce or unavailable. This may help teachers to learn the practice of improvisation to implement inquiry in classrooms with problems in resources. Inquiry-based PD may also need to include opportunities for teachers in less developed countries to discuss ways of implementing inquiry in large classes. It is recognized that inquiry-based teaching is a complex and sophisticated way of teaching, thus this approach demands significant PD and specifically an inquiry-based PD program (Crawford, 2000, 2007). According to Capps and Crawford (2013), without inquiry-based PD support it is unlikely that teachers will be successful in enacting inquiry-based instruction. This is also in line with the findings of Fitzgerald et al. (2017) who argued that the lack of professional development experiences for teachers is one of the barriers to effective implementation of inquiry in science classrooms.

Towards an understanding of the relationship between the specific practices of scientific inquiry implemented by teachers and student learning

Engaging in questioning and student learning in chemistry

In looking at whether teachers’ implementation of each of the six scientific inquiry practices in teaching chemistry was related to student learning, engaging in questioning was the only practice that showed a positive relationship with student learning. In this study, engaging in questioning, which is the inquiry practice with the highest percentage of implementation by teachers, seemed to have the potential to promote chemistry learning of Grade 7 students. Researchers who conducted a meta-analysis of research studies in the United States published from 1980 to 2004 on the
effect of specific science teaching strategies on student achievement reported that teacher questioning strategies exhibited a significant positive influence on students’ achievement in science (Schroeder, Scott, Tolson, Huang, & Lee, 2007). They reported that the effect size of teacher questioning strategies was 0.74, which was close to the upper-effect size benchmark value of 0.84. Notably, Hattie (2003) also found that teacher questioning was one of the stronger positive influences on student learning when he rank-ordered average effect sizes of commonly studied influences on student learning. In this study, the inquiry component engaging in questioning was interpreted as the questioning practices of teachers that encourage students to verbalize their ideas, expand their thinking, and ask scientific questions for investigations, which could be teacher-centered or student-centered.

*Teachers’ specific practices of engaging in questioning observed in the classroom.* The practices of engaging in questioning implemented by most teachers were asking questions that elicited students’ own ideas and asking questions that required students to make justifications. When teachers engaged their students in these type of questioning practices in chemistry, they provided their students with the opportunity to actively participate in thought-provoking tasks mediated by their questioning practices, which may help enhance students’ conceptual understanding. This was evident in Teacher F’s class where the students were frequently engaged in these types of questioning practices and had the highest achievement in chemistry. Chin (2006) argued that engaging students with teacher questioning that elicits, probes, and extends students’ thinking in science could provide cognitive scaffolding for students that guides them towards successively higher levels of learning. However, there was also some teachers in this study who implemented engaging in questioning practices
that were fairly superficial initiation, response, evaluation questioning, rather than the type of deeper questioning that builds conceptual knowledge.

In addition, some teachers observed in this study gave their students the opportunity to think and ask their own questions in chemistry. This practice of engaging in questioning could create a learning environment where the students could freely and comfortably ask questions about the lessons. This learning environment may encourage students to know more about chemistry, which may help them learn the subject. This supported the research of Chin and Osborne (2008) on student questioning in secondary school classrooms. They argued that students developing and asking their own questions is “a first step towards filling their knowledge gaps and resolving puzzlements…to articulate their current understanding of a topic, to make connections with other ideas, and also to become aware of what they do or do not know” (p. 2). In addition, Osborne (2014) argued that as students become immersed in scientific inquiry particularly asking questions, they begin to understand the importance of the driving question to any scientific research, they ask questions about what they observe, and they refine their notion of what makes a good scientific question. The findings of the current study support earlier research that claimed it was important that teachers should teach and encourage students to develop and ask good questions in science.

Furthermore, Chin and Osborne (2008) argued in their literature review that teachers can explicitly teach students questioning skills to improve their performance in science-related tasks such as formulating research questions for projects and asking higher-level questions. Encouraging students to formulate and ask good questions is a crucial teacher practice (Treagust & Tsui, 2014), particularly in inquiry-based science teaching. It could help students to better construct their own knowledge, develop their
interest and motivation, monitor their understanding, and argue (Chin & Osborne, 2010; Treagust & Tsui, 2014). In this study, teachers engaging in questioning practices in inquiry-based chemistry teaching encouraged students to verbalize their ideas, and scaffold and expand their thinking, and guide students toward conceptual and skills development by encouraging them to ask questions. According to Chin (2007), these types of questioning practices were employed in classrooms “to coach students along guided paths towards the construction of canonical scientific knowledge” (p. 837). Most of these types of questioning practices were observed in classrooms of Teachers F, I (class 1), and B (class 1) where their students achieved high gain scores in chemistry. It can be inferred that these types of questioning practices may have helped these students to build their knowledge in chemistry by enhancing their understanding of the concepts. With this, the aforementioned argument of Chin (2007) is supported by the present study.

**Designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information and student learning in chemistry**

In this study, there was no significant relationship between each of these inquiry practices of teachers: designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information, and learning in chemistry of Grade 7 students. In looking at the results of other studies, Zuzovsky (2013) reported similar findings, indicating that despite the advocacy for an inquiry-oriented student-centered modes of instruction, such as planning and conducting experiments, making observations, and working on experiments in small groups, the regression coefficients of such practices were small and in most cases statistically
insignificant. She also found that the frequent implementation of practices in experimentation such as designing or planning experiments, collecting data, and analyzing data were negatively associated with learning outcomes in low-achieving countries but positively associated with learning outcomes in high-achieving and medium-achieving countries. The data for Zuzovsky’s study were obtained from the TIMSS 2007 database, which provided the achievement scores in science. It is important to note that the Philippines did not participate in the TIMSS 2007. In other studies, practices such as planning experiments, making observations, collecting data, analyzing data, and making inferences were also found to have no impact or negative impact on student learning (e.g., Areepattamannil, 2012; Pine et al., 2006).

