Reform efforts in science education in the United States currently focus on inquiry-based teaching and learning methods. The National Science Education Standards developed in 1996 by the National Research Council promote inquiry as a primary part of science learning. According to the Standards, inquiry is required in order for students to learn the skills and processes associated with science and to develop an understanding of scientific concepts. Also according to the Standards, inquiry includes “making observations, posing questions, examining books and other sources of information, planning investigations, reviewing what is already known in light of evidence, using tools to gather, analyze and interpret data, proposing answers explanations and predictions, and communicating the results (pg. 23).” Unfortunately, in spite of the call for reform in the Standards, many teachers of science in the United States still use traditional methods of teaching in their classroom. This problem could be due to the fact that many teachers believe inquiry does not improve student learning, or that they believe the implementation of inquiry-based methods is too challenging for them. This lack of reform could also be due to the fact that teachers don’t know enough about the process of inquiry and the learning cycle to feel comfortable with the implementation process.

There are three purposes for the consideration, here, of this problem: (1) to determine if inquiry-based teaching and learning methods provide opportunities for meaningful learning to occur in science classrooms, (2) to determine what challenges teachers face during
implementation of inquiry-based teaching and learning methods and (3) to determine what crucial skills teachers should foster in their students while using inquiry-based teaching and learning methods to enhance student learning at various levels of education. These were addressed in the form of three research questions to which an analysis of the literature might respond.

**Literature Review**

To address the first purpose, the research question formed was “How might inquiry-based teaching and learning methods provide opportunities for meaningful learning to occur in science classrooms?” I found an article titled “The impact of teacher classroom practices on student achievement during the implementation of a reform-based chemistry curriculum” (Roehrig & Garrow, 2007). In this article, the authors conducted a study to determine relationships between inquiry-based teaching and student achievement. The study was conducted through the implementation of a reform-based high school chemistry curriculum called *Living by Chemistry (LBC)*. Quantitative methods were used to measure student learning of the concepts of gas laws, phases of matter and density, along with any relationships between the teachers’ implementation and student learning. Semi-structured interviews and classroom observations were also used, to better understand the teachers’ experiences with the implementation process. The teachers and students were from a large, urban school district in the United States that was committed to instituting reform in science education with a diverse student population (38.8% Hispanic, 26.6% Caucasian, 17.6% Asian and 16.6% African American, with 29.4% English language learners). The *LBC* curriculum was piloted in 2002-2003 and was implemented district wide for all 10th graders in 2003-2004. The activities and strategies in *LBC* were designed to take into consideration the prior knowledge and preconceptions of students while encouraging them to work as a learning community. The investigations in the chosen unit (Unit 3-Weather) followed a learning cycle format similar to the 5E Model of Inquiry proposed by Bybee in 1997, and included short inquiry-based laboratories, demos and real world applications. The four teachers in the study came from two high schools with different rankings within the State of California and had different years of teaching experience and experience with inquiry-based teaching methods. All four of the teachers attended the professional development provided by the school district during the implementation process. The teachers were observed eight times during the school year, and detailed notes were taken to document teacher and student interactions with the curriculum. The observations were then scored using the Reformed Teaching Observation Protocol (RTOP), which looks at lesson design and implementation, content and classroom culture. The lesson design and implementation subscale was modified for this study to include the steps of the 5E model (engage, explore, explain, elaborate and evaluate), since the teachers were implementing an existing curriculum instead of their own lessons. The teachers also shared their beliefs about teaching at the beginning and end of the school year using the Teachers’ Beliefs Interview (TBI), which allowed the researchers to classify the responses as traditional, instructive, transitional, responsive or reform-based.
The results of these assessments showed that two of the teachers (one from each school) had more traditional practices and beliefs about teaching and learning, while the other two teachers (one from each school) had beliefs and practices aligned with reform efforts in science education. The research study showed that the students of the two teachers with the reform-based beliefs and practices (higher RTOP scores) had significantly higher average test scores than did the students of the teachers with more traditional beliefs and practices (lower RTOP scores). In terms of the chemistry content chosen for this study, these students also had higher scores on questions that asked about microscopic explanations and macroscopic relationships, which point to a deeper learning beyond a mathematical understanding. These higher scores are related to the fact that these students were “routinely included in the sense-making process and in making meaning of the curriculum activities (p. 1807).” The data in this study lead the authors to conclude that “beliefs about teaching and learning are critical factors in teachers’ implementation of reform-based practices and ultimately in student learning (p. 1807),” even though this was not the focus of their study. In the case of the two teachers with lower RTOP scores, both believed that their students were “not capable” of learning through inquiry, which affected the way they implemented the LBC curriculum.

