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College Leve Inqury Learning's Influence on Later Science Thinking Behavior

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College of Education

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Eric Chesloff

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Abstract

College-Level Inquiry Learning's Influence on Later Science Thinking Behavior

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Eric G. Chesloff

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

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Abstract

Society needs scientists who can collaborate to become keener analysts so that they might better inform citizens. College students who are well educated in science are likely to become better analysts. The purpose of this grounded theory constructivist-oriented study was to illuminate the influence of undergraduate freshman inquiry learning on thinking skills in science courses during the senior college year. The conceptual framework involved the 3 components of the cognitive learning cycle: exploration, concept invention, and application. Research questions concerned college seniors' perceptions of their freshman process-oriented guided inquiry learning (POGIL) experience in general chemistry and its influence on their current learning in terms of data collection and interpretation, knowledge synthesis, and group interaction. Currently, little or no such senior student perception data exist. The grounded theory approach was used in an inductive analysis toward developing a model of action deriving from the participants' perceptions. Individual and discussion group interviews were conducted with 15 college seniors. Data were sent to participants for member checking, were peer reviewed, were coded, and were analyzed for patterns and themes. Participants reported that collaboration within POGIL promoted freshman and senior cognitive learning, particularly in concept practice, problem solving, and leadership. The findings indicate that improved understanding of the benefits of POGIL can help college chemistry course designers appreciate the benefits of collaborative activities in science. The resulting social change may be that graduates of such courses provide leadership and collaborative skills in their adult lives, benefitting society.

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Dedication

I dedicate this work to my mother, Frances Sieber Chesloff, a high school chemistry teacher who deeply cared about and was much loved by her students. I also dedicate this work to my father, Raymond Chesloff, who taught me relentlessly the power of discipline and hard work toward success. I am grateful for their "tough love" and effective parenting.

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First and foremost, I am grateful to my Lord Jesus for the power and strength to persevere in this seemingly daunting challenge. He has carried me through all my challenges and trials and I am certain will continue to do so. I am also unendingly grateful to my glittering gem of a wife, Janis, who has also patiently persevered during these last several years with unwavering love, sacrifice, and valuable verbal contributions of encouragement. As well, during my trials and tribulations of the last 6 years, she immersed herself in the caring and support not only of her husband, but also of her father-in-law, particularly during our dad's decline and passing.

I am immeasurably grateful to Dr. Sigrin Newell, who never gave up on me in my struggle to overcome a myriad of obstacles and reach the top of the mountain. As well, many heartfelt thanks go to Dr. Wade Smith, who provided encouraging words and constructive feedback. Many thanks are due as well to Dr. Frank Bernt, who evaluated the interviewee and focus group responses and interpretations and offered valuable relevant comments and suggestions. Finally, I wish to acknowledge Dr. Richard Schwartz, MD, a trusted and faithful friend for many years, who offered invaluable advice and contributions about document formatting and arranging.

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Chapter 1: Introduction to the Study

The major purpose of college-level science education is to teach students to think methodically as scientists while strengthening their grasp of scientific facts, principles, and applications. If they are educated scientifically, graduates are better equipped to find practical solutions to societal problems. As well, they are better equipped to contribute toward scientific policy and practice for the immediate and longer term benefit of society (Abdulwahed & Nagy, 2009; Caccavo, 2009).

The purpose of this grounded theory, qualitative, constructivist-oriented study was to improve the level of scholarly understanding of the influence of earlier undergraduate general chemistry courses incorporating process-oriented guided inquiry learning (POGIL) activities on thought processes and organizational skills during the later college years. This research was unique in that it focused on the influence of constructivist, inquiry learning methods within a freshman general chemistry course on senior-level thinking as perceived by students.

It is critical that citizens be knowledgeable about scientific issues. It is important for all to be aware that scientific issues, particularly those of chemistry, directly or indirectly influence the larger society. Therefore, effective scientific, and particularly chemical, education is important (Fensham, Gunstone, & White, 2013; McFarlane, 2013). Instructors need to better determine how to teach in order to foster long-term retention of chemical knowledge and scientific thinking (Spronken-Smith, 2010; White et al, 2011; Zhao, Witzig, Weaver, Adams, & Schmidt, 2012; Ziegler & Montplaisir, 2012).

Skillful teaching has lasting effects on learning and retention (Deaton, 2013; Moutlana & Moloi, 2014; Osterhold & Dennis, 2014; Range, Young & Hvidston, 2013). Active learning, peer teaching, and guided inquiry learning have gained increasing attention due to their efficacy. There are many quantitative studies that clearly demonstrate the short-term effectiveness of these types of learning (Campisi & Finn, 2011; Hale & Mullen, 2009; Xu & Talanquer, 2013). However, the scholarly literature does not contain any data regarding the long-term influence (i.e., 3 years and beyond) of active learning on later thought processes and learning patterns. In particular, there is little or no data regarding student-perceived influence of process-oriented guided inquiry learning (POGIL) from general chemistry on learning behaviors of the senior science student. What is lacking in particular are qualitative studies regarding what senior-level students think about how their general chemistry course has influenced their thinking and studying behaviors in their current science courses, particularly in chemistry (Bridgeman, Schmidt, & Young, 2013; Ketpichainarong, Panizpan, & Ruenwongsa, 2010; Knutson, Smith, Wallert, & Provost, 2010; Luxford, Crowder, & Bretz, 2011). It is anticipated that the current study will be part of a constructivist foundation upon which other studies can build toward generating a novel model of teaching and learning.

In this first chapter, the main research problem and purpose of the study are discussed. This is followed by the questions that he research was developed to answer, as well as the conceptual framework from which the research questions were derived.

Background

Active learning is a process that engages students and enhances their understanding and short-term retention (Brownell, Kloser, Fukami, & Shavelson, 2012). Whether studying in a physical classroom or remotely online, students have measurably benefitted from working together to construct and retain knowledge and enhance their overall learning (Pierce & Fox, 2012). Whereas passive lecture has traditionally dominated the teaching format in the undergraduate science classroom, emerging research has demonstrated the greater value of active, participatory learning in promoting understanding and short-term retention (Brownell et al., 2012; Madden, 2011; Schultz, 2012).

Campisi and Finn (2011) investigated the learning efficacy of active techniques via student feedback and performance scores in a first-year undergraduate sports medicine research-methods course lasting one semester. The course had been previously taught using a lecture format. All students (*N* = 54, no control group) were directed to read peer-reviewed journals during an active research project that involved group collaboration. In this manner, it was intended that students learn research orientation and methodology. Through a list provided by the instructor, student groups of four chose topics for outside study. They then conducted literature reviews, devised hypotheses, and designed studies. They subsequently collected and statistically analyzed data and presented poster sessions on their findings. Assessments were generated via reflective surveys and pre- and post-25-question multiple choice exams. The students were informed beforehand that the exam results would not count toward their final grades.

The results indicated that students perceived overwhelmingly that their knowledge of research methods increased, and postcourse exam performance improved over pretest results by an average of 13.2% (from 56.1% to 69.3%, $p < 0.05$).

Snodgrass, Lux, and Metz (2011) investigated the learning efficacy of a student-oriented, guided inquiry pH laboratory exercise that occurred during a 2-week, 6-hour period as part of an introductory undergraduate cell biology and genetics course. Specifically, the purpose of the exercise was to determine the influence of pH on lactase enzyme activity, and rather than employ a "cookbook" approach, the students were able to participate to some degree in the design of the actual experiments. For example, students could choose to vary pH values, sample incubation times, and enzyme concentration profiles. Overall learning efficacy was determined by perception surveys that consisted of Likert and open-ended type responses, and by objective evaluation of open-ended content-based questions administered pre and post exercise. The results revealed that the vast majority (at least 83%) of students perceived that the student-design format enhanced their learning. Less than 10% objected to inquiry-based learning. Emergent themes included the recognition of self-responsibility in experimental design and analysis, as well as encouragement toward applying quantitative skills in the context of careers in the natural sciences. Objectively, pre- and postexercise exam evaluations revealed a statistically significant ($p < 0.0005$) increase in retention and understanding.

While the studies described above are useful and provide promising results, the larger, encompassing goal of creating lifelong learners and better citizens appears to have been inadequately addressed. Hence, this research was intended to help fill the gap in understanding by focusing particularly on students' perceptions of the influence of earlier science courses on their ability to organize their thinking and to process information, particularly in senior-level science courses.

Research Problem

There has been considerable work published regarding the science learning efficacy of process-oriented, guided inquiry (POGIL) approaches (Miao, Engler, Giemza, Weinbrenner, & Hoppe, 2012; Myers, Monypenny, & Trevathan, 2012). These authors' research has furnished feedback on the efficacy of POGIL methods on science learning enhancement. Specifically, what is lacking are qualitative studies about how undergraduate science students at the senior level perceive the influence of their POGIL-oriented general chemistry course on their thinking behavior in their science courses (Justice, Rice, & Warry, 2009; Knutson, Smith, Wallert, & Provost, 2010).

Purpose of the Study

The purpose of this grounded theory, qualitative, constructivist-oriented study was to improve the level of scholarly understanding of the influence of freshman undergraduate general chemistry courses incorporating process-oriented guided inquiry learning (POGIL) activities on thought processes and organizational skills in science courses during the senior college year. This was intended to help fill a gap in the scholarly literature by determining the relationship between inquiry learning during general chemistry and senior-level learning. There is an ample supply of primarily quantitative and secondarily qualitative data attesting to the immediate (current academic semester or year) learning efficacy of inquiry methods (Brownell, Kloser, Fukami, &

Shavelson, 2012; Flynn, 2012; Eppes, Milanovic, & Sweitzer, 2012; Phillips & Grose-Fifer, 2011). As well, there are data that demonstrate the longer term efficacy of inquiry methods (Knutson, Smith, Wallert, & Provost, 2010; Justice, Rice, & Warry, 2009). However, these data are 1 year quantitative science and 2 years qualitative nonscience, respectively. The research is unique in that it focused on the perceived influence of constructivist, inquiry learning methods within the freshman general chemistry course on senior-level thinking in current science courses.

While the influence of freshman-level problem-based learning approaches on thinking skills in the junior and senior years has been studied (Murray & Summerlee, 2007), the later (i.e., senior undergraduate) influence of POGIL methods experienced in freshman general chemistry has not been documented. One purpose of undergraduate education is to prepare students to eventually become intelligent consumers of scientific information and to more effectively contribute to the betterment of their world. Therefore, such a study would provide feedback about the efficacy of the constructivist approach in general, and particularly the use of inquiry learning within a freshman chemistry course toward achieving that purpose. This study will help general and higher level course chemistry instructors refine and adjust their teaching methodologies to enable them to plan their teaching for maximum long-term efficacy.

Conceptual Framework

The conceptual framework for this study was based on the cognitive learning cycle (Abraham & Renner, 1986; Kolb, 1984; Spencer, 1999). The learning process is conceived as having three basic components: exploration (collection of data), concept invention (pattern induction and interpretation), and application (synthesis of new knowledge, hypothesizing, predicting). This approach is compatible with the constructivist worldview and most compatible with the manner in which students grasp concepts and retain knowledge. At the end of a cycle, evaluations are conducted to ascertain whether adequate learning has been achieved. If it has not, then a student needs to experience an additional learning cycle.

Specifically, in chemical education, the process-oriented guided inquiry (POGIL) approach has been established as an immediately effective student learning tool (Farrell, Moog, & Spencer; 1999). Social interaction is a necessary part of POGIL in order for students to establish the new concepts (Spencer, 1999).

The components of the cycle are connected as follows: Rather than being teacher centered, learning becomes student centered, wherein students gather their own data through experimentation, then formulate conclusions, patterns, and generalizations, and finally use these generalizations to formulate new, more sophisticated questions that are intended to perpetuate the experimental learning cycle. Testing must occur periodically to confirm or disconfirm that these learning tools were effective in achieving learning objectives.

In the student-centered learning context, the teacher acts as the facilitator or guide, perhaps asking leading questions, and the students act in a cooperative, collaborative setting (social aspect). Student-centered learning engages students more fully in exploration. The intention in such a process is that students will develop critical thinking and problem-solving skills as well as improving communication and cooperation. In Chapter 2, I discuss the elements of the learning cycle more fully. The three components of the cognitive learning cycle indicated above (exploration, concept invention, and application), as well as social interaction, are explored within the context of undergraduate college chemistry instruction. Specifically, the influence of students' inquiry learning activities in groups on their later thinking is investigated.

Research Questions

The research questions were derived from the conceptual framework, which was based on the cognitive learning cycle, along with the social interactive component. I sought to learn how students described their general chemistry experience—in particular, the POGIL research projects that were conducted within the course.

RQ1: How do senior undergraduate students describe the process-oriented guided inquiry learning (POGIL) aspect(s) of their freshman-year general chemistry experience:

1. In terms of data collection (exploration)?
2. In terms of interpreting their data and inducing patterns or themes (concept invention)?
3. In terms of knowledge synthesis, hypothesis, and prediction (application)?
4. In terms of a group setting (social interaction)?

RQ2: How do senior undergraduate students describe the influences of the inquiry learning aspects of their freshman general chemistry course on their approaches to learning in their current science courses:

1. In terms of data collection (exploration)?

2. In terms of interpreting data or inducing patterns or themes (concept invention)?
3. In terms of knowledge synthesis, hypothesis, and prediction (application)?
4. In terms of a group setting (social interaction)?

Nature of the Study

This study focused on how senior students perceived the influence of their inquiry learning (POGIL)-oriented general chemistry course(s) on their current thinking processes and study methods within their science courses. Specifically, I selected the grounded theory approach because its objective is to develop a generalized theory of behavior or model of action deriving from the participants' perceptions (Creswell, 2009; Patton, 2002). I rejected the narrative approach, as this focuses more on chronological history as conveyed in story form. I rejected phenomenology, as this refers to the reactions of individuals as they experience a specific event or phenomenon. Ethnology was rejected because that approach focuses on one or more aspects of a large cultural group, such as behavior or language. More particularly, such an approach entails immersion of the researcher into the day-to-day experiences and observation of such behaviors, which were not applicable to the study in question. Grounded theory was useful in the study, as the participants all had undergone the process and expressed their perceptions of that process. As the researcher, I strove to develop a general explanation based on the perception data gathered so as to provide groundwork for further research (Creswell, 2007; Patton, 2002).

Although inquiry learning is really a culmination of the prior theoretical work of several researchers (Moog & Spencer, 2008), I did not investigate using a learning styles approach (Bergesteiner, Avery, & Neumann, 2010; Kolb, 1984), though learning styles are a byproduct of the constructivist worldview (Kolb, 1984). I did not directly invoke Piagetian learning theory (Moog & Spencer, 2008), as I was not examining the four stages of cognitive learning development. Finally, although Vygotsky (Moog & Spencer, 2008) did incorporate the idea of scaffolding, which is used in the inquiry learning approach, I did not directly explore the "zone of proximal development," which is essentially the difference between what a learner can do without teacher assistance and what he can accomplish with that assistance.

The information gained in this study will direct future research toward the development of a substantive grounded theory. In turn, such a development will help professors improve their POGIL teaching so as to achieve greater long-term effects.

The data source was students from a public East Coast 4-year university. Four focus groups were used, with two students comprising each. Seven other students participated individually as interviewees. I therefore recruited a total of 15 student participants. Students were contacted via Skype. Data collection consisted of audio recordings of all individual and focus group interviews. Additionally, I took handwritten notes during all interviews. Analysis was done using progressive, inductive coding processes (Miles & Huberman, 1994).