However, the relatively low frequency of these practices in this study may have influenced the results. Although these practices were implemented in classrooms, most of these practices, and particularly the practices of designing and conducting investigations, collecting data, analyzing data, and developing explanations, were very infrequently observed. Specifically, the explicit teaching of the skills related to these inquiry practices was infrequently observed. For instance, teachers implemented the practice of designing and conducting investigations in teaching chemistry; however, they seemed not to give emphasis to teaching the use of variables in investigation. This is more likely to be due to the lack of detailed information in the new Grade 7 chemistry curriculum guide on how to teach the skills related to these inquiry practices in the lessons outlined in the curriculum. This is in line with the findings of ACTRC (2014) that the skills for these inquiry practices in the Philippines’ new science curriculum guide were less well represented in the Grade Level Standards (K, Grade 1, Grade 2, etc.) and sparsely represented in some parts of the learning competencies for the
different science units at the grade levels (e.g., Living Things and the Environment, Grade 8). ACTRC found that as the new science curriculum becomes more detailed, the specific skills required for scientific inquiry can become less apparent. With this, teachers observed in this study may experience uncertainty in implementing the aforementioned inquiry practices in teaching a particular lesson, which may not give students the opportunity to maximize their learning of the skills related to these inquiry practices in chemistry. It may be that substantial information on how to deliver the skills related to these inquiry practices in every inquiry-based lesson should be included in science curriculum documents for basic education as this may encourage classroom teachers to implement these practices, which may offer students a better exposure to learning science through these inquiry practices. It can be argued that it is not enough to develop inquiry-based activities for every lesson and include that in the curriculum documents, but it is also important to include background information on the practices of scientific inquiry and the related skills involved in the lesson and how to deliver these in classrooms as this may also give teachers the confidence to use these practices of inquiry more frequently in teaching inquiry-based lessons with their students.

In addition, at the time this study was conducted, teachers may still be adjusting to the way science should be taught in classrooms—via inquiry-based teaching, as promoted by the new chemistry curriculum, where the implementation of varied practices of scientific inquiry (e.g., conducting investigations, collecting data), not only the practice of engaging in questioning, by both teachers and students is necessary. This situation may be challenging for teachers since scientific inquiry was not effectively communicated in the previous science curriculum for basic education in the Philippines. Their implementation of these inquiry practices can be further complicated with the
design of the new science curriculum. The new science curriculum in the Philippines had shifted from a discipline-based approach where only one area of science was studied by students per grade level (e.g., biology for Grade 8, chemistry for Grade 9) to a spiral progression approach where the concepts and skills from four different areas of science (chemistry, biology, physics, and earth and space) are taken by students with increasing complexity per grade level. Because of this reform, science teachers at a particular grade level in most schools are responsible to teach these four areas of science using the new curriculum. This is another major adjustment for teachers in their science teaching (ACTRC, 2014). Thus, effective implementation of an inquiry-based approach in the classroom was coupled with many challenges facing teachers as discussed in the earlier part of this chapter. With this, it can be inferred that most students involved in this study may have not been properly or extensively exposed to varied practices of scientific inquiry (e.g., designing and conducting investigations, collecting data, analyzing data), which may cause students to miss relevant understandings and skills related to these inquiry practices in chemistry. Based on this finding, it is crucial for education administrators to provide robust support for teachers to enact the practices of scientific inquiry in classrooms and the spiral curriculum through creating a continuing PD program that mainly focuses on implementing varied practices of scientific inquiry in science teaching and on discussing the spiral curriculum. More details about inquiry-focused PD are discussed in the next part of this chapter.

Although the practices of designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information had no statistically significant influence on student learning, they may be helpful for improving
other student characteristics (e.g., attitude towards science, creativity in science).

However, this aspect needs further investigations. This study showed that there were specific practices of scientific inquiry used in classroom teaching that had no impact on Grade 7 students’ chemistry achievement. With this, the aforementioned arguments of the studies mentioned earlier (e.g., Areepattamannil, 2012; Pine et al., 2006; Zuzovsky, 2013) are supported by the present study.

**Towards a fine-grained assessment of inquiry-based instruction in the science classroom**

In this study, a validated observational instrument for assessing specific inquiry teaching practices of teachers in the science classroom was created. This instrument is the *Scientific Inquiry Teaching Observation Instrument (SITOI)*. The SITOI is directly aligned with the process of scientific inquiry as it contains specific teaching indicators, ranging from teacher-centered to student-centered, related to the six practices of scientific inquiry—engaging in questioning, designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information. Since there is a lack of observational instrument specifically designed to assess the specific inquiry practices of teachers, the development of the SITOI would be beneficial for the science education community to capture the granular view of inquiry-based instruction of teachers in the science classroom as evident in this study. This allowed a more fine-grained examination of the relationship between specific practices of inquiry and student learning in order to identify which specific inquiry practice has significant impact on learning. As shown in this study, the SITOI also provided a more detailed understanding of the nature of inquiry practices implemented in the classroom,
which may help educators and researchers to determine the quality of inquiry-based instruction in the science classroom.

**Implications of the Study**

There are a number of implications flowing from this study, which will be addressed under the following four headings: implications for education administrators, implications for science curriculum development, implications for inquiry-based science teaching, and implications for further research.