After learning that teachers’ beliefs about reform-based learning influences their implementation of inquiry in their classrooms, I decided to turn my attention to my second research question and learn more about other issues teachers face when implementing inquiry. In “Constraints experienced by beginning secondary science teachers in implementing scientific inquiry lessons” (Roehrig & Luft, 2004), the authors conducted a study to understand the factors that impacted beginning secondary science teachers in the United States and their inquiry-based instruction. During the study, fourteen beginning (first, second or third year) teachers were followed for one year as they participated in a science-focused induction program. This qualitative, cross-case study involved the collecting of demographic information, open-ended and semi-structured interviews about teaching beliefs, classroom observations (minimum of seven during the study) and a nature of science questionnaire (VNOS-C). Additional artifacts included list-serv and personal emails and observations of induction workshops. From this data set, individual cases of each teacher were developed and the cases were compared and contrasted to one another. While many cases showed similarities in teaching beliefs and practices, they differed in their amount of content knowledge and pedagogical knowledge, along with their perceptions of science.

Three groups of teachers emerged in the study: (1) Inquiry Teachers (4 of the 14 teachers in study), (2) Process-Oriented Teachers (2 of the 14) and (3) Traditional Teachers (the remaining 8 of the 14). The Inquiry Teachers all wanted their students to learn science through inquiry, either student-centered, where the students design and conduct their own experiments, or guided, where the teacher provides the design. These teachers also held “contemporary” views of the nature of science, where science is “empirically based, tentative, subjective and reliant on creativity and imagination (p. 13).” These teachers also held student-centered beliefs, where students do more of their own questioning, thinking and evaluating. These beliefs came from the fact that this group of teachers had prior experience in science before they became teachers, like working as a laboratory technician or a field biologist. However, the use of inquiry
in the classroom presented some challenges to this group of teachers, like classroom management, perception of students’ abilities and lack of understanding about inquiry instruction prior to the study. The induction program provided these teachers with the guidance and support they needed to overcome these challenges during the study. While the Process-Oriented Teachers both used activities and laboratories that taught students process skills, they often failed to make connections to the underlying scientific concepts. In reference to one experiment performed in one of these classrooms, the authors noted that “at no point in the activity were students asked to explain their data or to develop any conceptual knowledge about the nature of the chemical reactions that they had observed (p. 15).” These teachers viewed the nature of science as a process, which produces data that can be interpreted in different ways and by the end of the year, both teachers believed in student-centered approaches to teaching science. While these factors had the greatest effect on their implementation of inquiry, these teachers’ content knowledge and prior experience in science also influenced the implementation process. Both teachers also held the belief that “students needed basic skills more than science” because “they need to be able to think rationally, read, write and use evidence to defend their ideas (p. 16).” This explained their rationale for using process-oriented methods in their classrooms. In contrast to the other two groups of teachers, the Traditional Teachers provided the information in their classroom using teacher-centered methods like lecture and discussion, with laboratories being used to help verify a concept. None of the teachers in this group allowed their students to “investigate their own questions, devise their own procedures or draw their own conclusions” because this took “too much time” and there was no guarantee that the students would “come up with the right answer anyway (p. 17).” Statements like this one support these teachers’ more traditional views about the nature of science, where science is a body of knowledge that is verified through experimentation and where students need to learn the facts, instead of learning how scientists gained this body of knowledge and supporting evidence. These teacher-centered beliefs had the largest impact on their implementation of inquiry, along with either a lack of content knowledge or lack of pedagogical knowledge. The results of this study show that the factors of content knowledge, views on the nature of science, teaching beliefs and pedagogical knowledge all work collectively to influence inquiry implementation. For example, “a teacher with a strong understanding of the nature of science and a desire to implement inquiry instruction may ultimately be hindered by perceptions of the students’ abilities and their school context (p. 19).” Taking each factor into consideration separately, this study found that a contemporary view of the nature of science was needed by the teachers, but not sufficient for supporting inquiry implementation. The study also found that the teachers needed primarily student-centered beliefs that remain consistent throughout the year to make the implementation of inquiry occur. Strong content knowledge alone was not a guarantee that inquiry implementation would be successful, but the combination of strong content knowledge and student-centered beliefs along with a contemporary view of the nature of science “increased the likelihood that inquiry would be implemented in the classroom (p. 20).” Other issues in implementing inquiry showed up during the study, such as low student ability and motivation and classroom management issues during inquiry, which can appear unmanaged to observers. This study showed that it is important for beginning teachers to participate in some sort of induction program that provides them with support during the inquiry implementation process.
After reading this article, I wondered if experienced teachers faced the same issues while implementing inquiry-based teaching and learning in their classrooms and benefited from support as well. In “Evidence for teachers’ change while participating in a continuous professional development programme and implementing the inquiry approach in the chemistry laboratory (Taitelbaum, Marnlok-Naaman, Carmeli & Hofstein, 2008),” the authors studied a continuous professional development (CPD) program in Israel that focused on the use of inquiry-based teaching and learning methods in the chemistry classroom laboratory. In this study, fourteen experienced chemistry teachers in Israel participated in an inquiry CPD that focused on “a set of characteristics and protocols assembled in a portfolio, which can be used to demonstrate evidence-based practice in teaching chemistry in the classroom laboratory using inquiry-type experiments (p. 594).” The CPD model was designed and implemented over a three year period. In year one the teacher’s guide was developed and planning for the summer courses was completed. In year two and year three, two sets of seven teachers (novices in inquiry) completed the summer course. The course was modified between years two and three. After the summer course was completed, the teachers participated in workshops to share artifacts from their teaching and reflected on their teaching. From this reflection, the teachers created an evidence-based portfolio that contained three written pieces of evidence. During the school year, teachers continued to discuss issues using a web-based forum and they were also videotaped for the research project. These videotapes, along with interviews, teacher portfolios and workshop documentation were used to collect qualitative data for the study.