Definitions

Clicker questions: Multiple-choice questions typically posed on a screen intermittently by an instructor during a PowerPoint lecture via an electronic personal anonymous-response system. The student response is generated individually via a handheld "clicker," a type of remote control device, and it is received and recorded electronically.

Cognitive learning cycle (Abraham & Renner, 1986; Bergesteiner, Avery, & Neumann, 2010; Kolb, 1984; Spencer; 1999): A learning process having three basic components: exploration (collection of data), concept invention (pattern induction and interpretation), and application (synthesis of new knowledge, hypothesizing, predicting).

Process-oriented guided inquiry learning (POGIL): POGIL is a student-centered method of learning, and uses specialized materials to help students construct new knowledge. It incorporates the learning cycle of exploration, concept invention, and application to guide students in their pursuit of knowledge. Students work in small groups, each with a specified role, in order that all fully participate in the learning process.

Assumptions

First, I assumed that active learning in general is a sound, effective method of teaching and learning. Second, I made the assumption that not all students have the same learning styles, and they are not equally receptive to the inquiry learning approach. I assumed that lecture had not been totally abandoned in the science classroom. It is helpful as a scaffolding tool in communicating basic concepts and goals, and many students are accustomed to and successfully learn with it. Finally, I assumed that those professors who claim that they are using inquiry learning in the classroom are actually using it.

Scope and Delimitations

The focus of the study was the long-term influence of active learning, specifically inquiry learning, methods within a freshman general chemistry course on later thinking and processing behaviors of upper class undergraduates academically. The sample was composed predominantly of senior students who took general chemistry, 18 to 22 years of age. I strove to represent the genders approximately equally, but the ratio was 13 women to two men in the actual sample. One student had graduated in the spring of 2014, and another student was chronologically a junior, although she had taken a course load equivalent to senior status by that point.

It was anticipated that although the specific results of the study would not be transferable to other populations, the general concepts, proposals, and conclusions about effective teaching for long-term retention would be transferable. In that regard, inquiry learning principles should be transferable at least to other science courses due to the nature of active learning in general and inquiry learning methods specifically.

Limitations

Difficulty was anticipated in ascertaining how participants' responses were influenced by how much or little they liked their freshman chemistry professors. From the standpoint of the researcher's role, although it is practically impossible to totally eliminate bias (Patton, 2002), every effort was made to conduct interviews in a detached yet interested manner. Interviews were conducted via Skype from my home and presumably from either the dormitory rooms or homes of the participants throughout the entire data collection process. Therefore, any change in dependability should not be due to a change in interview venue. Finally, I maintained a daily journal to document as necessary and reflect on my reactions to the interviewees so that my attitude was adjustable as necessary in terms of placing undue emphasis or reliance on more articulate responses.

Significance

The study had the potential to explore various aspects of the influence of active learning methods on long-term student thinking patterns and behaviors in collegiate chemistry. While eventually a new model of undergraduate chemistry teaching and learning may be developed partly from the contributions of this study, the more immediate goal was to more clearly understand which aspects of and to what degree active, participatory learning methods are effective in enhancing scientific learning. This understanding may pave the way for professors to develop improved learning techniques for active, participatory teaching and learning at the undergraduate level. If professors succeed in developing these techniques, it may be possible for students to develop improved long-term scientific and organizational skills. Such students may become citizens who are better able to make wise political decisions about scientific issues facing society.

Summary

The problem of interest in this study was the scarcity of data concerning the positive long-term influence of inquiry learning activities on thinking behavior among college science students. The purpose of the study was to help close that gap by gathering data regarding how students perceive that influence. The data were gathered from a large public university with an ethnically diverse population that has incorporated inquiry learning activities into its freshman general chemistry course for the past 5 years. It was anticipated that with a relatively small but information-rich sample (Patton, 2002), significantly generalized patterns and themes could be derived that would show whether inquiry learning methods had been significantly effective in creating better learners in the long term.

In the following chapter, I establish through a discussion of current literature the immediate efficacy of active learning methods on academic understanding and performance while simultaneously demonstrating the lack of data regarding the longer term influence of these methods. In Chapter 3, I discuss my role as the researcher during the data gathering process, the population sampling methods, and the actual data collection method(s). In Chapters 4 and 5, I discuss the actual data collection and the interpretation of those data in the context of responding to the research questions.

Chapter 2: Literature Review

Introduction

In Chapter 2, the research problem and purpose of the study are restated, followed by a description of the literature search strategy. This is followed by a description of the literature review by POGIL-relevant categories, including the conceptual framework, key concepts, active learning, inquiry learning, general chemistry inquiry learning, higher chemistry and other science learning, and learning outside the sciences.

Problem and Purpose of the Study

The problem is the scarcity of evidence demonstrating the relationship between inquiry learning encountered in a general chemistry course and subsequent science student thinking and studying behavior. The purpose of the present study was to provide a clearer understanding of the perceived influence of inquiry learning activities within undergraduate general chemistry courses on the thought processes and learning abilities in the senior year.

One purpose of a college education is to teach individuals how to think (Brown, 2010; Douglas & Chiu, 2012). Especially in science (Miao et al., 2012), educators' desire is to teach pupils to become more analytical thinkers and better contributors in the larger society (Donald, Bohm, & Moore, 2009; Justice, Rice, & Warry, 2009; Myers, Monypenny, & Trevathan, 2012).

In this chapter, I briefly discuss the literature search strategy and the conceptual framework, and I provide an extensive literature review relevant to the research problem and the gap within the scholarly literature. The current literature abounds with articles about the immediate efficacy of active learning methods in improving teaching and learning. In the summary of Chapter 2, I discuss the literature gap demonstrating the need for this study.

Literature Search Strategy and Keywords

The relevant databases used included ERIC, Education Research Complete, ScienceDirect, PsychInfo, Academic Source Complete, Business Source Complete, ProQuest, Springer Online Journals, and Sage. Keywords and search terms included *active learning*, *chemistry*, *cooperative*, *undergraduate, experiential*, *POGIL (process oriented guided inquiry learning), learning cycle*, and *student-centered learning*.

Literature Related to Conceptual Framework

The phenomenon of interest was the perceived influence, if any, of process-oriented guided inquiry learning (POGIL) activities within a general chemistry course on thinking and processing behavior of senior undergraduates. The conceptual framework was the cognitive learning cycle (Abraham & Renner, 1986; Kolb, 1984; Spencer, 1999). The learning process is conceived as having three basic components: exploration (collection of data), concept invention (pattern induction and interpretation), and application (synthesis of new knowledge, hypothesizing, predicting; Spencer, 1999, p. 567). This approach is compatible with the constructivist worldview and most compatible with the manner in which students grasp concepts and retain scientific knowledge. The scientific method, which has been used since ancient Greek times, is the inherent method in constructivism. Scientific knowledge is established through a cycle of observations, conclusions, and further questioning (Chang & Goldsby, 2013; Fensham, Gunstone, & White, 2013). This is applied particularly in the use of POGIL activities, which were initially explored in the undergraduate science classroom as the inquiry learning (POGIL) method was developed (Moog & Spencer, 2008).

The learning cycle consists of three parts (exploration, concept invention, application). In addition, the conceptual framework includes the influence of a group context (social interaction), which seems most appropriate, as real-world research is typically collaborative (Spencer; 1999). Initially, the learner has a concrete experience, followed by observation, followed by (abstract) conceptualization, followed by experimentation (Kamis & Kahn, 2010). In practical terms, learning is a cyclic process beginning with field experience that involves data collection, followed by collective processing and interpretation of data, followed by conclusion and application of the information, which, consonant with the scientific method, involve further experimentation. This encourages a process of ongoing learning. This process occurs not in isolation, but in collaboration with others (social component).

Kolb (1984) articulated aspects of experiential learning and the learning cycle. Experiential learning theory actually describes four stages that incorporate initially concrete and later abstract elements. Specifically, Kolb articulated that effective learners need to develop four modes of learning equally: concrete experience (CE), reflective observation (RO), abstract conceptualization (AC), and active experimentation (AE). The four stages collectively and chronologically comprise one cycle. Kolb posited that learning requires first grasping knowledge by dealing with worldly experience via two different and opposing processes, namely concept interpretation (comprehension) and immediate tangible interaction (apprehension; Abdulwahed & Nagy, 2009; Kolb, 1984). The learning modes mentioned above correspond to abstract conceptualization and concrete experience, respectively. Abstract conceptualization and concrete experience together comprise what Kolb termed the *prehension* dimension of learning. Then, a construction phase is needed to complete the learning process, which Kolb termed the *transformation* dimension of learning (Kolb, 1984). This is accomplished through intention (reflective observation) and extension (active experimentation).

Importantly, what is distinctive about Kolb's theory is that apprehension and comprehension are deemed independent means of grasping knowledge, and intention and extension are deemed independent means of transforming experience. Moreover, all four elements of knowledge construction are given equal importance in their contribution to the learning process (Kolb, 1984). This result is in striking contrast to earlier models of learning (Abdulwahed & Nagy, 2009), which stress the preferred application of comprehension and intention. This is manifested in "traditional" lecture-oriented classes, which stress passive theory presentation followed by a written exam.

Abdulwahed and Nagy (2009) stressed the major implication of developing all four elements of the learning process as ultimately producing deeper and lasting learning. In particular, they focused on science laboratory classes, wherein students typically are enmeshed largely in the active experimentation (AE) phase of the learning process, which is part of the transformation dimension. In order for knowledge to be properly constructed, according to Kolb's theory (Kolb, 1984), knowledge must be first grasped and then transformed. As the prehension dimension is poorly or not activated, the knowledge gained is typically poorly retained (Abdulwahed & Nagy, 2009). Abdulwahed and Nagy (2009), in a study in England, proposed incorporating virtual laboratory exercises prior to the actual laboratory session so as to stimulate development of technique and interpretational skills. They posited that according to Kolb's learning theory, activation of the prehension dimension leads to better activation of the transformation dimension of learning, leading to active construction of lasting knowledge, or higher level learning. They described an investigation of 70 undergraduate engineering students in a series of experiments in a process control laboratory over a period of 8 weeks. The students were divided into groups of 16-18 students each. There were two control and two treatment groups. The treatment groups were exposed to a virtual laboratory presentation in the classroom prior to each lab session. Pre lab testing of both control-group and treatment-group students revealed statistically significant score differences (Mann-Whitney U Test Sigma < 0.05), indicating a superior grasp by treatment group students of tasks required to perform each laboratory. Regarding whether such "pre-exposure" led to true knowledge transformation, post lab testing revealed a statistically significant score difference between groups for some, but not all questions. However, the treatment group performed significantly better on questions arising from specific technique and procedure (Sigma < 0.05) versus general theory.

In summary, the conceptual framework herein described has been applied in both quantitative and qualitative research in order to obtain immediate feedback on the learning efficacy of inquiry learning methods. The current study was influenced by the results of the studies described in this chapter; they provided the foundation and inspiration to investigate the longer term influence of inquiry learning, specifically process-oriented guided inquiry learning methods.

Literature Related to Key Concepts

Inquiry learning, in particular process-oriented guided inquiry learning (POGIL) (pogil.org), is subsumed under the larger aegis of active learning. Active learning, in turn, involves active student participation of some manner and to some degree, following the constructivist educational worldview (Creswell, 2007; Kolb, 1984). While constructivism has been applied successfully in undergraduate humanities courses, instructors are increasingly recognizing the need for and benefit of constructivist application in science (Cardellini, 2010; Systemic Approach to Teaching and Learning [SATL], 2013). Active learning that involves some degree of inquiry also necessarily has a social component, because inquiry usually involves collaboration among students or peers.

The scholarly literature has an abundance of examples of active learning in general and inquiry learning in particular. As innovation is currently in demand in an increasingly technological world, novel ways of developing the creative thinker are being explored at younger ages (Knodt, 2009). At the undergraduate level, however, the scholarly literature contains many examples of inquiry learning research, particularly in general chemistry. It is important here to note that while general chemistry was the area where POGIL was first applied, its application has ranged well beyond general chemistry. Such research has been applied to other more advanced chemistry courses, the other basic sciences, computer science, and even beyond science into disciplines such as marketing, languages, and aviation. Most of the literature cited demonstrates the level of immediate, rather than long-term efficacy of active learning or POGIL techniques on retention and student performance.

Active Learning Methods

Active learning incorporates some level of student participation, which may be independent or cooperative. Moreover, from a student perspective, substantially more is gained when students work cooperatively in pursuit of a common goal. Problems are solved efficiently, and hands-on involvement produces true knowledge construction. In a qualitative study in China described by Yuqing, Xiaoshan, and Jian (2010), 48 undergraduate electronic and information technology students' performance was observed before and after a national electronics design contest. All students were from a single university. Competition and contest training was conducted for 21 days prior to the contest. The training incorporated practical and theoretical knowledge. Sixteen teams were formed from the 48 students. Qualitative data were gleaned from reflection reports and emails. The findings indicated that contest participation significantly enhanced the students' active learning, particularly in terms of collaborative problem solving and hands-on ability.

In general, although there are many forms of active learning, inductive (constructivist) learning has become increasingly favored over traditional deductive learning, particularly in the undergraduate science classroom (Campisi & Finn, 2011; Stewart, Brown, Clavier, & Wyatt, 2011). Shultz (2012) described the inclusion of scientific abstracts into an upper level (junior) undergraduate genetics course. Sixty-nine junior-level students were involved in a quantitative study within a single course lasting 10 weeks per quarter. The students were split into groups of approximately equal numbers and studied over two quarters. Selected abstracts were chosen per the material the instructor intended to teach. Students were required to read the abstracts in class; take a short, relevant quiz; and discuss the answers among themselves before the quiz was graded. The instructor then followed up with a class discussion. The idea was to promote critical analysis via collaboration through active peer discussion. Performance evaluation of abstract tests of five possible points each revealed average improvement from 2.027 to 2.5 the first quarter and from 1.853 to 2.181 the second quarter.

Brownell, Kloser, Fukami, and Shavelson (2012) compared the learning efficacy of a traditional, prewritten workbook-type undergraduate biology laboratory course and a laboratory course that was research oriented. Twenty students comprised each group (traditional and research-based), and $N_{\text{total} =}$ 108 students. The students were followed over one semester. The traditional method used pre-established cookbook-type procedures with predictable results. However, the research-oriented course incorporated elements of true scientific research such as developing hypotheses, data collection and analysis, and result reporting. The study incorporated mixed methods that included surveys, observations, and student interviews. The results clearly indicated a significant elevation in student confidence in conducting independent research and interest in conducting future research; the effect size for Cohen's *d* was at least moderate (0.5) in all categories surveyed. Between-group significance was based on ANOVA ($p < 0.05$), and within-group significance was based on paired-samples t test ($p < 0.05$).