**Implications for education administrators**

Scientific inquiry as a teaching approach is advocated by science education reform movements in different parts of the world (Abd-El-Khalick et al., 2004; Heinz et al., 2017; Mumba et al., 2007; Xie et al., 2014). However, these reforms do not guarantee teachers will teach new curriculum documents using scientific inquiry. This study showed that most teachers who enacted scientific inquiry in chemistry classrooms had previously attended an inquiry-based PD program. With this, a school-based continuing PD program that is inquiry-focused and that can offer potential solutions to the challenges of implementing inquiry reform documents (e.g., lack of resources and facilities, large classes) may be a promising approach and needed to establish in order to support teachers to enact the reform documents as intended. In this case, it may be helpful to develop a framework for an inquiry-focused PD, which can guide schools and teacher training institutions in conducting an inquiry-focused PD program to help teachers implement inquiry in classrooms. It can be inferred from the findings of this
study that a framework for an inquiry-focused PD may include these two characteristics:

1. **Incorporating improvisation into PD programs for science teachers.**

   Allowing teachers to develop improvised science teaching materials or equipment may not be usually seen in a PD program. However, in this study, some teachers used improvised equipment and locally available materials as substitutes for scientific equipment and glassware to implement inquiry teaching despite the lack of facilities and resources. With this, improvisation in science teaching may be worth including in the framework of inquiry-focused PD for teachers, as this could be a viable solution for the problem of limited teaching resources and equipment in schools to make inquiry teaching possible in the classroom. The inclusion of improvisation into the features of inquiry-focused PD may help develop teachers’ improvisation skills, which is also important to address the challenges of teaching resources especially in rural schools where scientific equipment and materials are not always available.

2. **Supporting teachers in performing and learning about scientific inquiry.**

   Allowing teachers to perform scientific experiments during the PD program may help them become familiar with the entirety of scientific inquiry practices and train them in proper teaching of these practices in the classroom. This may also help teachers to be more confident in incorporating other practices of inquiry into their teaching of science. In addition to performing scientific experiments, it is important for teachers to learn the aspects of scientific inquiry (e.g. Lederman et al., 2014; Schwartz et al., 2008), and these aspects should be discussed with them explicitly during the PD program so that they will be able to know the fundamental understanding about inquiry. These aspects are important since they may serve as a foundation to properly conducting scientific
inquiry. Thus, it is also important for teachers to explicitly discuss these aspects with their students.

The inquiry-focused PD framework may be a crucial component in a pre-tertiary science education community especially now that many schools are advocating inquiry-based science curriculum. This type of PD framework can be developed in accordance with school context and governance, and in collaboration with science education specialists and practicing scientists to capture the essence of scientific inquiry for science teaching. Thus, it is important for education officials or school administrators to be active in providing robust support in developing this kind of PD framework and in creating means to provide substantial resources for teachers to implement the reform documents the way they are intended to be implemented.

**Implications for science curriculum development**

This study showed that the practice of engaging in questioning in inquiry teaching had a positive relationship with student learning. It is acknowledged that in inquiry teaching teachers need to know how to ask good questions effectively. However, it can be argued that in inquiry teaching it is also important that teachers know how to engage their students in scientific questioning as this may start to develop students’ scientific thinking and may encourage them to do investigation or research, which may lead to further learning. With this, it is important for curriculum designers to explicitly incorporate into the inquiry-based science documents the possible approaches of how teachers can effectively teach students questioning skills such as how to develop researchable questions for investigations or how to ask good scientific questions. This may help teachers to be more productive in employing the practice of soliciting
questions from their students and at the same time may help students to stimulate their thinking and understanding about the lesson.

Furthermore, the entirety of scientific inquiry process may be important to consider in implementing an inquiry-based science curriculum. This means that aside from focusing on one or two inquiry practices in teaching, teachers may also need to consider other practices of inquiry that are appropriate in their lessons. Although the practices of designing and conducting investigations, collecting data, analyzing data, developing explanations, and communicating information showed no statistically significant influence on student achievement, they may have benefits to other student characteristics. With this, student skills for each of these inquiry practices that are appropriate to the grade level and the possible approaches to deliver these skills may also need to be explicitly incorporated into the curriculum so that teachers understand how they will implement these inquiry practices in classrooms. In addition, it may be helpful to specify in the curriculum documents the available improvised materials or equipment necessary to teach a particular lesson so that teachers will have an alternative solution for implementing inquiry approach in case resources are not available.

**Implications for inquiry-based science teaching**

Inquiry-based science education is commonly associated with an implicit approach to teaching. However, enacting inquiry-based science reform documents in the classroom is not all about implicit teaching where most of the time teachers allow students to discover all information on their own in order for them to learn. It also involves explicit teaching where the teachers can openly discuss and explain to the students the fundamental concepts in science that they need to build a foundation for
learning. It can be inferred from the findings of this study that it is important for teachers to explicitly explain to the students not only the fundamental concepts in chemistry but also the different aspects of scientific inquiry so that they understand the essence of scientific investigation. Learning these aspects of scientific inquiry may help students perform the process of science properly. Focusing too much on an implicit approach to inquiry teaching may cause students to misinterpret or misunderstand the concepts or process and thus may lead to errant learning or misconceptions. With this, it is important for teachers to have a mixture of implicit and explicit approaches to enacting inquiry-based science documents so that efficient teaching and productive learning are more likely to occur.

**Implications for future research**

In this study, a number of scientific inquiry practices showed no significant impact on student achievement. It may be that these practices may have beneficial effects on other student characteristics. Because of this, further explorations on the influence of scientific inquiry practices on other student characteristics such as creativity, critical thinking skills, or scientific disposition are worthwhile to perform. This may provide a broader understanding of how scientific inquiry practices can affect a variety of student outcomes. This study reported that contexts and resources are crucial factors in the implementation of inquiry teaching practices in chemistry classrooms. It provided an evidence-based documentation of specific teacher behaviors in using scientific inquiry as a teaching approach in challenging teaching and learning environments. However, the relationship between classroom contexts and resources and the capacity of teachers to implement inquiry teaching practices was not investigated.
Further research on this aspect may provide empirical evidence on the impact of contexts and resources on teachers’ capacity to implement inquiry teaching practices, which may address anecdotal accounts about this from science educators. In addition, further work on the influence of contexts and resources on the effectiveness of inquiry teaching practices in learning can be undertaken to see what specific features of classroom context or what degree of resourcing are needed for inquiry to be effective in learning.