The teachers in the study had access to 100 inquiry-type experiments that were developed through the Inquiry Chemistry Laboratory (ICL) program in Israel and were incorporated into the regular chemistry curriculum used in grades 11-12. Some of the experiments were completely open-ended, where the students designed and planned their own experiments, while others only required the students to conduct partial inquiry. In this ICL program, the students worked in groups selected by the teacher and all groups conducted a pre-inquiry experiment to trigger a set of questions. Once a research question and hypothesis were developed, the students then planned an experiment to answer their question. Each group had a different question, hypothesis and experiment. During the experimentation, the students recorded their observations and discussed results, while the teacher circulated around the room to help the students as needed. Since the teacher’s knowledge and pedagogy influences the outcome of the inquiry approach, the CPD model was developed to help teachers learn to “scaffold their students in acquiring the inquiry skills (pg. 598).” The study had two main focus questions: (1) as a result of the CPD, what were the changes in the teachers’ classroom laboratory practices? and (2) how did the teachers cope with collecting artifacts, turning them into evidence and using them to construct their portfolios? The study found that the teachers that participated in the study changed their laboratory practices in the following ways:

- the teachers began grouping students into heterogeneous groups that changed periodically, as opposed to having homogeneous groups or no groups at all
- the teachers began to approach the student groups sooner and spent more time with the groups, as opposed to staying at their desks
• the teachers moved to more student-centered activities, as opposed to more teacher-centered activities

The study also found that the teachers were better able to select evidence and reflect upon their practice, as well as learn from their peers. In summary, the CPD program provided its teachers with continuous support that allowed them to become more reflective of their practice and also reduced their anxiety of working with students in small groups as they participated in inquiry-based experiments. This article helped confirm my belief that in order for teachers to successfully implement inquiry-based methods into their classroom practice, they need some form of ongoing support and encouragement from other teachers going through the same process. After reading this article I decided to look at studies that addressed my final research question regarding other things teachers should do while using inquiry-based teaching and learning methods to enhance student learning at various levels of education.