White et al. (2011) introduced the Assessment of Critical Thinking Ability (ACTA), citing a need for critical thinking during scientific investigation, especially as applied not only to science, but also to law and public policy. Their open-ended assessment was administered to four different groups of students: students enrolled in a freshman biology course (N = 106), senior science majors (N = *47*), science graduate students (N = 19), and postdoctoral fellows in biology and chemistry departments (N = 13). The authors evaluated the participants' ability to integrate conflicting studies into a unified conclusion (Ability 1), design experiments to resolve ambiguities (Ability 2), and propose alternate interpretations of studies (Ability 3). The authors used a four-level rubric to evaluate levels of competence as follows: Level 1—Does not engage with the data at all, Level 2—Does not engage the data critically, Level 3—Analyzes the data critically, including at least one ambiguity, and Level 4 – Critically analyzes all the data. The data showed that critical thinking ability improves over the course of education, particularly in science. However, more specifically regarding abilities of analysis, most students, regardless of their science level, demonstrated far greater mastery of Ability 1 than either Ability 2 or 3. The authors concluded that the data suggest a deficiency in science curricula to foster development of essential critical thinking abilities. Additionally, they concluded that the sooner students are exposed to environments wherein they must exercise critical thinking, the sooner the development of these skills is realized. For example, for Ability 1, according to the two-tailed Mann-

Whitney U-test comparing independent samples, freshman versus seniors scored 2090.5 (p = 0.104), seniors versus graduate students scored 430.5 (p = 0.813), and graduate students versus postdoctoral fellows scored 94.5 (p = 0.270). At the other extreme, the same test for Ability 3 resulted in a score of 2168.5 (p = 0.189) for freshmen versus seniors, 402.5 (p = 0.515) for seniors versus postgraduate students, and 102.0 (p = 0.426). Although the above results do not indicate statistical significance, within Ability 2, seniors versus graduate students scored 254.5 (p = 0.005). Overall, the authors presented an important study, albeit over the short term. Their data exposed deficits in critical thinking ability even at the postdoctoral level, a general indication of the desperate need to implement more efficient teaching and learning strategies so as to develop more competency in science learning.

The literature by no means indicates that lecture should be totally abandoned in the classroom, particularly in science. If used creatively and in combination with active methods, it can result in rather successful learning. Roberts, Conner, Estepp, Giorgi, and Stripling (2012), in a qualitative case study, investigated the classroom techniques and behaviors of five instructors at a college of agricultural and life sciences over the course of two contiguous semesters. In addition to providing background information on their teaching philosophy, the instructors were observed using a video camera. Learning activities such as lecture time, questioning time, and cooperative learning time were charted. In addition, cognitive levels and teacher immediacy (positive/negative verbal/nonverbal behaviors) were tabulated. The results indicated a high sensitivity level exhibited by the instructors as a group. They were found generally to use lecture and questioning as their main teaching tools but did reach higher levels of cognition as such. While the instructors did model several desirable behaviors, the investigators expressed that generalizability could not be allowed.

Inquiry learning is based on the work of several theorists over the last century, including Dewey, Vygotsky, and Piaget (Moog & Spencer, 2008). Its use is supported based on the observation that students are more engaged in the subject matter, particularly that of chemistry, when they contribute as active participants rather than passive recipients in a strictly lecture format. This was corroborated by Cooper (2010), who asserted that problems have arisen as a result of the current lecture-based format, which is the way general chemistry is typically taught. In particular, according to the author, among other shortcomings, the course typically covers too much material, thereby favoring breadth over depth, it is taught as if all students were chemistry majors, it uses ineffective methods to enable students to understand concepts, it uses course design that ignores research on how students learn, and it fails to stimulate interest in the subject. Therefore, from several quarters, pressure has been applied to change the teaching methodology of general chemistry to a more active basis. While lecture has its place in the pantheon of teaching and learning methods, active methods have been shown overall to favor retention of chemical information (Herreid, 2013). In a descriptive essay, Herreid asserted that the literature reveals, at least preliminarily, that the lecture method of teaching produces only 4-8% of retention of material after six weeks. If the case-study method (hands-on independent student work, i.e., laboratory) is used as the chief method, 45-65% of material is so retained. Particularly, in advanced chemistry, active, participatory techniques engage students more extensively and produce subjective and objective learning gains. Herreid (2013) did concede, however, that more in-depth investigations are necessary to strengthen the above preliminary conclusions. In an investigation by Phillips and Grose-Fifer (2011), which consisted of two distinct studies, 70 organic chemistry II students (Study I) and 189 biochemistry students (Study 2) participated in a performance enhanced interactive learning (PEIL) workshop to supplement their lecture courses. That entailed a weekly two-hour workshop wherein students had an opportunity to collaboratively solve chemistry problems relevant to current lecture material and to make class presentations. PEIL and (control-group) non-PEIL results were compared, and the PEIL students performed significantly better (t = 2.02, $p < 0.045$, for biochemistry, and $t = 2.33$, $p < 0.02$ for organic chemistry). As well, students in a Likert survey reported significant gains in their depth of understanding and level of interest in the subject matter. In a study by Flynn (2012), a total of four organic chemistry classes ($N = 1000$ total for Organic Chemistry I, and $N = 1120$ total for Organic Chemistry II) were studied over a two-year period. Interventions included post-class questioning in an online forum setting and various active learning techniques during lecture class time. Student performance improved over time ($t = 5.60$, $p < 0.0001$), and in a Likert survey, a majority reported improved level of participation when post-class questions were available ($t = 2.45$, $p < 0.0101$).

Within an undergraduate engineering curriculum, transitioning more quickly into experimental design that actively and cooperatively engages students and has promoted higher levels of intellectual growth. Eppes, Milanovic, and Sweitzer (2012) described a decade-long effort by the mechanical engineering department at the University of Hartford to develop a program designed to elevate higher-level skill development and encourage deeper cognitive learning. Within the program, assignments essentially become more challenging and open-ended. As an example, the laboratory portion of an engineering course is designed as a three-tiered process: In module 1, classical experiments introduce the student to basic ideas, instruments, and procedures, in module 2, transitional experiments introduce some independent design elements but retain some defined objectives, and in module 3, groups of students collaborate in the design and execution of an experiment of their own selection but relevant to current course material. The objectives regarding learning outcomes were: Form concepts and deduce to one proposal, conduct research using available information, assess alternatives, design and conduct an experiment, operate within time and budget strictures, write a formal report, and present a report orally to a judging committee composed of faculty, alumni, and professional engineers. The skill areas evaluated are: written and oral communication, information literacy, collaboration, and design process. According to the authors, the most recent data show over 90% achievement of capstone skills, including 100% for technical reports, 95% for team skills, 91% for formal presentation, and 91% for design project. A student-centered, hands-on approach to learning, particularly in the sciences, may be initially met with resistance from faculty, who tend to teach the way they were taught. However, many develop the confidence to alter their approaches after examining the evidence for success. In quantitative study by Oliver-Hoyo (2011), two undergraduate chemistry classes, one a control group and the other an intervention group, were studied over one semester simultaneously for objective performance and student attitudes toward learning. The number of students participating (*N*) was not reported. The control group was subjected to traditional lecture teaching methods, while the intervention group was subjected to a highly collaborative learning environment on a regular basis. Specifically, students were assigned to small groups at round tables that were computer equipped allowing data sharing. Data were analyzed using ANOVA (for performance) and Likert survey (for attitude). The results indicated that over 77% of the students in the intervention group outperformed those in the control group, and a clear majority of the intervention group students expressed positive attitudes above those in the control group. Unfortunately, the actual raw data are not tabulated.

Inquiry Learning Methods

Guided inquiry learning is a subset of active learning. There is debate within guided inquiry about the type and degree of instructor scaffolding required for a successful experience. Scaffolding can range from student-generated questions and investigations(Miao, Engler, Giemza, Weinbrenner, & Hoppe, 2012) to significant initial instructor support and guidance, gradually withdrawn as students display more confidence and initiative in problem solving (Gijlers & de Jong, 2013; Lee, 2011; Moog, 2011; Moog & Spencer, 2008; Tsai & Tsai, 2014;). In a study by Lee (2011), three consecutive entering university freshman groups (*N* = 3,018, N = 3,048, and *N* =3,599) were evaluated from university records regarding the relationship between whether they had taken a Methods of Inquiry (MOI) course taught in the university and retention to graduation within 4-5 years. The MOI course taught students active approaches to learning (i.e., engagement of the material), techniques of learning (i.e., concept mapping, practice exams), and dynamic elements of learning (i.e., persistence, enthusiasm, curiosity). They were also introduced to the concepts of critical thinking and analysis. The results indicated that students who had taken the MOI course were about twice as likely to return to school the following year or to have graduated versus those who had not.

Johnson, Caughman, Fredericks, and Gibson (2013), in a qualitative study, examined by interviews the reflections of three undergraduate mathematics instructors teaching abstract algebra with a constructivist orientation. The major idea was to allow and encourage the development of formal mathematical themes and ideas emanating from initially informal ideas and activities within a specialized inquiry-oriented curriculum. The results indicated a consistency among the three instructors regarding their perceptions that the students developed a deeper level of conceptual learning with the inquiry approach versus with lecture.

In a New Zealand study, Spronken-Smith (2010) conducted an analysis of inquiry-based learning at the undergraduate level and investigated the strength of its connection to undergraduate research. She determined three modes of such learning: Structured, guided, and open. The first entailed an instructor furnishing the problem and means to solve it. The second entailed the instructor furnishing the problem but students exploring the means to solve it in self-directed fashion. Within the third mode, students generated the question or problem and self-directed in solving it. Educationally, the strongest connections between research and teaching were found in the third mode, which was most completely student-centered and self-directed. A survey of 940 students revealed a clear preference for the open inquiry mode of learning. The author did point out that a purposefully-designed, structured inquiry course is potentially useful in building inquiry and research skills as well.

In a South African mixed-methods study, Ramnarain (2013) investigated 263 teachers' perceptions of implementing inquiry-based learning curricula in the classroom from urban, suburban, township, and rural schools. Quantitative data were obtained via Likert scale responses, while qualitative data were obtained via individual interviews of 10 teachers within the 263 total. Data analysis showed that 94.2% of the teachers agreed or strongly agreed that inquiry learning assisted their students in developing experimental skills, and that 83% of teachers agreed or strongly agreed that students derived greater benefit through independent inquiry versus teacher demonstration. These responses were amplified and elaborated during the interviews. One teacher, for example, thought that inquiry methods allowed students to develop investigative and observational skills as well as problem solving abilities. Another teacher thought that practical work developed competency in measurement and recording observations, and developed confidence overall. That teacher stressed student actions versus demonstration as the more effective teaching agent.

In a qualitative study, Jones, Scanlon, and Clough (2013) investigated via a semiformal case study of inquiry learning, how technology (software) and environment influence different groups of learners. Forty secondary grade-school students were monitored over an 11-week period, during which they met for an hour weekly. The students self-formed groups in which they independently investigated various aspects of food sustainability (i.e., meat production, food decomposition) using various media, including videos and internet searches. The study environments varied during the week and included the classroom, a nature reserve, field trips, and students' homes. Supportive software was developed so that it was usable and accessible regardless of the particular environment. Data were acquired using audio, video, and field notes and transcriptions of meetings with teachers, interviews with parents and students, focus group meetings, and students' written work. The results indicated that the mobile technology provided support for the entire inquiry investigation without adult intervention. Specifically, students were able to visualize their own data and exchange data interactively. The technology allowed students to choose their subtopics of inquiry and take responsibility for its planning (personal inquiry). Student feedback indicated clearly their engagement in the activities and their personal relevance.

Donald, Bohm, and Moore (2009) introduced grade-school students to inquiry-based learning through investigation of beach ecology via formation of preliminary research questions and a subsequent field trip. The objective was to evaluate retention of information. The students were directed to write up their findings in a scientific report and present those findings in seminar-like fashion. They were then formally tested twice, with a two-month vacation interval between tests. Stronger students did not show any change in retention, but those students considered weaker improved their scores significantly ($p < 0.001$), with the lowest score improving from 11/36 to 22/36, suggesting a greater degree of engagement with inquiry learning activities. According to the authors, their research indicates that longer term knowledge retention is promoted by the use of inquiry learning activities, but that further research is needed about levels of engagement, critical thinking, and problem solving ability.

In a qualitative dissertation, Barthlow (2011) studied the influence of POGIL-oriented teaching on college preparatory high school chemistry students mainly in terms of their tendency to have alternate conceptions of particle theory. A total of 318 students participated, with 169 students in the control group and 149 in the intervention group. POGIL teaching was randomly assigned. The results, analyzed by ANCOVA, revealed that the use of POGIL versus traditional lecture method significantly reduced students' tendency for alternate conceptions of particle theory in chemistry and significantly improved their relative performance ($F(1,3132 = 15.224$, $p < 0.0001$).

Akinoglu (2008), in a study of 100 sixth to eighth grade students in Turkey, used surveys to garner information from science students regarding their perceptions of the effectiveness of various teaching methods, including active inquiry learning activities. In turn, those activities included science projects that required students to plan and solve complex science problems independently with the instructor acting as facilitator. As a result, 47% of students reported an increased level of interest in science and technology class.

Brown (2010) incorporated inquiry learning activities into an ordinarily lecture-based one semester undergraduate medicinal chemistry course. Students were monitored during the fall semesters over a 3-year period (2007 – 2009, N = 66, 73, and 78, respectively). Grades quantitatively improved from an overall B-C orientation (2007) to one that was A-B centered (2008 and 2009). Mean exam scores went from 82.3 (2007) to 85.0 (2009). The fall 2007 average scores were significantly different ($p < 0.05$) from those of 2008 and 2009. Two-tailed unpaired student's *t* test was used. The fall 2007 average test score was significantly different from those of 2008 and 2009, and the scores of the active learning classes of 2008 and 2009 were not significantly different from each other (p = 0.017, 0.010, & 0.957, R^2 = 0.04165, 0.04623, & 0.00002039, respectively). As well, students reported a relatively high satisfaction level with the course design and execution, although these responses were not quantitatively evaluated.

Simonson and Shadle (2013) described the major tenets of inquiry learning activity, based on learning cycle fundamentals and using cooperative small-group interaction as its practical cornerstone. As such, students analyze data, draw conclusions, and synthesize knowledge largely independent of the instructor. Textbooks are incorporated only in supplemental fashion. Using relatively small samples (N = 52 – control group, N = 64 -- inquiry learning group) within an undergraduate biomechanics course, they demonstrated a trend of overall superiority with respect to the final grades of inquiry learning students. The number of A grades increased by 10%, and the number of B grades by 13%. Mid-level performers appeared to numerically benefit the most, as the number of final C grades reduced approximately 20%. The number of D grades in the inquiry group was 32% of those in the standard lecture group. The impetus for implementing inquiry learning was the relative lack of student engagement when passive lecture methods were used.

Goldey et al. (2012) described implementation of an inquiry-oriented college freshman biology course that effectively replaced a more traditionally taught biology course, with the goal of improving student learning and retention. The course incorporated guided inquiry-based experiments, primary literature searches, analysis and interpretation of data, and collaborative classwork. Class assignments and examinations demanded higher order processing. Despite no statistically significant objective grade improvement over the previous traditional course, 94% of students were retained within the BA and BS biology track over the three-year study period, as compared to 79% retention prior to implementation.

As inquiry learning is primarily learner-based, students may need some scaffolding at least during an initial period after they are introduced to it. Hagemans, van der Meij, and de Jong (2013) described using concept mapping as a learning support during inquiry learning activities. Sixty eight upper-level science track students from three physics classes were studied. Comparing pre- and posttest scoring, students in concept mapping groups outperformed those in the control group ($p < 0.001$, Cohen's $d = 1.03$).