Limitations of the Study

In this study, only one covariate (student pretest scores) was included in the statistical model to analyze the relationship between teachers’ scientific inquiry practices and students’ chemistry learning. However, other factors associated with schools, teachers, and students (e.g., resources, socioeconomic status, home background, teacher content knowledge, teacher pedagogical content knowledge, college preparation in chemistry) may influence student learning. Future multilevel analyses should include these as covariates to provide a clearer view of the impact of teachers’ scientific inquiry practices on students’ chemistry learning.

This study also used a multilevel modeling approach with a small number of groups or classes to analyze relationships. Replicating the study with a larger number of classes would illuminate further the relationships between the teacher practices of scientific inquiry and student learning, allow for more robust findings, and support generalizability to a broader population.

The analyses of the inter-rater agreement statistics for the validation of items included in the Scientific Inquiry Teaching Observation Instrument (SITOI) were not
conducted in this study. Because only two people were available to conduct observations and the number of joint observations was small, it was not possible to analyze the inter-rater agreement of a small group of observers to determine if the developed items in the instrument were used by the observers with the same interpretation or understanding of the items. Use of a larger number of observers conducting the same number of observations in the future will be necessary to establish the inter-rater agreement statistics of the SITOI.

Finally, the study was conducted in a developing country. It provides insights into the impact of inquiry practices on student learning, but also demonstrates that contextual factors such as lack of classroom space or appropriate laboratory resources may hinder teachers’ implementation of inquiry practices in the science classroom. Further research that utilizes the SITIO in developed countries with smaller class sizes and more extensive resources will support our understanding of whether the findings also apply in these contexts.
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## Appendices

### Appendix A

**Scientific Inquiry Teaching Observation Instrument (SITOI) Version 1**

<table>
<thead>
<tr>
<th>Teacher ID:</th>
<th>Class ID:</th>
<th>Observer:</th>
<th>Date:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start time:</td>
<td>End time:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elements of Science Inquiry</th>
<th>Classroom Practices</th>
<th>Frequency of Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engaging in Questioning</td>
<td>Students are asked to formulate their own investigation questions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Students are asked to formulate hypotheses as part of an investigation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher helps students figure out what will make a good investigation question (e.g. testable, empirical)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher engages students in questioning that leads to explanation, justification, and reasoning</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher engages students in questioning that did not lead to discussion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher explicitly tells the students the questions or hypotheses they will investigate</td>
<td></td>
</tr>
<tr>
<td>Designing and Conducting Investigations</td>
<td>Students are asked to design procedures to investigate research questions, including choosing appropriate variables, techniques, and tools to gather, record, and analyze data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Students are asked to identify treatment and control variables</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher helps students design investigations through discussing with them the role of variables and controls and guidelines to design and conduct investigations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher provides the variables to investigate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher provides/explicitly tells specific procedure to follow in the investigation</td>
<td></td>
</tr>
<tr>
<td>Collecting Data</td>
<td>Students are asked to make accurate measurements using scientific tools and instruments</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Students are asked to use physical models or simulations, and manipulate representations of phenomena to collect data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Students are asked to collect data or explore phenomena outside</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Students are prompted to make descriptive observations from the activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Students are prompted to collect, manipulate, download, or access data from existing scientific databases</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Students are asked to devise and use their own organizational scheme for recording data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to record data on worksheets,</td>
<td></td>
</tr>
</tbody>
</table>
Notebooks, learner modules, workbook with a format prescribed by the teacher

Teacher provides data for students

### Analyzing Data

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students are asked to use mathematics (e.g. graphs) to transform, represent, or interpret data.</td>
<td></td>
</tr>
<tr>
<td>Students are asked to use physical models or simulations, and manipulate representations of phenomena to assist with the analysis and interpretation of data.</td>
<td></td>
</tr>
<tr>
<td>Students are prompted to assess the reliability and/or validity of the knowledge generated in an investigation by critiquing methodological flaws and how well procedures were followed.</td>
<td></td>
</tr>
<tr>
<td>Teacher demonstrates actual phenomena using models to help students analyze and interpret data.</td>
<td></td>
</tr>
<tr>
<td>Teacher explicitly tells students specific direction on how data is to be analyzed.</td>
<td></td>
</tr>
<tr>
<td>Teacher provides data analysis for students.</td>
<td></td>
</tr>
</tbody>
</table>

### Developing Explanations

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students are prompted to build logical arguments about the cause-and-effect relationships between variables.</td>
<td></td>
</tr>
<tr>
<td>Students are asked to examine evidence to develop explanation independently.</td>
<td></td>
</tr>
<tr>
<td>Students are asked to evaluate and revise their explanations in light of alternative explanations posed by the teacher, other students’ investigations, or other sources of existing scientific knowledge.</td>
<td></td>
</tr>
<tr>
<td>Teacher explicitly states specific pieces of evidence and then help students develop explanations.</td>
<td></td>
</tr>
<tr>
<td>Teacher explicitly states specific connections to alternative explanations.</td>
<td></td>
</tr>
<tr>
<td>Teacher explicitly tells the students what to conclude from an investigation.</td>
<td></td>
</tr>
</tbody>
</table>