One important phase of the inquiry learning cycle is having students use and interpret evidence collected during investigations to support their findings. In “Using data comparison and interpretation to develop procedural understandings in the primary classroom: Case study evidence from action research” (Warwick & Siraj-Blatchford, 2006), the authors performed an action research project that used secondary data to study the procedural understandings of primary school children. This secondary data was presented in the forms of tables and graphs and related to data collected by the students themselves. This secondary data was presented as either the work of scientists or the work of other students. For this study, there were two primary research questions: (1) can the use of secondary data sets in the context of science investigations make a contribution to primary children’s ability to engage with the interpretation of scientific data and to their appreciation of the evidential value of procedures? and (2) does the use of such data sets reveal anything to primary children about the nature of science, and particularly about science as a social process? The research project took place over one school year in England, with four classes of students, ages 7-10 years. Each class conducted a different “fair test” investigation that was chosen because the students could show their understanding of various elements of the experiments while discussing them with the researchers. The elements discussed included “fair testing, the control of variables, accuracy, repeatability and the graphing of results (pg. 446).” Data was collected through student interviews (three to four groups per class), a thick description of classroom events for one lesson, the written work of the students and a teacher interview. The well established groups interviewed included at least one high achieving group, one average achieving group and one low achieving group. The researchers found that the use of secondary data motivated the students to raise and address questions through comparison of their data to the secondary data. They also found that use of cooperative groups allowed the students to attempt to derive meaning from the data. Students in this study were also forced to account for the differences in their data and the secondary data by looking at their procedures and the procedures used to gather the secondary data. Within this small study, the researchers saw that the oldest group of children was more aware of the significance of differences in the data and some were able to see themselves as part of a community of scientists. In contrast, one of the middle groups of children showed little sign that their work was “real science”, while the youngest group of
children was more likely to use the secondary data as a way of checking their work for errors. This study implies that comparing data within an investigation can engage students in a more “dialogic approach to scientific problem solving (pg. 459).” It also implies that this type of comparative analysis mirrors the collaborative nature of science and works best when the inquiry approach is contextualized.

Once students are able to interpret and analyze their data, they need to use their evidence to explain the concepts they are learning. In “Developing sixth graders’ inquiry skills to construct explanations in inquiry-based learning environments (Wu & Hsieh, 2006),” the authors studied how inquiry skills were developed by sixth graders to construct their explanations. Their research questions were: (1) how do students develop their inquiry skills throughout a series of inquiry-based activities? and (2) does the teachers’ role change throughout the series of activities? According to the authors, “one of the major knowledge productions created through inquiry learning is explanations that address scientifically oriented questions and are supported by empirical evidence (pg. 1291).” Some of these explanations are deductive-nomological (D-N), as discussed by Hempel in 1965. In these explanations there is a statement of specific “antecedent” conditions and general laws along with a description of the phenomenon to be explained. An example of this would be a discussion of gas molecules and wavelength of colored light when asked why is the sky blue. A second type of explanation is teleological and sometimes functional, like when a biology teacher states that plants contain chlorophyll in order to conduct photosynthesis. A third type of explanation is a casual-mechanical one that is used to discuss the motion of two balls after a collision. The adequacy and completeness of an explanation depends upon what the “explainer” knows and what the “explainee” is assumed to know, so in this study the definitions of explanations were modified while taking pedagogical considerations into account. For this study, the authors looked for four inquiry skills in the students’ explanations:

- identifying casual relationships
- describing the reasoning process
- using data as evidence
- evaluating explanations

Two sixth grade classes at a public school in northern Taiwan participated in this study. The 58 students in the study had a range of academic abilities and most were considered middle class. Both classes were taught by the same teacher (one of the authors) and six students from each class were nominated by the teacher for intensive observation. None of the students had experience in inquiry-based learning and needed guidance during the first three of the six activities designed by the teacher. Over six weeks, the authors made classroom video recordings, took field notes, collected student artifacts, administered pre- and post-tests and prepared interview transcripts. The pre- and post-tests were designed to assess the students’ inquiry skills before and after the activities. The six targeted students were also interviewed three times (before Activity 1, after Activity 2 and after Activity 6) and were asked to use materials or analyze data to formulate explanations. The results of the data collection showed that the students were better able to construct scientific explanations after the inquiry-based activities. The students also made progress in three of the four inquiry skills listed previously. They showed only a slight improvement on the last skill of evaluating explanations. The authors
also found that the role of the teacher changed during the series of activities. During the first activity, the teacher was often the guide and diagnostician for the students. In the second activity, the teacher demonstrated the investigation planning process and modeled how to construct explanations from evidence, along with acting as a guide. By the time the sixth and final activity occurred, the students were able to take on the role of the teacher, while the teacher became more of a collaborator by participating in group discussions and exchanging ideas with students. The authors concluded their article by suggesting that teachers should provide ongoing scaffolding in order to facilitate the development of inquiry skills. Since scaffolding is done over a period of time and since the phases of data collection and analysis and explanation development are so crucial to the inquiry learning cycle, I wondered what could be done to help students that are absent during these phases.