However, if an inquiry learning activity is infused with interactive technology, such as computer simulations, students may be able to garner the initial support they need through such interaction. Moore, Herzog, and Perkins (2013) described a study of undergraduate chemistry students learning about atomic polarity through interactive computer simulation models. Students were allotted 10 minutes of preliminary interaction time with the program ("implicit" versus explicit scaffolding). The majority reported that the use of the program was easy. Levy, Aiyegbayo, and Little (2009) investigated, in a qualitative study, the effectiveness of a computer based learning management system with undergraduate academic staff in the Arts and Social Sciences Departments as a tool to support inquiry-based learning. They concluded that with a flexible attitude, such a management system can be adapted to allow student-centered development of useful inquiry-based activities.

Undergraduate student self-concept (self-perceptions of one's own abilities/performance) improve when students are exposed to inquiry learning activities. Within constructivism, self-concept is considered under the affective domain, one of three domains considered when evaluating learning (Lewis, Shaw, Heitz, & Webster, 2009). Interestingly, when compared with other types of active learning such as collaborative learning and problem-based learning, students may perceive that collaborative and problem-based learning approaches are more helpful when used with lecture. However, students tend to be more engaged and think more deeply when simple inquiry-type learning activities are used. In a study by Mohamed (2008), a total of 57 introductory-level undergraduate chemistry students were studied over the course of one summer and one fall quarter. Students were divided into distinct groups using either traditional lecture or collaborative activities as the instructional method. Performance results indicated that the collaborative learners were significantly higher achievers than those under lecture format [$F(2, 194) = 7.63$, $p < 0.001$]. The author suggested that when introducing active, student-centered learning methods, providing short preliminary lectures prior to engagement in inquiry learning activities may provide needed temporary scaffolding.

According to Kulatunga and Lewis (2013), the manner in which peer leaders (graduate or higher level undergraduate students acting as class facilitators) verbally interact and communicate with POGIL group members can influence the argumentation and discussion within the group during POGIL activities. The quality of questions posed by the peer leader can stimulate deeper and more productive discussions by each group, leading to enhanced understanding and learning. They studied undergraduate students in a first-semester general chemistry course that incorporated weekly 50-minute POGIL sessions. Sessions were conducted by peer leaders comprised of trained undergraduate or graduate students. Students worked in small groups of three or four. Data were acquired from two small student groups via video recordings. The verbal behavior categories analyzed were: direct teaching, short questions, encouraging, maintaining, probing and clarifying, acknowledging and validating, confronting discrepancies and clarifying options, and offering suggestions. The percentage of verbal statements from each category from peer leaders did not differ significantly (chi square (7) = 4.78, $p = 0.687$). Moreover, the results showed a strong relationship between student argumentation and peer leader verbal behaviors. Data and warrant components of argumentation were analyzed. 64% and 61% of the data components arose from short questions posed by the two peer group leaders, and 61% and 62% of all warrants arose from probing and clarifying verbal cues.

General Chemistry Inquiry Learning

In a quantitative study, Lewis and Lewis (2008) studied 2,838 general chemistry students over a three-year period, comparing performance in standard lecture versus peer-led guided inquiry format. Using both an external standardized exam model and internal (instructor-created exams) to evaluate performance change over time, they found a 4.7 percentage point improvement in midterm exams of students in the peer-led guided inquiry environment.

Murphy, Picione, and Holme (2010) investigated comparative quantitative test performance in an undergraduate chemistry course by replacing traditional lecture inpartially or totally with inquiry learning activities depending on the section. The results were actually mixed; in some cases mean test scores were higher in inquiry learning sections and in other cases higher in control, or lecture sections. As well, in certain cases, mean differences were not significant, so the study would seem to confirm that lecture is yet useful in the undergraduate classroom.

As observed in an Australian study of first-year or freshman chemistry undergraduates, the collaborative workshop method based on inquiry activities can produce grade improvements and elicit favorable comments from students as a preferred method of teaching (O’Brien & Bedford, 2012), although students may initially resist and protest the switch from lecture. Such workshops typically use role assignments, such as “manager,” “presenter,” “recorder,” and “reflector” (Moog & Farrell, 2011). Furthermore, a general chemistry laboratory procedure that requires more inquiry promotes a deeper level of cognition and social interaction (Xu & Talanquer, 2013, pp.

29-36). This would suggest that with perhaps a brief preliminary lecture, students should be challenged to devise their own lab methods to solve a particular problem. Such a challenge would tend to promote greater inquiry, analysis, and social interaction. In terms of laboratory report write-up, inquiry-oriented laboratories tend to promote a shift from purely factual knowledge acquisition and regurgitation to a largely problem solving mentality (Xu & Talanquer, 2013).

Of course, there is a threshold below which inquiry may not be as effective as educators might anticipate. The student must have adequately developed basic cognitive, affective, and collaborative skills expected at the collegiate level in order to succeed in any type of collaborative exercise (Geiger, 2010). According to research by Geiger (2010), the level of incoming student preparedness should influence the rate of increase of inquiry-type learning and cognitive challenge for optimum learning to occur. Highly dependent learners typically find an inquiry-oriented environment stressful. The threshold for success, for example, in general chemistry appears to be Piaget's formal operational stage of cognitive development, and those students not operating at that level run a significant risk for failure.

Loo (2013) described a case study specifically addressing chemical information literacy for undergraduate students. Students were initially instructed on the use of the scientific literature to be applied when preparing laboratory reports. Sessions incorporated not only passive instruction but collaborative and specifically POGIL elements wherein students learned their chemical information skills. Instruction followed an iterative process wherein after initial instruction, student teams addressed exercises and problems, solving them collectively, during which the instructor served as facilitator, guiding students to goals by encouraging ongoing analysis and reflection. Finally, the class came together for discussion and exploration of further objectives. The author reported success from those sessions in that students gained valuable practical experience with the exercises and developed a strong collaborative spirit. However, he also reported challenges that included extensive preparation time and scaffolding effort to ensure student participation and collaboration.

Inquiry Learning in Advanced Undergraduate Chemistry

Although inquiry operational materials have been written primarily for general chemistry, inquiry application has now extended at least into organic chemistry and beyond (Pursell, 2012). When higher level chemistry students are exposed to research and inquiry-based experiences, retention improves and critical thinking is boosted. Knutson, Smith, Wallert, and Provost (2010) described a research- and inquiry-based one-year biochemistry course that incorporated primarily laboratory work. In that laboratory context, groups of students were required to design and execute a laboratory research project incorporating various biochemical methods. The instructor acted more as a facilitator rather than assuming a traditional role. Pre- and posttesting revealed objective performance improvement from an average of less than 20% to 88%. One-year follow-up testing revealed an average score of 85%, reflecting a high long-term skill retention rate. Unfortunately, however, the data were not formally analyzed for statistical significance.

Luxford, Crowder, and Bretz (2011) reported about an inquiry learning activity that was incorporated into a unit on molecular symmetry within an advanced inorganic chemistry course. The investigation occurred over two class periods, each 50 minutes long. The class of 19 students was comprised of 5 undergraduates and 14 graduates. The students self-organized into groups of no more than four each and given molecular modeling kits. During each period, students worked with the kits to make models in order to visualize symmetry in molecules. In an anonymous survey students overall reported improvements in their perception of three-dimensional symmetry in regard to complex molecular structures. No descriptive statistical analysis of significance was included here, however. In a descriptive and prescriptive paper, Bridgeman, Schmidt, and Young (2013) discussed analogical methods to help teach second-year undergraduate chemistry students about vibrational modes of molecules in molecular orbital theory. For example, students could actively participate in their learning by using human choreographic poses and images to help learn about molecular vibrational modes and spectral assignments. Students reported that they were better able to visualize and understand the vibrational aspects of molecular orbital theory via the use of visual and kinesthetic representations.

Inquiry activities have had positive learning effects in organic as in general chemistry. In a study by Chase, Pakhira, and Stains (2013), one first semester general chemistry and one first semester organic chemistry section were studied ($N = 271$ and $N = 182$, respectively). Each course contained one discussion section per week, wherein POGIL activities were introduced. Intervention and control groups (sections) were compared. Grades improved significantly for the students in the general chemistry intervention groups versus those in the corresponding control groups (ANOVA, $p < 0.048$). However, such a comparison within the organic chemistry course yielded no such difference. However, in another study by Hein (2012), when the inquiry-learning approach was incorporated into an organic chemistry course, students performed better (39.2% versus 29.0% percentile ranking) on a national American Chemical Society final exam than their strictly lecture-oriented counterparts.

In a study of introductory organic chemistry students, Schroeder and Greenbowe (2008) showed that performance in an organic chemistry course can be elevated by introducing inquiry learning activities with the Science Writing Heuristic. A group of summer session students ($N = 24$) was compared with another group ($N = 111$) that had taken the course the previous spring and were exposed to strictly lecture format. The intervention group was given POGIL activities consisting of experiments and organic problem solving, all done collectively in small groups. Sharing of information was permitted among groups as well, and each activity culminated in a larger class discussion period. Overall objective performance within the intervention group was superior to that of the previous control group, and a Likert survey showed favorable student perception regarding the aid the laboratory activities gave them toward understanding lecture material. An important post-script is that non-science majors taking the course reported a perception of relatively high understanding and ease in taking the course.

The guided inquiry aspect of POGIL is significant. Otherwise, students may perceive an excessive workload and disorganization if open inquiry were used in laboratory. For example, Barron (2011) conveyed the effectiveness and necessity of at least some degree of scaffolding in an inquiry-learning-oriented forensic science laboratory class of 34 graduate students. Over the course of a semester, students with a chemistry background were distributed among groups with only a biology background. The chemists served as scaffolding agents in supportive roles. As well, student groups were given a standardized set of analytical directions rather than being asked to compose them. A Likert student survey revealed that the students with a biological background were less confident than those who had more chemistry in their backgrounds, particularly in the earlier stages and without supportive scaffolding. However, 65% of the biologists reported that actively interacting with the chemists later helped their understanding of the subject matter.

In a mixed-methods study of Thai biotechnology students (Ketpichainarong, Panizpan, and Ruenwongsa, 2010) 54 fourth-year biotechnology students were studied over one academic year. They were organized into study groups of 5-6 students each, and the groups were directed to conduct cellulase activity experiments at three successive levels: Guided inquiry, open inquiry, and independent experimental project design. At the first level, instructors were available to facilitate and guide experimentation. At the second level, students designed their own experiments to measure cellulase activity. Finally, at the third level, student groups applied their acquired knowledge to design project applications for use in industry. Each group ultimately presented their research to the larger class. Conceptual understanding was significantly raised at every level (t = 4.610, 14.168, & 13.590, p <0.001). The consensus of the interviews was that students appreciated the challenging nature of the laboratory, learned to think through peer interaction, and enjoyed all activities because they resembled "real life events."

Inquiry Learning Applied to Other Sciences

Inquiry learning principles can be applied to other basic sciences with results similar to that of general and other chemistry. For example, Brown (2013) conveyed the effectiveness in using guided inquiry as part of a set of diagnostic tools in a medical parasitology class. Case-based guided inquiry was used in diagnosing hypothetical medical cases. After initial case presentation, the learning cycle elements were used to identify signs and symptoms (exploration), connect biology to pathology (concept invention), and finally to construct a reasonable diagnosis (application). 87% of students reported at least good gains in confidence and understanding. In a study of undergraduate microbiology students (Taylor, Wagner, & Canterberry, 2012), students worked in groups in a hands-on project involving scanning and transmission electron microscopy. They studied interpretation of actual micrographs of bacteria and fungi samples by comparison of the various aspects of the two types of electron microscopy.

While no statistical analysis was included, pre- and post-testing revealed improvement of microscope operation and application from 44% to 70%, and improvement of content knowledge from 42% to 58%.

Myers, Monypenny, & Trevathan (2012) investigated the influence of inquiry learning activities on perceived learning within an undergraduate internet technology course. They incorporated three to five POGIL-infused class sessions per week during a semester course. POGIL activities incorporated directed (answer from provided information), convergent (require group work to answer), and divergent (range of possible valid responses) questions. Students worked typically in randomly-formed small groups of 4 students each, with a role assigned to each student within a group. Student feedback surveys post-course indicated that students substantially favored inquiry learning versus traditional lecture in terms of course delivery. The survey overall indicated that interactive, collaborative teaching methods fostered improved student perceptions regarding concept understanding and overall learning enhancement. Specifically, over 85% of students of a sample *N* = 142 agreed or strongly agreed that: The use of POGIL raised their learning productivity owing to interactivity, they appreciated the benefits to learning outcomes using the collaborative activities versus isolated, individual work, and POGIL assisted them in understanding difficult concepts.

Reflecting on their experiences teaching undergraduate biology courses that incorporated a POGIL-infused guided inquiry format, Gormally, Brickman, Hallor, and Armstrong (2011) concluded that considerable effort is required in converting from a standard lecture and “cookbook” laboratory course to one in which students must take the initiative in problem solving. They emphasized that such curriculum development is an ongoing process that requires student feedback and microadjustments. Yet from an objective standpoint they noted that although students initially resisted the innovations, by the end of the course they were able to more acutely determine their own abilities and readily acknowledge their achievements.

In a study by Brown, Pond, and Creekmore (2011), pharmacotherapy post-graduate students were enrolled in an elective toxicology course that used inquiry learning strategies 50% of the time. In a case-oriented class, in which students are placed in small teams to solve relevant problems, students assumed roles in groups (i.e., group manager, recorder, reporter, etc.) to develop answers to hypothetical patient cases. Students taking the case-based toxicology course within the larger Pharmacology II course performed significantly better on a national exam than those not so enrolled (89.5 +/- 2.0 versus 84.0 +/- 1.9, $p < 0.05$, two-tailed unpaired t tests).

In a study by Douglas and Chiu (2012), POGIL activities were incorporated into an Introduction to Materials college engineering course. A comparison control group was also used in the study. There was no statistically significant ($p < 0.05$) difference in objective performance between the control and POGIL groups during the first semester, but there was such a difference ($p < 0.05$) during the second semester. While the initial treatment (POGIL) group did not show a significant difference in objective performance in the course, the second group (following semester) did ($p < 0.05$).

Martineau, Traphagen, and Sparkes (2013) developed a teaching model in undergraduate biology that incorporated POGIL methods. Within that approach, students were arranged into teams that generated hypotheses based on fundamental biological questions. Afterwards, they were directed to design relevant experiments that would test those hypotheses. Students were required to assume roles that directed each of them to either read and interpret relevant literature, design experimental parameters, or develop data collection methods. Afterwards the hypotheses and experimental designs were presented to the entire lab section for votes on preferred design, and ultimately findings of each team were presented and discussed before the entire class. Weekly meetings consisted of one lecture and two lab sessions. Undergraduate biotechnology students performed significantly higher on a post-test versus pre-test of laboratory knowledge ($p < 0.001$) after performing a cellulose-cellulase interaction laboratory experiment that incorporated guided inquiry activities. In particular, the performance results suggested that students were able to determine how to measure enzyme activity based on their exposure to guided inquiry learning activities.

Inquiry Learning Outside the Sciences

Inquiry learning has been evaluated by increasing numbers of faculty and students in many departments as curiosity about the method has expanded (Kussmaul, Ellis, & Hislop, 2012). In particular, guided inquiry learning has been embraced by certain sociology instructors, who encourage students to ask deeper, more encompassing questions and write reflectively (Rusche & Jason, 2011).

The effect of active learning, particularly that of inquiry learning, activities can be adapted and observed beyond undergraduate science classrooms. Johnson (2011) demonstrated that learning German grammar is facilitated using inquiry learning activities that incorporate models and collaboration rather than primarily lecture. Hale and Mullen (2009) showed that performance in an upper level marketing class can be dramatically improved replacing lecture with inquiry learning activities. They compared a control group that used lecture to evaluate a series of slides and solve a problem in class with a set of inquiry-learning groups of students with assigned roles to evaluate the same slides and solve the same problem independent of the faculty lecturer. The result was an approximately 15% increase in quiz score performance by the inquiry-learning group.