### Communicating Information

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students are asked to present their experimental designs including hypothesis, variables.</td>
<td></td>
</tr>
<tr>
<td>Students are asked to share investigation results and their own thinking and interpretations about the meaning of those results.</td>
<td></td>
</tr>
<tr>
<td>Students plan presentation, specify content and layout to be used to communicate and justify information.</td>
<td></td>
</tr>
<tr>
<td>Teacher prompts students to respond to each other and encouraging student to student dialogue.</td>
<td></td>
</tr>
<tr>
<td>Teacher explicitly tells the result of an activity without giving the students an opportunity to report their own results.</td>
<td></td>
</tr>
</tbody>
</table>

OBSERVATION NOTES:
## Appendix B

Scientific Inquiry Teaching Observation Instrument (SITOI) Version 2

<table>
<thead>
<tr>
<th>Teacher ID:</th>
<th>Class ID:</th>
<th>No. of students:</th>
<th>Observer:</th>
<th>Start time:</th>
<th>End time:</th>
<th>Date:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elements of Science Inquiry</th>
<th>Classroom Practices</th>
<th>Frequency of Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engaging in Questioning</td>
<td>Teacher asks students a question about facts previously presented (requires short, specific answer)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students a question about facts NOT previously presented which elicit students’ own ideas (requires short, specific answer)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students a question that requires them to explain, reason, or justify a situation or phenomenon</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher prompts students to formulate and ask their own questions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher prompts students to ask their own substantive questions relevant to teacher’s discussion</td>
<td></td>
</tr>
<tr>
<td>Designing and Conducting Investigations</td>
<td>Teacher provides students specific procedure to follow in the activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher identifies the treatment and control variables of an activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to identify the treatment and control variables of an activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to design their own procedures for an activity with teacher assisting by discussing role of variables, controls and design of activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to design their own procedures for an activity with limited help</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to formulate their own objectives/questions for an activity</td>
<td></td>
</tr>
<tr>
<td>Collecting Data</td>
<td>Teacher provides data for students</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher prompts students to make descriptive observations from teacher demonstration</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher prompts students to make descriptive observations from activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to make measurements using scientific tools and equipment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to collect data or explore phenomena outside</td>
<td></td>
</tr>
<tr>
<td>Analyzing Data</td>
<td>Teacher provides data analysis for students</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher tells students specific direction on how data is to be analysed with the aid of models or sample situation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to analyze simple data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to analyze complex data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher prompts students to assess the reliability and/or validity of the results of investigation by critiquing methodological flaws or how well procedures were followed</td>
<td></td>
</tr>
<tr>
<td>Developing Explanations</td>
<td>Teacher gives students the explanation without giving them opportunity to explain</td>
<td></td>
</tr>
<tr>
<td>-------------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher gives students pieces of evidence/information/clue they need to make their own explanation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to form their own explanation or conclusion from results</td>
<td></td>
</tr>
<tr>
<td>Communicating Information</td>
<td>Teacher asks students to write information or data on activity sheets, notebooks, learner modules with a format prescribed by the teacher</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to devise and use their own format of writing information or data with limited help</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to describe illustration, diagram, or graph</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to report out data or results of an individual or group activity to whole class</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to report out data or results of an individual or group activity with teacher-student interaction</td>
<td></td>
</tr>
</tbody>
</table>

OBSERVATION NOTES:


<table>
<thead>
<tr>
<th>Components of Scientific Inquiry</th>
<th>Classroom Practices</th>
<th>Frequency of Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engaging in questioning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher asks a question about facts previously presented</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher asks a question that elicit student own ideas (requires short, specific answer)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher asks a question that requires students to make justification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher prompts students to formulate and ask their own questions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Designing and conducting investigations</td>
<td>Teacher demonstrates how to do the activity</td>
<td></td>
</tr>
<tr>
<td>Teacher provides procedure to follow for students to do the activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher identifies the treatment and control variables for the activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher guided students while conducting the activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher asks students to identify the treatment and control variables for activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher asks students to design their own procedures with teacher assistance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher asks students to design their own procedures for activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher asks students to formulate their own objectives for the activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collecting data</td>
<td>Teacher provides data for students</td>
<td></td>
</tr>
<tr>
<td>Teacher asks students to make observations from teacher demonstration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher asks students to make observations from individual or group activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher asks students to make measurements using tools and equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher asks students to explore phenomena and collect data outside</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analyzing data</td>
<td>Teacher provides analysis for students</td>
<td></td>
</tr>
<tr>
<td>Teacher tells students direction on how data is to be analyzed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher asks students to analyze data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher asks students to analyze complex data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher prompts students to assess the reliability and/or validity of data/results</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developing explanations</td>
<td>Teacher gives the explanation without giving students opportunity to explain results</td>
<td></td>
</tr>
<tr>
<td>-------------------------</td>
<td>----------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher gives the explanation with giving students opportunity to explain but no one can make an explanation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher gives pieces of evidence they need then asks students to form their own explanations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher prompts students to form their own explanations/conclusions from results</td>
<td></td>
</tr>
<tr>
<td>Communicating Information</td>
<td>Teacher asks students to write information using the prescribed format</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to make and use their own format of writing information</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to make and describe diagram, graph or table</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to report out results of activity to whole class</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to report out results of activity with teacher-student interaction</td>
<td></td>
</tr>
</tbody>
</table>

OBSERVATION NOTES:
# Appendix D

Final Version of the Scientific Inquiry Teaching Observation Instrument (SITOI)