In “Student absences during learning cycle phases: A technological alternative for make-up work in laboratory based high school chemistry” (Marek, Askey, & Abraham, 2000), the authors investigated the use of a “quasi-interactive” video presentation of parts of the learning cycle as an alternative to making up missed class work. In their study, the authors refer to the basic three phase learning cycle of exploration (lab activity), conceptual invention (class discussion of student collected data to develop explanation of concept) and concept application (additional experiments, readings, videos and/or problems). Two treatment groups of chemistry students from a large high school in the Midwestern United States were involved in this eight day study, along with one control group. The first treatment group completed the learning cycle guided by a videotaped instructor, while the second treatment group completed the learning cycle with a “live” teacher. The authors wanted to discover if the videotaped lessons could serve as a “viable make up strategy for students (pg. 1056).” Before the study began, five science teachers were given a survey to determine information about the effects of student absences and their current procedures for makeup work. Two of the five teachers listed student absences as their number one issue, and the other teachers listed absenteeism in their top three. Students were also surveyed prior to the study to determine which subjects they felt were the hardest to complete makeup work for, along with which type of chemistry assignment was the hardest to makeup. The students stated that math and chemistry were the most difficult classes to make up work in and 70% of the students noted that discussion notes in chemistry were the harder to make up than labs or worksheets. Students also completed a pre-test and post-test to assess their concept knowledge about the lesson in the study, along with the Birnie-Abraham-Renner (BAR) attitude test to measure their attitudes about their treatment process. Both treatment groups showed improvement in content knowledge as a result of the inquiry learning cycle, regardless of the presentation. There were also no significant differences in the attitudes of the students in the two treatment groups regarding the presentation of the learning cycle. However, as the learning cycle continued into the final days of the study, the videotape treatment group began to grow tired of the video presentations because of the lack of interaction with their teacher. This indicates that the videotaped lessons are a suitable substitute for actual participation in the learning cycle, although they should not be used as a permanent substitute.
Since several of my articles discussed the use of student groups, I decided to research the use of cooperative groups in the inquiry cycle. In “Cooperating in constructing knowledge: Case studies from chemistry and citizenship” (Barbosa, Jofili, & Watts, 2004), the authors presented three case studies about the use of group learning in the chemistry classroom. The article aimed to study the cooperative attitudes students develop while learning about science. It also aimed to show how the overlap between issues of science and society works to develop citizenship education. In order to promote citizenship, science courses should “emphasize scientific literacy, ideas about the nature of scientific knowledge inquiry and deal with the ways that decisions are made about issues involving science technology (pg. 937),” according to the authors. In their introductory research, the authors define cooperative learning methods using the ideas of Cohen (1994). In this definition, students work together in a group small enough for everyone to be able to participate on a collective task that has been clearly assigned. Students are also expected to carry out their task without direct and immediate supervision of the teacher. The authors also reference Slavin (1987) by stating his belief that group rewards for individual learning should be used to motivate students to offer high quality assistance to the rest of their group, which is crucial to improving learning. The authors note that in some cases the collective knowledge of groups can be lost or degraded, and they are searching for practices that allow this group knowledge to be retained. Also as part of their introductory research, the authors discuss the ideas of communal constructivism from Holmes, et al (2001). This is an approach to learning in which learners construct their knowledge by interacting with their environment and within a community, while retaining it in some form. In some instances, this approach includes students working in groups to develop portfolios that allow them to reflect upon their learning through project-based learning. This requires the science course to be adaptive, so that students see themselves as producers of their learning, and not just as consumers.

In their first case study, the authors discussed the use of cooperative learning in two college courses in Brazil. This study involved 6 classes of 40 first year veterinary students from 1997-1999 and four classes of 45 second year students in their teacher training courses from 2000-2001 (420 students in total). All students were asked to individually evaluate the course methodology and give suggestions for improvement at the end of their courses. Students improved their comprehension and showed greater levels of motivation in these courses. The students also reported that they developed more self confidence through sharing their ideas in a group setting. In their second case study, the authors discussed the use of cooperative learning in a chemistry course in Brazil. This study involved 69 science students in two eighth grade classes from a private school. One class used the “jigsaw” method of grouping while the other class completed their work as individuals. Individual tests were given to students before and after the treatment. Both classes showed an improvement in their content knowledge, but the class using cooperative learning showed more student motivation, participation and interest than did the class working as individuals. In their third and final case study, the authors discussed the use of cooperative learning in a web based course in Europe. The students were ages 14-18 and communicated with each other by means of a project website (set up by the Communicare Nelle Science project group members from France, Italy and the United Kingdom). Background information about the content was posted by teachers while student
groups completed activities that they then posted on the site. This allowed other groups to undertake similar activities or revise original activities to continue the line of investigation. Students also initiated an email discussion about a different topic to collect information from each country. The authors noted that in this study, the students were actively involved in the construction of group knowledge. They concluded from these three studies that group work can be a means for the “intellectual, personal, social and ethical development of learners (pg. 946)” while raising students’ self esteem as they become active members of the learning process. They also concluded that different methods of group work should be implemented, based on the needs of the students and the objectives planned by the teacher.