In a study involving collegiate aviation students, a significant learning improvement ($p < 0.05$) was noted after traditional lecture was replaced by inquiry learning activities (Vacek, 2011). In noting the compatibility of the traditional flight lab and inquiry learning models, the author concluded that inquiry learning is specifically applicable to aviation education.

In a qualitative study in Botswana, Mannathoko and Major (2013) investigated the extent to which grade school pupils were engaged in art, craft, and design activities as part of the development of creative and practical skills. Eight teachers from four schools in Botswana were interviewed and audio recorded in semi-structured fashion regarding their perceptions on the extent to which students were engaged in art, craft, and design (ACD) activities, the success in the strategies of teaching ACD, and the extent to which students demonstrated evidence of practical skill development. As well, data were generated via observations of classroom lessons via videography. Observations revealed that teachers only nominally engaged students in the practical activities and the students were improperly or insufficiently guided on procedure. These observations were corroborated by interview information. During the interviews, teachers indicated that they were insufficiently prepared to teach the practical aspects of ACD learning. Evidently the environment that was created for the students was not conducive to ACD learning, which prompted the authors to conclude that such teachers need to elect for appropriate in-service training.

Summary

The literature converges on two main themes: (a) the immediate objective efficacy of inquiry learning on objective learning enhancement, and (b) the reported increase in student confidence and interest in the subject matter. While this is encouraging, there is little data regarding longer-term efficacy of inquiry learning on thinking patterns in the science and non-science classrooms.

The literature is not entirely devoid of quantitative studies of the longer-term influences of inquiry-based learning. Justice, Rice, and Warry (2009) conducted a quasi-experimental study comparing social science and kinesiology students who had previously taken an inquiry seminar relevant to their program of study with those who had not. Among the skills evaluated were: reading and summarizing information, research design, critical thinking, and accessing information. The results indicated overall a significant skill superiority attained by inquiry students versus their non-inquiry counterparts, within two years of testing. Those students evaluated who had participated in inquiry-learning activities after taking the course seemed to maintain those acquired skills three to five years. At least preliminarily, these results are promising as far as exploring the long-term influences of inquiry learning activities on thinking behavior. What the literature review has demonstrated is that there is ample research demonstrating the immediate learning efficacy of inquiry learning, both in a qualitative as well as quantitative fashion. Specifically, undergraduate students, particularly those of science, demonstrate superior test performance and report greater interest, engagement in material, and greater self-confidence when inquiry methods are used. Moreover, not only is the inquiry approach effective in undergraduate science learning enhancement; its effectiveness extends beyond the science to the non-science classroom.

Yet, as the reader may surmise, there are few studies presented here that demonstrate that the efficacy of inquiry methods in the undergraduate classroom have had a positive lasting impact beyond the current semester or year during which the student took the course (Justice, Rice, & Warry, 2009; Knutson, Smith, Wallert, & Provost, 2010). Moreover, in this context, specifically qualitative studies investigating the long-term impact of inquiry methods on undergraduate science learning (i.e.) appear from this literature study to be non-existent. What the current study therefore will do is extend knowledge regarding the longer term (i.e., three years) effects of POGIL methods on thought processes of senior-level undergraduate students. Specifically, the purpose of the current qualitative study, which incorporates student interviews, was to explore how senior students' experience(s) with POGIL learning activities in their general chemistry courses have influenced their thinking, processing, and studying behaviors in their current science courses. Chapter 3 discusses population sampling and data collection methods as well as my role as the researcher.

Chapter 3: Research Design and Methodology

Introduction

The purpose of this dissertation was to ascertain the relationship, if any, between the undergraduate general chemistry courses with POGIL content that freshman students experienced and the thought processes and organizational skills of senior students. The research was unique in that it focused on the influence of constructivist, active learning methods, specifically POGIL technique, within a general chemistry course on senior student thinking and learning methods.

Within this chapter, I discuss my role as the researcher, the method used to sample the population of interest and its justification, the methods of data collection, the type of data streams collected, resolution of issues of trustworthiness, and ethical considerations. Specifically, I sought to learn through the interview process how participants described how their general chemistry knowledge had been obtained with POGIL. I sought to learn how they processed chemistry data and what patterns emerged from that processing. More importantly, I wished to know how they perceived a change in how these mechanical and mental processes helped them learn. I wished to know how they expressed that change, and whether it benefitted or detracted from their learning. I also wished to find out the influence of the collaborative group experience on their information processing.

Research Design and Rationale

There are much quantitative data attesting to the short-term learning efficacy of POGIL-infused science courses, particularly those in chemistry. However, there are no qualitative data regarding the long-term influence of POGIL on the thought processes and learning patterns of more experienced students (i.e., senior undergraduate students), particularly within their science courses. In particular, there are little or no data regarding senior students' perceptions of the influence of POGIL-infused general chemistry on their current learning behaviors. Specifically, for this study, I decided on the grounded theory approach over the other qualitative approaches because its objective is to develop a generalized theory of behavior or model of action deriving from the participants' perceptions (Creswell, 2009; Patton, 2002). The narrative approach focuses more on chronological history in story form and as such was rejected. Phenomenology was rejected because students in this case had not experienced a singular event, and ethnology was rejected because I was not focusing on one or more characteristics of a large cultural group, such as behavior or language. Further, I was not immersed in the students' day-to-day experiences and observation of such behaviors. A case study was not applicable, as I was not concerned with a single case bounded in time or place (Creswell, 2007). Grounded theory was useful and applicable within the current study, as all participants underwent the process and expressed their perceptions of that process.

Research Questions

RQ1: How do senior-level undergraduate students describe the POGIL aspects of their freshman-year general chemistry experience:

1. In terms of data collection (exploration)?
2. In terms of interpreting their data and inducing patterns or themes (concept invention)?

3. In terms of knowledge synthesis, hypothesis, and prediction (application)?
4. In terms of a group setting (social interaction)?

RQ2: How do senior-level undergraduate students describe the influences of the POGIL aspects of their freshman general chemistry course on their approaches to learning in their senior science courses:

1. In terms of data collection (exploration)?
2. In terms of interpreting data and inducing patterns or themes (concept invention)?
3. In terms of knowledge synthesis, hypothesis, and prediction (application)?
4. In terms of a group setting (social interaction)?

This study was conducted using a grounded theory approach. From the open-ended interview data collected during the study, I can contribute toward a new model of active teaching and learning. This contribution could lead to positive social change by giving educators insight into how to generate or enhance skills in students that lead to a lifetime of careful thought about scientific issues.

Participant Selection

Individual and focus group interviewing were the methods used during the study. Group interview data were obtained to encourage those who might not otherwise be willing to fully reveal their true perceptions and feelings during a private interview (Creswell, 2007). The population consisted of 15 senior undergraduates. The available population was identified by examination of students' university records in order to identify senior science students who had completed the POGIL-oriented general chemistry course. The dean of the College of Natural and Mathematical Sciences within the university agreed to examine eligible senior student records and to generate a student subject list based on the parameters I supplied. Following approval by the Institutional Review Board of Walden University (approval #05-30-14-0142700), the sample was generated by letters of invitation to participate. The gender distribution was different from the approximately 50/50 male/female ratio that was desired, indirectly owing to the paucity of responses overall. As stated earlier, participants were two men and 13 women. The only criteria beyond these distributions were that the students had attended the POGIL-oriented laboratory general chemistry courses at the university and were senior undergraduates. I invited considerably more than twice the number of participants needed due to lack of student responses and invitation acceptances. Students were invited based on random number generation.

According to Patton (2002), there is no established general rule for sample size in qualitative investigations. Purposive rather than random sampling is used because depth rather than statistical breadth is sought in qualitative studies (Miles & Huberman, 1994; Patton, 2002). Patton (2002) also stressed the idea of saturation, wherein sampling size is determined by type and amount of information sought. When that level is reached (saturation), redundancy then occurs, and no further new information is gathered.

Role of the Researcher

My role as the researcher was to act as a participant/observer during the individual and focus group interviews. Although researcher bias is difficult to eliminate, I conducted interviews in as objective a manner as possible using initially scripted questions and using the techniques of empathic neutrality (Patton, 2002). That is, I endeavored to conduct interviews and gather data as nonjudgmentally as possible. I followed up with further probing questions as prompted by students' initial responses. As the students were from a well-known East Coast university at which I did not have any established professional relationships, the probability of objectivity was enhanced. My data collection occurred via Skype due to practical considerations, including limited and/or conflicting schedules of the students and myself. I was careful to guard against the natural tendency to be more attentive to responses that were more in agreement with my research goals. In that regard, I daily reflected as necessary in my own journal writings concerning any attitude bias problems and adjusted accordingly. I asked all questions in a neutral manner so as not to unduly influence student responses.

Instrumentation

The interview was a primary data collection instrument, supported by the use of focus groups and researcher journaling to develop the grounded theory (Creswell, 2007). Interview questions were derived from the research questions, as shown in Table 1, although they were not direct translations of the research questions (Maxwell, 2013, pp. 100-101). The interview instrumentation followed the interview guide approach, after Patton (2002). This format established and retained some outlined structure, yet allowed for more comprehensive data collection among participants.

All data were collected by me personally. Data were collected via individual and focus group interviews of senior-level undergraduate students except where noted. Follow-up questions were asked as prompted by student responses. The initial invitation and consent form did indicate that follow-up interviews might be necessary so that participants knew beforehand that they might be recontacted for a second interview appointment later. As reinforcement, participants were reminded about the possibility of such follow-up contact.

Table 1

Research Questions and Corresponding Interview Questions

Research question	Description of individual interview questions	Description of focus group questions
1. How do upper level undergraduate students describe the inquiry learning aspect(s) of their freshman-year general chemistry experience: A. in terms of data collection (exploration)? B. in terms of interpreting their data and inducing patterns or themes (concept invention)? C. in terms of knowledge synthesis, hypothesis, and prediction (application)? D. in terms of a group setting (social interaction)?	1. Interviewees were asked to describe the structure of their general chemistry course in order to provide a basis for more specific questions on each facet (anticipate two parts: lecture and inquiry laboratory). (RQ1A) 2. Interviewees were asked to relate how (if at all) each part (of the structure) was effective in helping them understand chemical concepts, because I wanted to establish the distinct roles, if any, of each part in the learning process. (RQ1B) 3. Interviewees were asked to tell how (if at all) the inquiry lab portion of the course helped them to understand chemical problem solving. I wanted to know details about how their thinking process was modified, if at all. (RQ1C)	1. Group interviewees were asked to compare and contrast the structure of the laboratory (discovery) portion of their general chemistry course with other laboratory courses they were taking or might have taken. I wished to get multiple perspectives on group impressions of course structure. (RQ1A) 2. Group interviewees were asked to describe any advantages or disadvantages of collaboration in the lab, because I wanted details of how collaboration was molding the science thought process. (RQ1D)

(*table continues*)

Research question	Description of individual interview questions	Description of focus group questions
2. How do upper level undergraduate students describe the influences of the inquiry learning aspects of their freshman general chemistry course on their approaches to learning in their current courses: A. in terms of data collection (exploration)? B. in terms of interpreting data or inducing patterns or themes (concept invention)? C. in terms of knowledge synthesis, hypothesis, and prediction (application)? D. in terms of a group setting (social interaction)?	1. Interviewees were asked what science courses they were currently taking, because I wanted to determine whether they continued in chemistry or other natural science, per the focus of the study. (RQ2A) 2. Interviewees were asked how they recorded information communicated in lecture, because I wanted to determine if any recording patterns had changed since their freshman year. (RQ2A) 3. Interviewees were asked how they recorded their data in lab, because, as in Question 2 above, I wanted to determine if recording patterns had changed since freshman year. (RQ2A) 4. Interviewees were asked whether and how their experience in general chemistry laboratory had influenced the way they recorded information and studied, because this would provide specific detail on alteration of study patterns since freshman	1. Group interviewees were asked to compare and contrast the structure of their general chemistry lab with the lab or equivalent portion of their current science course(s), because I wished to find out whether the current structure was conducive to collaborative inquiry learning. (RQ2A) 2. Interviewees were asked to describe any collaborative work in senior science courses and the influence of the collaborative aspect of general chemistry on the present collaboration(s), because I wanted to find out the strength and endurance of the collaborative aspect of inquiry learning in freshman year general chemistry. (RQ2D)

(*table continues*)

Research question	Description of individual interview questions	Description of focus group questions
	year. (RQ2B) 5. Interviewees were asked whether their learning techniques in general chemistry had helped them learn in their current course(s), because this would corroborate any benefits expressed in responses to previous questions regarding the efficacy of inquiry learning in general chemistry. (RQ2C)	

Data Collection Procedures

Data were collected via Skype due to scheduling difficulties. In order to record data, I used a digital audio recorder, which allowed for later computer uploading. I also hand-wrote notes at each session. I transcribed the audio information gained from each individual and focus group interview. Besides individual student interviews, there were four discussions, each consisting of two student participants rather than five, due to both paucity of responses and scheduling conflicts.

Each interview and discussion lasted approximately 30 to 45 minutes, allowing for unanticipated responses and for where the resultant dialogue led. Participants were invited to attend via email letter. Considerably more than twice the number of students needed for the study were invited.

Data Analysis Plan

During the initial open coding phase, I used a set of descriptive codes based on anticipated participant responses to interview questions (see Table 2). New codes were added, as necessary, as data were collected, to saturation. Based on a review of data, categories of information were established and developed. I included data from discrepant cases, including students who either did not perceive inquiry learning as helpful or who believed it was actually detrimental to their subsequent learning. These students provided ample information regarding their reasoning toward their assertions.

Table 2

Initial Descriptive Coding List Based on Interview Questions

Interview question	Coding list
1. Describe the structure of your general chemistry course (anticipate two parts: Lecture and Inquiry laboratory). 2. Tell how (if at all) each part (of the structure) was effective in helping you to understand chemical concepts. 3. Tell how (if at all) in particular the Inquiry laboratory helped you to understand chemical problem solving. 4. Describe the advantages and disadvantages, if any, in working together during the laboratory.	G-DS: General chemistry description (1) G-LA: General chemistry lecture advantage (2) G-LD: General chemistry lecture disadvantage (2) G-IA: General chemistry inquiry activity advantage (3) G-ID: General chemistry inquiry disadvantage (3) G-SI: General chemistry social interaction (4)
5. What science courses are you taking now? 6. In lecture, how do you record information from the instructor? 7. In laboratory (as applicable), how do you gather and organize quantities or make observations? 8. Do you think your general chemistry laboratory has affected the way you take notes and study? If so, how and to what extent? 9. Do you think the way you learned in your general chemistry laboratory has helped you learn in your current course(s)? 10. Describe any collaborative work in your senior science courses. How has the collaborative aspect of general chemistry influenced the present collaboration(s)?	U-DS: Upper level science course description (1) U-LR: Upper level science lecture record (2) U-LBR: Upper level science lab record (3) +S: Positive influence of general chemistry lab on science learning (4, 5) +C: Positive influence of general chemistry lab on senior collaboration (6) -S: Negative influence of general chemistry lab on science learning (5) -C: Negative influence of general chemistry lab on senior collaboration (6)

Trustworthiness

Credibility

The sole data collection instruments were the individual interview and focus groups. Triangulation was achieved between individual and focus group interview results by comparing responses. Regarding reflexivity, I attempted to approach the interview process in a detached, neutral manner, and I reflected as necessary in my field journal. Member checking occurred after all data were collected by sending copies of interview records to participants. I had recorded data peer reviewed by another individual who is a faculty member in the department of education at a different 4-year university. Per regulations, he pre-signed a letter of confidentiality.