<table>
<thead>
<tr>
<th>Components of Scientific Inquiry</th>
<th>Classroom Practices</th>
<th>Frequency of Implementation (Put a tick in each box)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engaging in questioning (Q)</td>
<td>Teacher asks a question about facts previously presented</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks a question that elicit student own ideas (requires short, specific answer)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks a question that requires students to make justification</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher prompts students to formulate and ask their own questions</td>
<td></td>
</tr>
<tr>
<td>Designing and conducting investigations (DI)</td>
<td>Teacher demonstrates how to do the activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher provides procedure to follow for students to do the activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher identifies the treatment and control variables for the activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher guided students while conducting the activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to identify the treatment and control variables for the activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to design their own procedures with teacher assistance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to design their own procedures for the activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to formulate their own objectives for the activity</td>
<td></td>
</tr>
<tr>
<td>Collecting data (CD)</td>
<td>Teacher provides data for students</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to make observations from teacher demonstration</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to make observations from individual or group activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to make measurements using tools and equipment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to explore phenomena and collect data outside</td>
<td></td>
</tr>
<tr>
<td>Analyzing data (AD)</td>
<td>Teacher provides analysis/solution for students</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher tells students direction on how data/problem is to be analyzed/solved</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to analyze/solve data/problems</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to analyze complex data (e.g., secondary data from existing scientific databases)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher prompts students to assess the reliability and/or validity of data/results</td>
<td></td>
</tr>
<tr>
<td>Developing explanations (DE)</td>
<td>Teacher gives the explanation without giving students opportunity to explain results</td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>----------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher gives the explanation with giving students opportunity to explain but no one can make an explanation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher gives pieces of evidence they need then asks students to form their own explanations.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher prompts students to form their own explanations/conclusions from results</td>
<td></td>
</tr>
<tr>
<td>Communicating Information (CI)</td>
<td>Teacher asks students to write information using the prescribed format</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to make and use their own format of writing information</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to make and describe diagram, graph, or table</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teacher asks students to report out results of activity to whole class</td>
<td></td>
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<tr>
<td></td>
<td>Teacher asks students to report out results of activity with teacher-student interaction</td>
<td></td>
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**OBSERVATION NOTES:**
Appendix E

Teacher Questionnaire

School ID ___  Teacher ID ___  Class ID ___  Region ___ (administrator to fill)

Teacher Information

1. Gender:  □ Male  □ Female

2. How many years have you been teaching high school science? ______

3. Before the K to 12 curriculum, which science subject/s were you teaching?
   □ Biology  □ Chemistry  □ Physics  □ Earth Science
   □ General Science  □ Other

4. What was your undergraduate degree? ______________  Major in __________

5. Did you attend the national training for K to 12 Science?  □ Yes  □ No  If yes for grade ______

6. Did you attend any regional training for K to 12 Science?  □ Yes  □ No  If yes for grade ______

7. Do you have a copy of the Grade 7 Science Teacher’s Guide?  □ Yes  □ No  □ Photocopy

8. How confident are you in teaching the content from the new science curriculum?
   □ Not very confident  □ Confident  □ Depends on the topic

Class Information

1. How many students are enrolled in this class? ______

2. How many students usually attend this class? ______

3. Which section/s are you teaching? ______

4. For this class are you teaching… □ The usual curriculum □ A modified or enriched curriculum (regular classes)  (for special science class)

5. Are you using the Learner’s Material to teach this class?
   □ Not at all  □ Sometimes  □ Most of the time  □ All of the time
6. Does each student in this class have a copy of the Learner’s Material?  □ Yes  □ No  □ Photocopy

7. Do you have an appropriate workspace to conduct experiments in this class?  □ Yes  □ No  □ Some-what

8. Do you have the required equipment (e.g. microscope, platform balance) and glassware, graduated cylinders, thermometers, to conduct experiments in this class?  □ Yes  □ No  □ Some-what

9. Do you have a place to store experimental/science materials?  □ Yes  □ No  □ Some-what
Appendix F

Consent Forms and Plain Language Statements

Plain Language Statement for Teachers

I would like to invite your school to participate in a research project entitled Exploring Teachers’ Science Inquiry Practices and Students’ Inquiry Skills. I am undertaking this project as part of my PhD in Education at the Melbourne Graduate School of Education in the University of Melbourne, Australia. This project is a part of the Assessment, Curriculum and Technology Research Centre (ACTRC), a Partnership between the University of the Philippines and the University of Melbourne, supported by Australian Aid. My principal supervisor for this project is Associate Professor Esther Care.

What are the aims of the study?
The research project aims to explore the nature of classroom instruction related to science inquiry of teachers as they implement the new K to 12 science curriculum. It will provide an evidence-based documentation of inquiry-based teaching practices enacted by teachers in science classrooms, specifically in Philippine classrooms. It also provides information on the extent to which these practices are implemented in classrooms and the relationship between the implementation of these practices and the attainment of science inquiry skills.

What will you be asked to do?
If you consent to the research you will be asked to allow researchers to:

- Observe you teaching approximately 6–8 science lessons. The observations will be carried out across two different groups of students (sections) during the 1st quarter of the 2015-2016 school year. You will not be asked to do anything other than what you would normally do in the class. There is no audiotape or videotape involve in observations.
- Collect and analyse teaching materials, including teacher-generated materials, lesson plans, logs or teacher notes, for the 1st quarter.
- Collect and analyse copies of tests and de-identified student results for the students observed which you provide. You will be responsible for removing identification from the student results by replacing student names with codes to ensure confidentiality.

Your decision regarding your participation in the research will not in any way affect your work or the educational experiences of your students and you are free to withdraw from the research at any time.
How will confidentiality be protected?
No student, teacher, or school will be identified as part of this research. The researchers will use procedures in which any documents (classroom observations or materials collected) are identified only by use of codes. Teachers will be asked to remove all forms of identification from the student data prior to handing it to researchers. Those who will subsequently handle the data will do so using only codes. Schools and participants will not be named in any report as a result of this research. The information gathered will not be shared with anybody outside the research team (for example your Department Head or Principal) in any manner which would allow you to be identified.