Since this article referred to a case study involving college students, I decided to also research the use of inquiry by post secondary students and teachers. In “Teaching for Quality Learning in Chemistry” (Teixeira-Dias, Pedrosa de Jesus, Neri de Souza, & Watts, 2005), the authors looked at the questions asked by learners as they began to search for understanding in their undergraduate chemistry courses. These student generated questions are an important to the teaching and learning process for three main reasons, according to the authors:

- questions can lead to improvement of understanding and retention of what a student encounters
- questions can drive classroom learning and are highly effective in increasing student interest, enthusiasm and engagement
- learners’ questions can be diagnostic of their understanding

The authors of this study wanted to discuss the “means by which engagement can be enhanced rather than diminished (pg. 1125)” and this study involved 100 students during the 2001-2002 school year at the University of Aveiro in Portugal. The number of students in higher education in Portugal grew from 80,000 students in 1975 to 381,000 students in 2000 (a change of 11% to 53% in the 18-22 year age group) and as a result, there was a change in the diversity of the student population. The chemistry department at the University of Aveiro began to implement and adjust student centered approaches (of which inquiry is a form) in their courses. The “tuning” involved two types of adjustments: fine tuning-minor diversions suggested to or by students and coarse tuning-taking the minor changes and turning them into more structured strategies to stimulate active learning. These coarse tuning changes included developing QQ lectures, conference lectures, seminar tutorial sessions, practical laboratory sessions and mini projects, all of which were monitored in this study. The authors collected student questions from each of these sessions through a variety of methods, including an Intranet email system within the department, a classroom question box and oral questions asked during the sessions previously mentioned. The authors also asked students about their opinions of the lectures and course design through a questionnaire and semi-structured interviews. In order to analyze the questions, the authors looked at their quality and classified them in one of two ways: (1) “confirmation questions” (questions that attempt to determine the place and worth of information), which were considered to be lower quality or (2) “transformation questions” (questions that signal a reorganization of student understanding), which were considered to be higher quality. In the second semester of the school year, 70% of the student questions were classified as confirmatory, but the total number of transformation questions increased over the semester, showing an improvement in the quality of the questions. The greatest percentage of
student questions came from the QQ lectures and the laboratory sessions. Based on these results, the authors concluded that the coarse tuning made in the chemistry department was successful in improving the student questioning process.