Transferability

Although I did not anticipate that responses would be transferable, I expected that the general themes and concepts extracted from the data will be perceived by readers as transferable to other populations. I did anticipate and received thick descriptions in responses due to the nature of the interview questions.

Dependability

Dependability was assured by an audit trail consisting of handwritten and electronically recorded field data from interviewees and self-generated field notes and reflective journal entries. It also included recorded analyses of data and products of data reconstruction and synthesis, such as categories and themes.

Ethical Procedures

Participants were recruited by invitation letter sent by email. The invitation explained the purpose of the research. The participants were given all information regarding the study, and informed that participation is voluntary. Participants were informed that only their perceptions regarding their academic experiences would be explored, and that no information regarding nonacademic, personal matters would be discussed. Participants would be informed that they would be able to withdraw from the study at any time. All risks and benefits would be explained. More than twice the number of potential participants was invited to allow for potential withdrawals during the study. Confidentiality was be maintained at all times, and participants agreed to keep their responses confidential as well during the study. Participants were coded by number and were not identifiable by name. All recordings and transcripts were kept in physical locked and electronic password-protected files accessible only by myself, the primary investigator. These measures were in accordance with the IRB requirements of the Maryland university, which are that all potential student participants be fairly and adequately recruited and are properly informed about confidentiality of information and their right to withdraw from the study at any time. The Maryland university IRB application was submitted following conditional approval by the Walden University IRB. The Maryland university rules require outside researchers to request IRB permission before recruiting participants. The requirement includes recruitment activity description and examples of recruiting materials, including a consent form and other supporting documentation. Submissions also included a letter of Walden University IRB approval of the researcher's proposal. Following approval from both universities, the student participant recruitment process began with appropriate screening and invitation letters.

Summary

Within this chapter, the research design and specific methods were discussed. Specifically, the interview questions were presented, participant selection procedures were discussed, and data analysis, trustworthiness and ethical issues were discussed. In Chapter 4, the results of the data collection and analysis are presented and discussed.

Chapter 4: Data Collection and Analysis

Introduction

This chapter contains a description of the overall process of data collection and analysis, including the demographics, the mechanics of the actual data acquisition, the development of coding for analytical purposes, trustworthiness issues, and categorical results of the study.

The purpose of this study was to raise the level of scholarly understanding of the influence of a freshman undergraduate general chemistry course incorporating process-oriented guided inquiry learning (POGIL) activities on the thought processes and organizational skills students demonstrated in science courses during the senior college year.

The research questions that were addressed are as follows:

RQ1: How do senior undergraduate students describe the process-oriented guided inquiry learning (POGIL) aspect(s) of their freshman-year general chemistry experience?

RQ2: How do senior undergraduate students describe the influences of the inquiry learning aspects of their freshman general chemistry course on their approaches to learning in their current science courses?

Demographics

The sample population consisted of senior natural science majors at a major East Coast 4-year university who either were current students or had graduated in May 2014. The reason for the latter was a perceived lack of sufficient responses from current seniors. The recent graduates were not deliberately recruited; they evidently had email accounts that were still active and responded to the invitation. A total of 15 students participated. Seven participants were interviewed individually. All were female. Because of scheduling difficulties, it was not possible to hold traditional focus groups with five or more participants. Instead, a total of four discussions were conducted, each consisting of two participants. Of these, two of the groups were composed of one male and one female participant. The remainder of the discussion group participants were female. three students were BS biology majors, five were biochemistry majors, six were BA biology majors, and one was a BS physics major.

Data Collection

A total of 15 students participated in the study during the Fall 2014 semester. These comprised seven individual interviews and four discussion groups. The recruitment strategy consisted of an emailed combination invitation/consent letter sent to current university seniors majoring in one of the natural sciences. The list of eligible seniors was obtained from the office of the registrar after submission of the appropriate request forms. The eligible categories of students were the following: bioinformatics, biochemistry/molecular biology, biology (BA), biology (BS), chemical Education, chemistry (BA), chemistry (BS), physics education, and physics (BS). Students were assigned a number in sequence and chosen via random number generation (www.random.org/mads). A total of 33 students responded to the invitation.

Recruitment dates and times proved to be challenging to achieve, and it was ultimately decided that from a practical standpoint, Skype would need to be used exclusively to obtain audiovisual interview information in a timely manner. Even more difficult were the discussions, which, due to scheduling conflicts and "no-shows," consisted of only two participants each. To compensate for the obvious deficiency, an extra discussion group was organized. Scheduling conflicts and delayed email responses were problematic, particularly in arranging discussion groups. As the discussions involved only two participants each, these were not considered to be true focus groups. The focal points of the discussions included student descriptions of the lecture versus the POGIL sections of their courses, any advantages or disadvantages of these POGIL sessions in learning chemistry, whether the collaborative work in POGIL aided their chemistry learning, and whether the collaborative aspect of POGIL experiences had any influence on any current (senior) collaborative work. Discussions focused mainly on the collaborative and interactive aspects of POGIL, while individual interviews focused mainly on individual cognitive learning and problem solving at the freshman and senior levels.

After consent was obtained, data were recorded using a Sony ICD-UX523 digital voice recorder with uploading capability. Occasionally, due to an unanticipated Skype malfunction or reduced capability, certain participants could not actually be visualized although their responses could clearly be heard and recorded.

Data collection instruments consisted of individual interviews and discussions. Data from interviewees and focus groups were recorded electronically and via handwritten field notes. Self-generated field notes and reflections were recorded electronically and in handwritten fashion. Data analyses, reconstructions, and syntheses were similarly recorded.

Summary of Data Collection Procedures

All data were collected during the fall semester of 2014. They were collected at a 4-year university in the eastern United States. Data types were individual interview (seven students) and discussion group (four, each composed of two students). The means of data collection were the audio digital recorder with upload capability and handwritten notetaking. All interviews and discussions were conducted via Skype. My focus in this study was twofold: I sought to find out how the students compared and contrasted the lecture portion and the POGIL portion of their general chemistry course, how each part helped them learn chemistry, and whether there was any advantage or disadvantage to POGIL in helping them learn general chemistry concepts. Secondly, I sought to learn how their POGIL experiences influenced the way in which they currently studied and learned in their senior courses, and whether the collaborative aspect of their POGIL had helped them learn.

Data Analysis

The initial descriptive codes used in analysis of data were those in Table 2. The data that were collected included audiovisual input from participants via Skype, the audio portion of which was recorded electronically. Written notes were taken as necessary to clarify input. Participants were encouraged to speak freely as ideas and thoughts came to mind. After the interview and discussion group data were collected, the responses (from written notes and electronic recorder records) were evaluated and labeled according to the descriptive codes. For example, next to a response pertaining to the general chemistry course description (response from Question 1), the appropriate notation (G-DS) was given in the margin. As applicable, the other codes were placed in the margins alongside the participants' responses. Specifically, if the participant perceived that the lecture portion of the chemistry course was particularly beneficial, that point was appropriately coded (G-LA). A similar coding (G-IA) was used if some particular aspect of the guided inquiry portion of the course was beneficial in problem solving. The codes (S) and (C) denote influence (+ or -) of the general chemistry guided inquiry lab on senior science learning and collaboration, respectively. The codes were used only if there was an influence on those categories.

Secondary, interpretive codes were established for the more general trends or conclusions that emerged from these analyses as follows (Table 3): For Question Set 1 regarding the participants' general chemistry experiences, particularly those of the Guided Inquiry Laboratory, the more general codes of +LE (positive learning experience)/-LE (negative learning experience) and +SIE (positive social interaction experience)/-SIE (negative social interaction experience) were applied. For Question Set 2 regarding the influence(s) of the general chemistry guided inquiry experience on participants' senior science learning, the more general codes of +SLB (positive influence on the senior learning behavior)/-SBLB (negative influence on the senior learning behavior), and +SCB (positive influence on the senior collaborative behavior)/-SCB (negative influence on the senior collaborative behavior) were used. The possibility of a "neutral" (0SI) or no overall influence outcome was considered as well.

Table 3

Secondary Emergent Codes and Interpretations

Question set #	Code	Interpretation
1	+LE	Positive learning experience
	-LE	Negative learning experience
	+SIE	Positive social interaction experience
	-SIE	Negative social interaction experience
2	+SLB	Positive influence on the senior learning behavior
	-SLB	Negative influence on the senior learning behavior
	+SCB	Positive influence on the senior collaborative behavior
	-SCB	Negative influence on the senior collaborative behavior
	0SI	No overall influence

Tertiary, or pattern, codes, emerged from the secondary analyses. These are more inferential than those secondary conclusions, and included: +LE (enhanced overall chemistry learning experience)/-LE (hindered overall chemistry learning experience) for

Question set 1. +SI/-SI codes were applied to the possible influence(s) of the general chemistry guided inquiry experience on senior learning behaviors.

To question 1, all participants gave identical basic descriptions of the composition of their general chemistry courses (G-DS), with varying detail information. All lecture classes occurred three times per week for 50 minutes. Depending on the instructor, PowerPoint lecture slides accompanied the lecture. Two participants stated that online homework was part of the lecture portion of general chemistry. Participant I_7 stated that students were assigned homework three times per week from Mastering Chemistry, an online software package supplemental to the main text.

Evidence of Trustworthiness

Triangulation was accomplished by comparing responses of individual and discussion group interviews to determine whether and to what extent they concurred. All participants appeared to be forthcoming, and little prompting was needed to elicit detailed responses. For example, dissatisfaction within various aspects of the guided inquiry class was readily catalogued. As interviews progressed, and with regular post-interview reflective written notes made, I found it progressively easier to approach each interview in a neutral, detached manner. An additional follow-up question was created as a result these revelations and reflections: “What type(s) of changes would you implement to improve the guided inquiry class?”

The credibility strategy involved comparing individual interviewee and focus group member responses for any similarities or patterns, thus seeking a degree of triangulation. Post-interview reflections were conducted regularly and any adjustments in the interview process were minor if any. The use of Skype was an unanticipated advantage in providing a layer of detachment and to encourage maintenance of neutrality. Member checking was accomplished by emailing audio transcripts to each participant, with a note of explanation regarding the relevance and necessity of ensuring credibility of data. Only two participants responded. Focus group member F_{4a} stated, “Sounded good to me.” Discussion group member F_{3b} stated, “I listened to the audio and am fine with what has been said.” Confirmability was achieved by having recorded data peer reviewed by Frank Bernt, Ph.D., a faculty member in the department of education at a different 4-year university. His recommendations included replicating a future study with a (largely) male population, as the current study incorporated mostly female participants. He pointed out the importance of gender considerations in such studies as womens’ and mens’ attitudes about science as well as their proclivity toward social interaction may be quite different.

Regarding transferability strategy, following data analysis, I expect that the general themes and concepts extracted from the data will be perceivable by readers as transferable to other populations. Considering the important point above by Dr. Bernt, this transferability is relative, considering the likely attitude difference toward science between men and women. Responses were rather detailed as expected due to the nature of the interview questions. Dependability strategy has varied slightly from what was initially expected. Data consisted of video interviews via Skype, but the audit trail was generated from handwritten and electronically recorded field data from interviewees, self-generated field notes and reflective journal entries, and recorded analyses of data and products of data reconstruction and synthesis, such as categories and themes.

Results

Research Question 1

How do senior undergraduate students describe the process-oriented guided inquiry learning (POGIL) aspect(s) of their freshman-year general chemistry experience:

1. In terms of data collection (exploration)?
2. In terms of interpreting their data and inducing patterns or themes (concept invention)?
3. In terms of knowledge synthesis, hypothesis, and prediction (application)?
4. In terms of a group setting (social interaction)?

In terms of exploration, most participants stated that the POGIL material did not follow the lecture material covered during a particular week, or follow it closely enough.

> Depending on the day your section was, you might have already learned the concept, or if it was Monday, you probably hadn't learned the concept yet." F_{2a} said, "On days where it was something I had not seen before…….we were learning something for the first time but were kind of teaching ourselves….it only frustrated us because we had to teach ourselves because we hadn't learned it in (lecture) class. (interviewee I_6)

Therefore, depending on the date and time of the POGIL session, the topic evidently may not have been yet covered in lecture class, a perceived disadvantage. As far as concept invention is concerned, there is little if any evidence from interviews and discussion groups that POGIL enhanced students' general chemistry learning of concepts. Rather, they stated that lectures provided a solid foundation, and that POGIL did not complement their conceptual general chemistry learning.

> (POGIL) didn't really help me understand chemical concepts because it was supposed to be a group working together, but…inevitably you have the people who are there for participation…the person who knew everything…the person who typed too slowly or too fast..it was a giant waste of time. ….I explained it to the rest of my team…..A good portion of the class were engineers who (merely) wanted get a C (in the class)….We did have to know how to solve problems for the exam…I used the sheets on my own to study. (I_3)

> I didn't find the Discovery (POGIL) sessions very helpful, because I followed the textbook very closely and worked on the problems myself…I am more of an independent studier, so the Discovery sessions didn't really go well with me. (I_4)

This student had indicated that she had taken AP (advanced placement) chemistry in high school. She added that the "physical lab" (offered second semester in addition to the POGIL session) was more helpful in learning enhancement.

> …the Discovery (POGIL) portion was good for me to figure out the smaller details of what we were learning (i.e., electron orbitals). (I_6)

The remainder of the participants indicated that their POGIL experiences did not appreciably, if at all, enhance their learning of general chemistry.

In terms of application, participants generally felt that the POGIL session was a good opportunity to practice key concepts presented in lecture class.

> At times it was a nuisance mostly because I felt that the questions were not worded clearly and the professor would ask but in a very complex way which would make it difficult to understand what you were trying to get at. But other times it definitely made me think about other perspectives and other ways to come to a conclusion, so on a conceptual level it was helpful but in terms of exam preparation and class preparation it was not helpful. (I_7)

> …the actual content didn't match up with the course…It was almost like extra information and extra practice problems that we wouldn't be tested on, and as a result I wasn't focused on learning it. I'd do it because I had to and it was a grade, but if I didn't understand it wasn't a priority for me to understand or learn it. (F_{2b})

Only one interviewee, I_5, stated that the POGIL activity was the "best part of the course," and that it taught how to "apply the (chemical) knowledge rather than just memorize it." However, she also stated,

> "A disadvantage was the length of time. I just think that with a two hour block no one's attention span is…discussions are not that effective because there's not that much "hands-on." So Discovery (POGIL) could be 50 minutes."

The final part of Research Question 1 (regarding the social aspect of POGIL) elicited rather detailed responses, with both positive and negative comments. Interviewee I_2 responded that her POGIL experience helped more "with communication skills" than promoting chemistry learning. However, she continued by stating that the POGIL setting made it "helpful in trying to explain (chemical concepts) to other people," which helped to reinforce the knowledge gained. As well, collaboration provided opportunity for additional practice, as assigned roles rotated each week, and after four weeks, intergroup exchanges would occur.