If you decide to withdraw from the study at any time, or to withdraw unprocessed information that has been collected, you are free to do so. All information will be treated with utmost confidence subject to any legal limitations. It will be kept in secure files at the Assessment, Curriculum and Technology Research Centre of the UP College of Education, subject to guidelines for the management of research data and records and destroyed five years after publication of findings.

How will you receive feedback?
You will be given a copy of the summary of findings on completion of the research. Results of the study will be presented in academic journals and at academic conferences and workshops for science teachers.

This project has the clearance of The University of Melbourne’s Human Research Ethics Committee (HREC project number: 1443218.1). Should you have any concerns about the conduct of the research, contact the Executive Officer, Human Research Ethics, the University of Melbourne, on +61 3 8344 2073 (phone) or +61 3 9347 6739 (fax).

If you have any further questions about the project, please do not hesitate to contact the chief investigator of the study.

Yours sincerely,

Mr Dennis Danipog
PhD Candidate
Melbourne Graduate School of Education
The University of Melbourne
d.danipog@student.unimelb.edu.au
Ph: +61 3 8344 0967
I would like to invite your school to participate in a research project entitled **Exploring Teachers’ Science Inquiry Practices and Students’ Inquiry Skills.** I am undertaking this project as part of my PhD in Education at the Melbourne Graduate School of Education in the University of Melbourne, Australia. This project is a part of the Assessment, Curriculum and Technology Research Centre (ACTRC), a partnership between the University of the Philippines and the University of Melbourne, supported by Australian Aid. My principal supervisor for this project is Associate Professor Esther Care.

**What are the aims of the study?**
The research project aims to explore the nature of classroom instruction related to science inquiry of teachers as they implement the new K to 12 science curriculum. It will provide an evidence-based documentation of inquiry-based teaching practices enacted by teachers in science classrooms, specifically in Philippine classrooms. It also provides information on the extent to which these practices are implemented in classrooms and the relationship between the implementation of these practices and the attainment of science inquiry skills.

**What will you and your school be asked to do?**
If you consent to the research being carried out in your school, you will be asked to:

- Provide researchers with the names of science teachers so they can be invited to participate. Each teacher will have the right to decline to participate in the research.

You also consent to allow researchers to:

- Observe science classes of two teachers. Each teacher participating will be observed for approximately 6-8 lessons across two different classes of students within the 1st quarter of the 2015-2016 school year.
- Collect and analyse teaching materials, including teacher-generated materials, lesson plans, logs or teacher notes, for the 1st quarter.
- Collect and analyse copies of tests and de-identified student results for the students observed which you provide. You will be responsible for removing identification from the student results by replacing student names with codes to ensure confidentiality.

Your decision regarding your school’s participation in the research will not in any way affect the work of your staff or the educational experiences of your students and you are free to withdraw your school from the research at any time.
How will confidentiality be protected?
No student, teacher, or school will be identified as part of this research. The researchers will use procedures in which any documents (classroom observations or materials collected) are identified only by use of codes. Teachers will be asked to remove all forms of identification from the student data prior to handing it to researchers. Those who will subsequently handle the data will do so using only codes. Schools and participants will not be named in any report as a result of this research. The information gathered will not be shared with anybody outside the research team in any manner which would allow any member of your school to be identified.

If you decide to withdraw from the study at any time, or to withdraw unprocessed information that has been collected, you are free to do so. All information will be treated with utmost confidence subject to any legal limitations. It will be kept in secure files at the Assessment, Curriculum and Technology Research Centre of the UP College of Education, subject to guidelines for the management of research data and records and destroyed five years after publication of findings.

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Yours sincerely,

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A Partnership between the University of Melbourne and the University of the Philippines, supported by Australian Aid

HREC Project No: 1443218; Date: 29 April 2015; Version: Principal v2
Consent Form for Teachers

Exploring Teachers’ Science Inquiry Practices and Students’ Inquiry Skills

Name of Teacher: ................................................................................................................

School name: ..................................................................................................................

Name of Investigator: Mr Dennis Danipog

1. I consent to the participation in the above research study, the particulars of which – including details of procedures – have been explained to me in the Plain Language Statement and I have been given a copy of that explanation to keep.

2. I authorize the investigators in the above study to implement the procedures referred to under (1) above (observing classroom instruction, collecting and analyzing teaching materials and copies of tests).

3. I acknowledge that:

(a) the possible uses of the information arising from the study have been explained to me to my satisfaction;

(b) I have been informed that my participation in this research is voluntary, and that I am free to withdraw from the study at any time and to withdraw any unprocessed information that has been supplied;

(c) the study is for the purpose of research and development only;

(d) once signed and returned, a copy of this consent form will be retained by the principal researcher; and

(e) I have been informed that the confidentiality of the information provided by myself will be safeguarded, subject to any legal requirements (subpoena, freedom of information, mandated reporting), and in the following ways:
• no names or personal details of individual participants or schools will be revealed in any report of the study, and any contextual details that might reveal their identity will be removed;
• data will be stored in secure files at the Assessment Curriculum and Technology Research Centre of the UP College of Education for the management of research data and records, and destroyed five years after publication of findings.

Teacher’s Signature: ..................................................... Date: ........................................
Consent Form for Principals

Exploring Teachers’ Science Inquiry Practices and Students’ Inquiry Skills
Name of School Principal: ...........................................................................................................
School name: ................................................................................................................................
Name of Investigator: Mr Dennis Danipog

1. I consent to the participation of my school in the above research study, the particulars of which – including details of procedures – have been explained to me in the Plain Language Statement and I have been given a copy of that explanation to keep.

2. I authorize the investigators in the above study to implement the procedures referred to under (1) above (observing classroom instruction, collecting and analyzing teaching materials and copies of tests).