In “Benefiting from an open-ended experiment? A comparison of attitudes to, and outcomes of, an expository versus an open-inquiry version of the same experiment” (Berg, Bergendahl, Lundberg, & Tibell, 2003), the authors also looked at the use of inquiry in the college setting, by studying the differences between the effects open-ended experiments and expository experiments on student outcomes and attitudes towards learning. The questions for this research study were: (1) will an expository versus open-ended inquiry version of the same experiment have different outcomes for our students? and (2) can the instructions for a laboratory experiment be better suited to some of the students than to others, and if so, has it a bearing upon their attitudes towards teaching, learning and experimental work? The study involved 190 students in their first year of chemistry at the college level over a 20 week time period. In the first part of their study, the authors collected data from 105 students split into two groups: 65 in the expository group and 40 in the open-ended inquiry group. In the second part of the study, they collected data from 85 students in a revised open-inquiry group. Students also completed a self-evaluation at the end of the study. The laboratory experiment studied in all groups was “The Comparison of the Catalytic Effect of MnO2 and Catalase,” which was one of the four experiments in the “Chemistry of Life” course at this university in Sweden. As part of the data collection, the instructors of the lab classes learned how to fill in check sheets regarding the questions asked by the students in each of the three groups. The students completed a questionnaire to assess their attitudes in their lecture class prior to conducting their laboratory experiments. Based on the responses to this questionnaire, six students from each treatment group were chosen for interviews (3 students with high attitude positions or HiPos, and 3 students with low attitude positions or LoPos). During these interviews the students had the other experimental versions explained to them and were asked to choose which they would prefer and why. In the expository group, the three LoPos and two of the HiPos preferred the expository version, while the other HiPo was ambivalent. In the open-ended inquiry group, all six of the students preferred the open-ended version, but two of the LoPos had some doubts. In the revised open-inquiry group, all six students preferred the revised version, with no doubts. All of the students in the open-inquiry and revised open-inquiry groups could explain what they had done during the experiment, but only half of the expository students could do so. Almost none of the expository students could suggest changes to the experiment, but almost all of the students in the other two groups could do so. Students in both open-ended groups had a higher frequency of reflective questions than did the expository students, which indicates that they know what they are doing and have knowledge about the theory connected to the experiment. From student self-evaluations, the authors determined that there were no obvious differences between the three groups in terms of knowledge and comprehension. However, in terms of application, analysis/synthesis and evaluation, the expository group ranked the lowest, while the revised open-ended group ranked the highest. The same results were seen in the data of the HiPos and LoPos when pulled out as a subgroup. Overall, the authors concluded that the revised open-ended inquiry version
of the experiment was the most beneficial for the students, based on the data discussion above.

Conclusions

My first research question asked if inquiry-based teaching and learning methods provide opportunities for meaningful learning to occur in science classrooms. Roehrig and Garrow (2007) found that inquiry-based teaching methods can improve student achievement, as long as the teachers' beliefs and practices are reform-based. These results support the view that that inquiry is meaningful because it improves achievement. My second research question asked what challenges teachers face during implementation of inquiry-based teaching and learning methods. This led me to the findings of Roehrig and Luft (2004), that beginning teachers face constraints when implementing reform-based teaching and learning methods like inquiry, which include their views about the nature of science, their teaching beliefs, their level of content knowledge and their level of pedagogical knowledge. These findings support the belief that if beginning teachers are to implement inquiry into their classrooms, then they need some sort of support system that attends to these constraints. This study led to the Taitelbaum, Marnlok-Naaman, Carmeli and Hofstein article (2008), which emphasized the importance of providing support to experienced teachers through a continuous professional development plan, which helps reduce teacher anxiety and teaches them how to be reflective of their teaching practice. My third and final research question asked what crucial skills teachers should foster in their students while using inquiry-based teaching and learning methods to enhance student learning at various levels of education.

Warwick and Siraj-Blatchford (2006) showed the importance of engaging students in inquiry while teaching them how to interpret and analyze their data, along with their procedures, in comparison with secondary data. Wu and Hsieh (2006) reinforced the central role of explanations in the inquiry learning cycle, along with providing information about how students develop their inquiry skills and how teachers' roles change during the inquiry process. Barbosa, Jofili and Watts (2004) presented the importance of cooperative learning in science education, not only to help students learn science, but to also help them learn to become full and active members of society. Teixeira-Dias, Pedrosa de Jesus, Neri de Souza and Watts (2005) expressed the importance of student questioning as a way to increase interactions between the teacher, the learner and the learning task, so that the learner is more engaged in the learning process. Finally Berg, Bergendahl, Lundberg, and Tibell (2003) discovered that using open-ended inquiry experiments have more positive outcomes for students than do expository experiments. They also discovered that students with lower attitude positions need extra attention in terms of explaining and motivation with these kinds of experiments.

These findings have shown me that inquiry-based teaching and learning methods do provide meaningful learning in science. If teachers are to incorporate innovative methods like inquiry into their practice, they need ongoing, long term support to ensure success. This applies not only to new teachers but to experienced teachers as well. Once teachers have learned how to incorporate inquiry into their classrooms, they need to foster the skills of inquiry in their students. These skills include, but are not limited to the following: (1) interpreting and analyzing
data, (2) using data as evidence, (3) creating and evaluating explanations from data, (4) working cooperatively, (5) asking more transformational questions and (6) reflecting upon their work. I also realized that teachers need to find innovative ways to work with students when they miss part of the inquiry cycle and they also need to use more open-ended experiments in their classroom. Doing all of things can help students of all ages become more engaged in the learning process, allow them to learn about and discuss science as scientists do, help them retain their learning longer and teach them to become better informed citizens who can work with others.

References