> Sometimes people weren't as attentive…I was pretty good at doing the (lecture) textbook problems so I knew what was going on with Discovery (POGIL), but I'm not sure everyone was doing that, so it was a bit difficult to get everybody on the same page. (I_4)
>
> The advantage to the Discovery portion of the class was that we sat down with our classmates…..random students for almost two hours…We were pretty much practicing chemistry problems. It was really collaborative work. You were working with your peers to solve problems…..It did force us to work together and you had to know it to be able to do it and you couldn't leave until you completed it, so it made you work to understand it and get through it. (F_{2a})

From the above participant input, it can be concluded that the actual mechanics of the POGIL sessions were frustrating in terms of familiarity with the material and equality of participation. However, the sessions did induce some degree of collaboration among the students, particularly those who might have been introduced to collaboration for the first time, and the sessions did help to reinforce chemical concepts.

Other interviewees and discussion participants (I_7, F_{2b}, F_{3b}) stated that the POGIL setting "forced" one to collaborate, interact with other students, and to work together to solve problems, owing to the group setting with assigned roles.

> It was definitely an active learning environment because as I remember every lesson would end with some kind of challenge question…So all groups had to work as quickly as they could to figure out an answer, and once the answer was arrived upon, the whole class would go over this challenge question which was usually some kind of synthesis question that kind of put together different concepts that may or may not have been covered. It would help you go over the different concepts that were introduced during that Discovery session. (I_6)

The above comments indicate and confirm that for the most part, collaboration was beneficial in helping the students to solve problems and reinforce understanding of chemical concepts.

There were some negative comments about collaboration. One student within a discussion group had an indifferent attitude (F_{3b}), as she admitted that she attended only due to the requirements of the course. One focus group member (F_{1b}) stated that sometimes it felt as though she was the "only person that was prepared," although it "forced" her to assume the leadership role. It was emphasized during data collection that roles could not be exchanged. As a result, the rules regarding the role each student played emphasized the requirement of silence unless specifically allowed to speak. Some students did “work harder than others” (F_{4b}), and sometimes it could be “difficult to get through the material” (I_3), depending on the ability or attitude of group members. Indeed, depending on the specific role, some students were able to communicate to the rest of the group, while others “slept through the session.” (I_4) “Sometimes people were not as attentive as they should have been.” (I_4) An interviewee (F_{4b}) stated that sometimes sessions were “frustrating and painful” with slower learners as part of the group. At least part of the frustration was caused by the awareness of the fact of both group and individual grades for each session. Therefore, lack of contribution by one or more group members had to be compensated by extraordinary contributions by the remainder.

Other general comments were negative regarding the infrastructure of the sessions themselves. In particular, participants mentioned several times that academic and physical strictures during each POGIL session created a degree of stress and discomfort. One participant complained that the two-hour sessions were too long, and another stated that the teaching assistants assigned to monitor and assist during the sessions were not as attentive as necessary. Also, two participants complained that neither food nor beverages were permitted during each session. One mentioned that points were deducted from the final grade for tardiness or for “leaning on the table.” Four of the 15 participants complained that the assigned weekly roles were strictly enforced. One participant complained that access to the internet was denied during the sessions. One participant complained that the POGIL sessions (about 2 hours) were too long and recommended shortening them to 50 minutes.

Research Question 2

How do senior undergraduate students describe the influences of the inquiry learning aspects of their freshman general chemistry course on their approaches to learning in their current science courses:

1. In terms of data collection (exploration)?
2. In terms of interpreting data or inducing patterns or themes (concept invention)?
3. In terms of knowledge synthesis, hypothesis, and prediction (application)?
4. In terms of a group setting (social interaction)?

As far as Exploration is concerned, none of the participants indicated that POGIL has influenced the way they collect data in particular, which may range from taking notes with pen and pad or electronically. Regarding concept invention,

> I feel like it (POGIL) reinforced my need for independent studying… I felt it very redundant (sic)." I_5 stated, "Memorization at this point in my education is not going to help me at all, so I've tried to use the application of Discovery (POGIL) in all my studies."I_3 stated, "Discovery (POGIL) has had no (impact) on the way I study now. It was one person telling everyone else what to do. (I_4)

Otherwise, interviewees and focus group members indicated that at most, either POGIL did not have a "huge effect" in the way they learn (I_2), or they could not determine whether it did influence the way they learn (F_{4b}).

Regarding Application, only one interviewee indicated the universality of POGIL influence on how she solves current science class problems.

I'm taking biochemistry, genetics, epidemiology, seminars in biomedical sciences, physiology, and histology." In terms of application, she said, "Memorization at this point in my education is not going to help me at all, so I've tried to use the application of Discovery (POGIL) in all my studies. (I_5)

In terms of collaboration, she stated,

"In a seminar class, we have to find a (medical) research article and analyze it and evaluate it, so that would involve collaboration. I think it (POGIL) was one of the components that allowed me to work with other people."

It was good structure to sit down and work through problems with other people and that can prepare you for the rest of college having to work with other people to get through your difficult science coursework. (F2a)

….because that was a part of your grade, you had to participate in Discovery (POGIL). It actually showed me how to actively participate in the right way to contribute and that has helped me…for any class I've taken in college. (F_{2b})

The above responses indicate the lasting value of POGIL in terms of applying critical reasoning in the senior year and appreciating the value of collaboration in solving problems at that grade level.

However, in terms of social interaction, on the negative side, discussion participant F_4 actually indicated that she learned more about collaboration outside of class, “in clubs,” than within her science classes. On the positive side, collaboration for one interviewee (I_2) “helped define and reinforce a leadership role” in her current lab courses. Another interviewee (I_2) stated that “teaching (others) is a good way to learn.” Another interviewee (I_6) discovered that currently she is “a leader in discussions,” attributing that attitude to POGIL influence. So these responses pertaining to the social interaction aspect of POGIL reveal that in at least three cases, leadership qualities were identified and strengthened between the freshman and senior years.

Results Summary of Responses to Interview Questions in Context of Research Questions

In the freshman year, thrice weekly general chemistry lectures were conducted with the assistance of PowerPoint, occasionally accompanied by clicker questions. There was one weekly POGIL session. According to at least three participants, The POGIL material did not follow the lecture material closely enough. Although the lecture portion of the course provided a solid foundation learning chemistry, the majority of participants felt no perceptible value of POGIL in learning chemical concepts or test preparation. There were notable exceptions as previously expressed.

POGIL was perceived as beneficial in practicing key concepts. As well, POGIL helped with communication skills(i.e., it was helpful when trying to explain chemical concepts to others). As such, it compelled some students into a leadership role. Socially, POGIL "forced" students to interact to solve problems.

In the senior year, students reported that they collected data using pen and paper or computer. Some courses were discussion-oriented. Participants, at best, were not certain whether POGIL had enhanced their senior learning behaviors.

Only one participant stated that POGIL taught her how to apply knowledge that was useful in senior level problem solving, particularly in scientific article analysis. POGIL taught students how to work collaboratively, which was perceived to carry over to the senior year. It also taught leadership qualities that carried over to senior course discussion groups.

Summary

The responses from the interviewees and focus group members indicated overall that the most positive effect that General Chemistry POGIL had on their learning was establishing social interactive patterns through role playing. The responses overall indicated that there was minimal if any chemistry learning enhancement promoted by POGIL. As an incidental note, the physical strictures established by the authorities during the sessions appeared to hamper students' attitude toward learning the material presented. The academic strictures (i.e., strict role assignment), while fostering a collaborative environment, restricted certain individuals from more fully contributing to the discussion at hand.

Beyond collaboration, no perceived or individually identified influence was conferred on seniors' study habits or thinking or learning behaviors based on the responses. Chapter 5 discusses the interpretation of findings, limitations of the study, recommendations for future studies, and implications for social change.

Chapter 5: Discussion and Interpretation of Results

Introduction

The purpose of this grounded theory study was to improve the level of scholarly understanding of the influence of freshman undergraduate general chemistry courses incorporating process-oriented guided inquiry learning (POGIL) activities on the thought processes and organizational skills in science courses during the senior college year. The scholarly literature does not contain any data regarding the long-term influence of active learning, in particular POGIL, on later thinking and learning behaviors. Therefore, it was anticipated that this study could be part of a constructivist foundation upon which other studies could build toward generating a novel model of teaching and learning.

I conclude from the results that the students' lecture class provided a solid foundation for understanding general chemistry, but there was no well-defined perceived value of the POGIL sessions in contributing to learning general chemistry concepts or toward test preparation. On a more positive note, POGIL was beneficial in helping students to practice the key concepts learned in chemistry lecture class, so that their knowledge was applied to problems. Finally, students were constrained to interact, communicate, and collaborate in problem solving owing to the design of the POGIL sessions, which was perceived to be the greatest value and one that was lasting.

In this study, I found that there was significant perception, as described earlier, that POGIL enabled reinforcement of chemical concepts via practice in a collaborative social setting. Students practiced the application of key concepts, which reinforced learning through collaborative interaction. However, the responses also suggest that POGIL experiences indeed influenced learning at higher cognitive levels. Twelve of the 15 responses indicated that (a) the group practice helped some to teach concepts to others (concept invention), (b) the group interactions helped to solve problems (application), (c) the complexity of the worded problems ironically provided fertile ground for novel problem solutions (application), and (d) group interactions provided the environment to identify leaders (application).

In this study, I found that collaboration, or group effort, was the main perceived learning benefit in a POGIL general chemistry course. However, the fact that the participants in this study largely stated that collaboration had helped them during their senior year supports the idea of the lasting benefits of group effort. Also telling were several responses that implied that collaboration can spawn leaders, as indicated above, who are eventually propelled into leadership roles through repeated collaborative events. It is therefore not unreasonable to suggest that the professed "independent thinking" and "group leadership" tendencies are reflective at least to some degree of exposure to and experience of POGIL of general chemistry.

Interpretation of the Findings

The findings in this study mainly confirmed the long-term value of POGIL in perceived enhancement of general chemistry learning. Three participants did convey that POGIL sessions enabled them to reinforce concepts learned in lecture by solving practical problems. This particularly confirms what has been found in the literature, particularly in the study by Brown (2013). However, more often than not, the study's findings stressed the larger influence of the collaborative aspect of POGIL as a perceived positive influence in learning general chemistry. Such a finding is strongly confirmed in the literature (Knutson, Smith, Wallert, & Provost, 2010; Loo, 2013; Myers, Monypenny, & Trevathan, 2012;). It supports the importance of the social interactive aspect of the learning cycle in cognitive development (Spencer, 1999). Furthermore, the perceived lasting value of the collaborative aspect of POGIL between the freshman and senior college years was expressed by several participants, confirming a promising study by Justice, Rice, and Warry (2009). Although there was no perceived negative influence of POGIL on science learning, either at the freshman or senior level, there was by majority no enduring positive influence on either general chemistry learning or on senior science learning. This finding is, in the context of general chemistry learning, only mildly confirmatory of the literature, as I have focused on perceived learning benefits rather than objective testing results.

This study primarily addressed a gap in the literature, namely the perceived influence of freshman POGIL activities on the thinking behaviors of senior students. Scholarly knowledge was extended in that I found that there was very little perceived influence on senior thinking behaviors in terms of exploration, concept invention, or application. However, in terms of social interaction, knowledge was extended in that this study showed that freshman collaboration positively influenced senior social interaction within the context of chemistry or other science courses.

The Social Interactive Element

Social interaction was included in the conceptual framework description to enable students to incorporate the new POGIL concepts at the end of each cognitive learning cycle (Abraham & Renner; 1986; Kolb; 1984; Spencer, 1999). The data provided evidence of the perceived positive influence of the aspect of social interaction of general chemistry POGIL activities, both at the freshman and senior levels. Within the context of the exploration aspect of the learning cycle stated above, students presumably collected the available data in a manner similar to that of lecture; they presumably recorded it more or less completely depending on their weekly roles. However, besides the periodic scaffolding provided by the teaching assistants, they were required to induce their own patterns and generalizations (concept invention) from those data and other rather basic information provided at the outset of each session. Finally, the inherent design of each POGIL session required them to apply their knowledge in advanced, practical problem solving and make rational predictions about similar, albeit more advanced, situations (application). Indeed, the value of the POGIL sessions in helping them to practice key concepts and solve problems during the freshman year was expressed by several participants (I_2, I_5, I_6). However, only one participant (I_5) definitively expressed that the POGIL sessions had positively influenced how she processed information in her senior courses in general. She specifically stated that she learned from freshman POGIL that successful senior learning requires more than merely memorizing information. Further, she was able to apply POGIL techniques to her other courses, particularly as a senior.

The remainder of the participants expressed either that POGIL had not influenced their senior thinking and learning behaviors or that they "couldn't tell" whether it had.

The social interaction aspect as stated by Spencer (1999) proved to be the most positive in the participants' POGIL learning experiences in general chemistry and in their senior courses. Clearly, the perceived influence of group work helped with communication skills, as it encouraged interaction and collaboration (I_2, I_7, F_{3b}). Group work also helped in practicing chemical concepts (F_{2a}, F_{3a}), so it can be considered a catalyst for application. Teaching others, as the role allowed, helped to reinforce the knowledge gained (I_2, I_6, I_7**)**.In some cases, for seniors, the POGIL group work helped define and reinforce a leadership role in current courses where discussion or laboratory was incorporated (I_2, I_6).

Therefore, as has been reasoned earlier, POGIL positively influenced learning in several aspects of the cognitive learning cycle (i.e., concept invention, application) and most readily the aspect of social interaction. The social change wrought from these experiences is most immediately seen within the context of the academic community, wherein students are potentially better scientific researchers and better communicators. Within the larger context of society, they become better informed citizens better equipped to find practical solutions to problems, and as potential leaders are better equipped to contribute toward scientific policy and practice for society's immediate and long-term benefit.

In summary, then, it can be stated that POGIL experiences taught the skills of collaboration in problem solving, particularly in the undergraduate classroom. It is perhaps not essential that students report a direct influence of certain aspects of their freshman chemistry experiences on their senior learning methods and thinking behaviors. Students did report that as seniors they were more independent, self-motivated learners and readily used collaboration to help them solve problems in the classroom context. What can reasonably be concluded, then, is the substantive learning value of the collaborative aspect of POGIL in both freshman chemistry and senior learning experiences. As such, it is not unreasonable to expect senior undergraduate students to be capable of promoting social change.

Conceptual Framework and Grounded Theory Model

As stated earlier, the constructivist world view undergirds this study, which is informed by Kolb's (1984) experientially oriented approach to learning (Exploration, Concept Invention, Application) in general and the POGIL approach to chemical education specifically as described by Moog, Farrell, & Spencer (1999), which incorporates a critical social component (Spencer, 1999). In summary, the constructivist view describes student-oriented learning, wherein students cooperatively/collaboratively gather data, solve problems, draw conclusions, induce patterns and themes, and ultimately derive more sophisticated questions that are intended to perpetuate the experimental learning cycle. Testing occurs periodically to confirm or disconfirm that these learning tools are effective in achieving learning objectives.

The general concepts expounded by Kolb (1984) in terms of constructivist, experiential learning have been and can be successfully applied specifically through the POGIL approach in freshman chemistry, based on the results of the current study. The study revealed that practicing problems during POGIL sessions did in fact aid students in learning to solve general chemistry problems (concept invention), and that constraining them to work in a group situation reinforced the value of collaboration (social interaction). Besides POGIL instructions leading to improved collaborative skills in problem solving, I found in this study that individual leadership skills emerged as a result of POGIL peer teaching sessions. Therefore, leaders self-identified, which extended to the senior year.