3. I acknowledge that:

(a) the possible uses of the information arising from the study have been explained to me to my satisfaction;

(b) I have been informed that my school’s participation and the participation of my teachers in this research is voluntary, and that I am free to withdraw my school from the study at any time and to withdraw any unprocessed information that has been supplied;

(c) the study is for the purpose of research and development only;

(d) once signed and returned, a copy of this consent form will be retained by the principal researcher; and

(e) I have been informed that the confidentiality of the information provided by myself and teachers at my school will be safeguarded, subject to any legal requirements (subpoena, freedom of information, mandated reporting), and in the following ways:
• no names or personal details of individual participants or schools will be revealed in any report of the study, and any contextual details that might reveal their identity will be removed;
• data will be stored in secure files at the Assessment, Curriculum and Technology Research Centre of the UP College of Education for the management of research data and records, and destroyed five years after publication of findings.

Principal’s Signature: ............................................................ Date: ...........................
Appendix G

Sample Coded Lesson Observation Notes

School ID: 2  Date: 29 June 2015
Teacher ID: F  Topic: Factors Affecting Solubility
Class ID: 2F  Start time: 12:43 pm
No. of students: 43/43  End time: 1:45 pm
Observer: DLD  Obs No.: 1

1. To teach and help students distinguish the type of Solutions, Teacher F showed two setups: (1) To a beaker that contained water, she added a small amount of sugar, then she stirred the contents; (2) To a beaker that contained water, she added a large amount of sugar, then she stirred the contents. She asked the students to observe from this demonstration. (CD2) Then, she asked the students the question, “What will happen to the sugar?” (Q2) The students answered, “The sugar dissolves easily in setup 1.” Teacher F asked, “Why?” (Q3) The students answered, “Because the water has a greater amount than sugar which helps the sugar to dissolve easily.” Then the teacher asked more questions, “What do you call this solution in setup 1?” (Q2) “Which solution is unsaturated? Saturated?” (Q2) “Why did you say so?” (Q3)

Start of a new lesson: Factors affecting solubility

2. Again, the teacher showed a demonstration in front of the class. She had a small graduated cylinder with oil. She added water into it. Afterwards, she added powdered juice. Then, she asked students to observe. (CD2) From this demonstration, the teacher asked, “What do you think is the factor that affects solubility of a powdered juice?” (Q2) “What do you think is the factor that causes oil not to dissolve in water?” (Q2)

Activity proper

3. The teacher provided some safety reminders before the students perform the activity. She required the students to do the activity for 10 minutes. She provided activity sheets per team of students. There were five teams in the class and each team had 7-8 students. She instructed the students what to do in the activity by discussing the procedures. (DI2) She asked the students to measure the volume of water using a 50 mL beaker. (CD4) She asked each team to write their results following a prescribed format in a Cartolina paper. (C1)

Group presentations and discussions

4. After performing the activity, Teacher F asked each team to report their results in front of the class. First, she called team 1 to present their results. There was an interaction between the teacher and students (teacher asked questions and students answered them). (C5)
5. Team 1 explained the procedure and results of the nature of solute and solvent part of the activity. Two students reported in front of the class. After presentation, the teacher asked the students, “Why do you think it is dissolved?” (DE4) team 1 answered, “The water and vinegar attracted [to] each other.” “Based on your results, what is the factor that affects solubility, team 1?” (DE4) The students answered, “The nature of solute and solvent.”

6. After this the teacher explained what is meant by “like dissolves like” and the polarity of a substance. Then, the teacher asked, “What do you think are the substances that can dissolve in water?” (Q2)

7. The teacher asked team 2 to explain the procedure and results of the temperature part of the activity. There was also an interaction between the teacher and students. (C5) In this case, one student read the procedure and showed the results in front of the class. After the presentation, Teacher F asked team 2, “Based on your observation, what do you is the factor that affects solubility?” (DE4) “From your results, what is the relationship of temperature to the rate of solubility?” (DE4)

8. But when the students cannot answer this question, the teacher gave an example that shows the relationship between temperature and rate of solubility, and then she repeated to ask the same question, “By using hot water the solubility is faster while using cold water the solubility is slower.” (DE3) “What is the relationship of temperature to the rate of solubility?”

9. The teacher asked team 3 to explain the procedure and results of the pressure part of the activity. There was an interaction between the teacher and students. (C5) Here, one student read the procedure and showed the results in front of the class. After the presentation, the teacher asked team 3, “Based on your results, what is the relationship between pressure and the rate of solubility?” (DE4)

10. Next, the teacher asked team 4 to explain the procedure and results of the particle size part of the activity (with interaction between the teacher and students). (C5) One student read the procedure and showed the results in front of the class. After the presentation, the teacher asked team 4, “Based on your results, what is the relationship of particle size to the rate of solubility?” (DE4)

11. Finally, Teacher F asked team 5 to explain the procedure and results of the agitation/stirring part of the activity (with interaction between the teacher and students). (C5) Also, one student read the procedure and showed the results in front of the class. Then, she asked, “From your results, can you explain the factor that affects solubility here? (DE4)

Applications and closing

12. To apply the concepts in other areas of science, (e.g., Biology) the teacher asked these questions to the whole class, “Why many fishes cannot survive in warm water?” (Q3) “Why major ocean fisheries of the world are located in colder regions?” (Q3)
13. After discussing the results of the activity, the teacher asked the whole class: Do you have any questions in mind about our lesson? “Please raise your questions, if any” (Q4)

14. Then, teacher F gave the students a homework, “Find the formula of percent by mass and volume.”

***End***
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Danipog, Dennis

Title:
Assessing the scientific inquiry practices of teachers and investigating their relationship with student learning

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2018

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