Based on the data collected in this study (see Table 4), the immediate benefits of POGIL in freshman chemistry are mainly improved collaborative skills in problem solving and concept reinforcement. The longer-term (senior grade) benefits of POGIL are reinforced collaborative and leadership skills.

Table 4

Grounded Theory Model: Benefits of Teaching POGIL in Teaching Freshman Chemistry

College year	Exploration	Concept invention	Application	Social interaction
Year 1 (freshman)	Note taking, either via computer or handwritten *(A time-honored method for recording essential facts and data. A very individualized and personal means of establishing a basic body of knowledge for learning and study purposes)*	Problem Solving "…It would help you go over the different concepts that were introduced during that Discovery session." (I_4) "….the Discovery (POGIL) portion was good for me to figure out the smaller details of what we were learning (i.e., electron orbitals)." (I_6) "…..it definitely made me think about other perspectives and other ways to come to a conclusion, so on a conceptual level it was helpful….." (I_3)	*No Clear Results*	Collaboration "…It was really collaborative work. You were working with your peers to solve problems…." (F_{2a})
Year 4 (senior)	Note taking, either via computer or handwritten	Problem Solving	"Memorization at this point in my education is not going to help me at all, so I've tried to use the application of Discovery (POGIL) in all my studies." (I_3)	Collaboration Leadership Skills

Limitations of the Study

It would be difficult to determine how participant responses would be influenced by what they thought of their freshman chemistry professors. None of the participants volunteered that type of information beyond describing the structure of their lecture courses. I did not probe the matter by asking any of them directly what they thought of their professors, because students did not interact directly with their professors during POGIL sessions. It is difficult if not impossible to eliminate bias. I had pledged to conduct interviews in as detached a manner as possible. Actually, I perceived that a layer of detachment was established by the use of Skype for all interviews and focus groups versus actually being physically present in the same room. Thusly, Skype communication provided an extra measure of "distance and detachment" between me and participants that helped to reduce any bias. I believe that the level of detachment was significant enough that I would recommend the use of Skype in similar types of future data collection procedures.

Recommendations for Action

Based on the responses in this study, I would recommend:

1. Instructor textbook lectures should be pre-recorded and be totally accessible to all students. All students will then have an opportunity to be exposed to the material relevant to the POGIL lesson for a given week.

2. Incorporate a weekly physical laboratory session that allows application of the POGIL concepts learned. This will allow reinforcement through hands-on experimentation by all students.
3. Each student within a group should be held accountable for a discrete, definitive portion of the POGIL exercise solution. Either at the end of each POGIL session or at the very beginning of the next, each group should be required to give a summary written report to the POGIL session supervisor regarding their approach to solving that (or the previous) session's problem(s). Each student should be required to sign off on the report, describing his/her specific role and contribution toward the solution of that week's problem.
4. Relax the rigidity of weekly roles in order to allow any group member to seize a teaching opportunity when teachable moments arise. While not a 100% guarantee, less role rigidity will encourage more group members to become more actively engaged in the POGIL process each session.
5. Shorten each session to one hour and perhaps increase the number of weekly sessions to two.
6. As these are college students, and are being educated specifically to thin independently, treat them more as adults. Allow them to sit and stand as needed, drink water, and allow students limited access to the internet or other informational sources.

7. Encourage chemistry faculty teaching sophomore and junior classes to explore the use of POGIL strategies in these classes so that learning gains made during the freshman year are not lost. As well, encourage the exploration of the use of POGIL within the other physical sciences (i.e., biology, physics, and earth sciences).

Recommendations for Research

Future studies should compare and contrast participant responses to the research questions posed in this study, but at sophomore and junior levels, possibly to establish a firmer connection between the skills learned in POGIL freshman chemistry and later years. As well, subsequent studies could probe more deeply the social interaction aspect of POGIL and any influence on later thinking behavior. From a qualitative study standpoint, further studies need to address students' concerns and objections, particularly as freshmen, regarding POGIL science courses.

Finally, similar studies can be conducted at other universities and the responses compared to determine the extent of transferability. Conducting similar studies at other universities with perhaps more relaxed (or even more stringent) structure may very well influence the perceived outcome. If POGIL is successful in enhancing collaborative skills, future POGIL studies with freshman chemistry students may focus on improving that learning tool so that the other facets of the Cognitive Learning Cycle can benefit.

Implications for Positive Social Change

As this is a qualitative study, the major potential impact for college chemistry departments is the value of interactive, collaborative efforts in solving problems. This potential was keenly expressed by almost all participants; collaborative interaction was experienced as a means of problem solving that was easily carried with them to their senior years. Perhaps even more significant is that the “forced” establishment of groups and especially assigned roles encouraged certain individuals to distinguish themselves as leaders. Both of these points are echoed in the potential for certain individuals to distinguish themselves later as scientists or group leaders who direct research projects or influence research policies. At universities, for example, curricular or research problems are solved commonly via group input, and in this fashion those with leadership potential rise to the level of their abilities.

Another implication from the results of this study is the possible interest of university departments and administrations in expanding POGIL horizontally across physical science departments and vertically to higher grade levels, necessitating a modification or radical change in curricular design. This would therefore involve personnel at the departmental and higher administrative levels. If even one aspect of POGIL is working perceptually, i.e., social interaction (Spencer, 1999), at the freshman level, it may prove fruitful to investigate its learning benefits at the sophomore level and beyond. It is not unreasonable to assume that most physical science departments will encounter a need for problem solving and some application of the scientific method. POGIL may be beneficial in these areas.

Beyond academia and within society as a whole, POGIL better educates students so that they become better informed citizens better equipped to find practical solutions to problems, and as potential leaders are better equipped to contribute toward scientific policy and practice for society's immediate and long-term benefit.

Conclusion

The results of this study primarily demonstrated the importance of introducing student-student collaboration in chemistry problem solving. In this study, collaboration in the undergraduate science classroom helped students solve problems. These skills lasted throughout the college years. Such interdependence also helped to identify potential group leaders and teachers. The results were not overwhelmingly favorable in terms of the perceived lasting intellectual benefits of POGIL to the senior year, as compared with those of freshman year.

However, based on the interpretations of this study regarding the link between responses and the reasoned influence of POGIL at higher cognitive levels within the learning cycle, it is not unreasonable to anticipate that graduates exposed to and experiencing general chemistry POGIL activities would apply the learned skills within the larger social context. Leadership and collaborative skills are highly valued in the workplace, regardless of the content area. Therefore, this study is encouraging in terms of deeper investigations of the connections between the collaborative context of POGIL and its long-term influences on later scientific thinking.

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Appendix A: Research Questions and Corresponding Actual Interview Question Protocol

Research questions(s)	Individual interview questions	Focus group questions
1. How do upper level undergraduate students describe the inquiry learning aspect(s) of their freshman-year general chemistry experience: A. in terms of data collection (Exploration)? B. in terms of interpreting their data and inducing patterns or themes (Concept Invention)? C. in terms of knowledge synthesis, hypothesis, and prediction (Application)? D. in terms of a group setting (Social Interaction)?	i. Describe the structure of your general chemistry course facet (anticipate two parts: Lecture and Inquiry laboratory). (RQ 1A) ii. Relate how (if at all) each part (of the structure) was effective in helping you understand chemical concepts. (RQ 1B) iii. Tell how (if at all) the inquiry lab portion of the course helped you understand chemical problem solving. (RQ 1C)	i. Compare and contrast the structure of the laboratory (Discovery) portion of your general chemistry course with other laboratory courses you are taking or may have taken. (RQ 1A). ii. Describe any advantages or disadvantages of collaboration in the lab. (RQ 1D)
2. How do upper level undergraduate students describe the influences of the inquiry learning aspects of their freshman general chemistry course on their approaches to learning in their current courses: A. in terms of data collection (Exploration)? B. in terms of interpreting data or inducing patterns or themes (Concept Invention)? C. in terms of knowledge synthesis, hypothesis, and prediction (Application)? D. in terms of a group setting (Social Interaction)?	i. What science courses are you currently taking? (RQ 2A) ii. How do you record information communicated in lecture? (RQ 2A) iii. How do you record your data in lab? (RQ 2A) iv. Has your experience in general chemistry laboratory influenced the way you record information and study? If so, describe that influence. (RQ 2B) v. Have your learning techniques in general chemistry helped you learn in your current course(s)? (RQ 2C)	i. Compare and contrast the structure of your general chemistry lab with the lab or equivalent portion of your current science course(s). (RQ2A). ii. Describe any collaborative work in your senior science courses and the influence of the collaborative aspect of general chemistry on the present collaboration(s). (RQ 2D)

Appendix B: Description of Individual Interviewee Questions

Research questions	Individual interviewee question descriptions
1. How do upper level undergraduate students describe the inquiry learning aspect(s) of their freshman-year general chemistry experience: A. in terms of data collection (Exploration)? B. in terms of interpreting their data and inducing patterns or themes (Concept Invention)? C. in terms of knowledge synthesis, hypothesis, and prediction (Application)? D. in terms of a group setting (Social Interaction)?	1. Interviewees were asked to describe the structure of their general chemistry course because I wanted to provide a basis for more specific questions on each facet (anticipate two parts: Lecture and Inquiry laboratory). (RQ 1A) 2. Interviewees were asked to relate how (if at all) each part (of the structure) was effective in helping them understand chemical concepts, because I wanted to establish the distinct roles, if any, of each part in the learning process. (RQ 1B) 3. Interviewees were asked to tell how (if at all) the inquiry lab portion of the course helped them to understand chemical problem solving. I wanted to know details about how their thinking process was modified if at all. (RQ 1C)
2. How do upper level undergraduate students describe the influences of the inquiry learning aspects of their freshman general chemistry course on their approaches to learning in their current courses: A. in terms of data collection (Exploration)? B. in terms of interpreting data or inducing patterns or themes (Concept Invention)? C. in terms of knowledge synthesis,	1. Interviewees were asked what science courses they are currently taking, because I wanted to determine whether they continued in chemistry or other natural science, per the focus of the study. (RQ 2A) 2. Interviewees were asked how they record information communicated in lecture, because I wanted to determine if any recording patterns have changed since their freshman year. (RQ 2A) 3. Interviewees were asked how they

Research questions	Individual interviewee question descriptions
hypothesis, and prediction (Application)?	record their data in lab, because as in #2 above, I wanted to determine if recording patterns have changed since freshman year. (RQ 2A)
D. in terms of a group setting (Social Interaction)?	4. Interviewees were asked whether and how their experience in general chemistry laboratory has influenced the way they record information and study, because I wanted specific detail on alteration of study patterns since freshman year. (RQ 2B)
	5 Interviewees were asked whether their learning techniques in general chemistry have helped them learn in their current course(s), because I wanted to determine corroboration of any benefits expressed in responses to previous questions regarding the efficacy of inquiry learning in general chemistry. (RQ 2C)

Appendix C: Description of Discussion Group Questions

Research question	Discussion group question description
1. How do upper level undergraduate students describe the inquiry learning aspect(s) of their freshman-year general chemistry experience: A. in terms of data collection (Exploration)? B. in terms of interpreting their data and inducing patterns or themes (Concept Invention)? C. in terms of knowledge synthesis, hypothesis, and prediction (Application)? D. in terms of a group setting (Social Interaction)?	1. Group interviewees were asked to compare and contrast the structure of the laboratory (Discovery) portion of their general chemistry course with other laboratory courses they are taking or may have taken. I wished to get multiple perspectives on group impressions of course structure (RQ 1A). 2. Group interviewees were asked to describe any advantages or disadvantages of collaboration in the lab, because I wanted details of how collaboration is molding the science thought process. (RQ 1D)
2. How do upper level undergraduate students describe the influences of the inquiry learning aspects of their freshman general chemistry course on their approaches to learning in their current courses: A. in terms of data collection (Exploration)? B. in terms of interpreting data or inducing patterns or themes (Concept Invention)? C. in terms of knowledge synthesis, hypothesis, and prediction (Application)? D. in terms of a group setting (Social Interaction)?	1. Group interviewees were asked to compare and contrast the structure of their general chemistry lab with the lab or equivalent portion of their current science course(s), because I wished to find out whether the current structure is conducive to collaborative inquiry learning (RQ2A). 2. Group interviewees were asked to describe any collaborative work in senior science courses and the influence of the collaborative aspect of general chemistry on the present collaboration(s), because I wanted to find out the strength and endurance of the collaborative aspect of inquiry learning in freshman year general chemistry. (RQ 2D)

Appendix D: Walden IRB Study Approval

Approval #05-30-14-0142700

Appendix E: Consent Form for Adults

CONSENT FORM

You are invited to take part in a research study of senior students' perceptions of the influences of the inquiry learning aspects of their General Chemistry experiences on their thinking and study habits in their senior science courses. The researcher is inviting current senior undergraduate students of UMBC who have previously taken General Chemistry to be in the study. This form is part of a process called "informed consent" to allow you to understand this study before deciding whether to take part.

This study is being conducted by a researcher named Eric G. Chesloff, who is a doctoral student at Walden University.

Background Information:

The purpose of this study is to find out what students thought about the group inquiry learning in their General Chemistry course and how it influenced, if at all, the way they learn in their senior science courses.

Procedures:

If you agree to be in this study, you will be asked to:

> Consent to at least one, and possibly an additional follow-up, interview, either individually or as part of a small focus group. Interviews are anticipated to last between one-half and one hour.

Here are some sample questions:

> Do you think the way you learned in your general chemistry laboratory has helped you learn in your current course(s)? Do you think your general chemistry laboratory has affected the way you take notes and study? If so, how and to what extent?
>
> Do you think the way you learned in your general chemistry laboratory has helped you learn in your current course(s)?

Voluntary Nature of the Study:

This study is voluntary. Everyone will respect your decision of whether or not you choose to be in the study. No one at UMBC will treat you differently if you decide not to be in the study. If you decide to join the study now, you can still change your mind later. You may stop at any time.

Risks and Benefits of Being in the Study:

Being in this type of study involves some risk of the minor discomforts that can be encountered in daily life, such as fatigue, stress or becoming upset. Being in this study would not pose risk to your safety or well-being.

The study results will potentially aid college general chemistry instructors in the design of the inquiry portion of their courses so as to impart the greatest learning potential to their students.

Payment:

In appreciation for your cooperation in this study, at the conclusion of data collection you will be mailed a Starbucks $20.00 gift card.

Privacy:

Any information you provide will be kept confidential. The researcher will not use your personal information for any purposes outside of this research project. Also, the researcher will not include your name or anything else that could identify you in the study reports. Data will be kept secure by substituting a code for your actual name, protecting electronically recorded data in a password-protected computer, and protecting hand-written data in a locked filing cabinet. Data will be kept for a period of at least 5 years, as required by the university.

Contacts and Questions:

You may ask any questions you have now. Or if you have questions later, you may contact the researcher via the following email addresses: eric.chesloff@waldenu.edu, or ecdc5@verizon.net. If you want to talk privately about your rights as a participant, you can call Dr. Leilani Endicott. She is the Walden University representative who can discuss this with you. Her phone number is 612-312-1210. Walden University's approval number for this study is **IRB will enter approval number here** and it expires on **IRB will enter expiration date.**

The researcher will give you a copy of this form to keep.

Statement of Consent:

I have read the above information and I feel I understand the study well enough to make a decision about my involvement. By returning a completed survey, replying to this email with the words, "I consent," I understand that I am agreeing to the terms described above.

Printed Name of Participant ______________________________

Date of consent ______________________________

Researcher's Signature ______________________________