ANALYSIS OF INQUIRY-BASED CLASSROOM ACHIEVEMENT IN CONJUNCTION WITH THE IMPLEMENTATION OF REFLECTIVE STUDENT PRACTICE IN A SCIENCE CLASSROOM

by

CHRISTOPHER CHOUDOIR

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Abstract

Inquiry-based science education, in conjunction with reflective practice, promotes an educational environment of active thinking and improved comprehension of scientific phenomena. This study investigated how high school chemistry students formulated an understanding of Boyle’s Gas Law through two distinct educational approaches. Students in the control group of this study received a standard instructional approach: lecture, lab, and test. On the other hand, students in the experimental group received instruction via computer simulation, group discussion, reflection activities, laboratory assignment, and assessment. Objective analysis of calculations and data interpretation, in coordination with subjective assessment of student short-answer responses, demonstrates that students in the experimental group scored better on the laboratory activity and the two different assessment activities upon conclusion of the respective lessons.
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Introduction

The soul of science and science education embodies a desire to explain the universe and its phenomena. Be it explaining phases of the moon and seasons or developing a deeper understanding of the chemical processes in our bodies, students of science work to develop hypotheses to encourage cognitive growth. However, science education in the United States has slowly left this inquisitive ideology behind. Local, state, and national testing benchmarks have hindered many science classrooms in ways that have prevented the teaching of inquiry science in favor of dogmatic lessons of fact. The wonderment of students is lost in the acknowledgement of student memorization of isolated facts in hopes of higher achievement on mandated tests. As educators and citizens, we must begin to look past the teacher-centered format of many classrooms today and develop student-centered environments that promote scientific inquiry and development of depth in understanding.

Classroom teachers, curriculum directors, and colleges of education must begin to prepare educators and students of education for more than a test; all must begin to accept the need to create a society of reflective and active thinkers. As projected by Lee and Butler-Songer (2003), “Traditional learning situations that utilize lectures and demonstration rarely challenge students to practise (sic) particular activities of the culture of the science community” (p. 923). Inquiry-based education encourages learners to ask questions, develop models (ideas for explaining scientific phenomena), and share these models with others. The culture of the science community strongly mirrors the practices of active thinkers and cognitive development, not only strong academic curriculum.

Active thinking in and out of the classroom requires teachers to promote questions of “wonderment.” Chin and Brown (2002) discuss the need for questioning as it “lies at
the heart of scientific inquiry and meaningful learning.” As such, the need for engaging students in the act of inquiry behooves our interest as educators and citizens to promote a student-centered atmosphere that requires students to develop and respond to questions regarding phenomena around them. Such ideology is not apparent in teacher-centered classrooms that focus on the passive transfer of knowledge from teacher to student. Moreover, to further the cognitive development of our students, we must pursue challenging activities that require students to ask questions and not rely on the questions presented by the teacher.

Inquiry-based curriculum is not hands-off education by teachers. As described by Reid and Yang (2002), scaffolding by the teacher is necessary to ensure that students create links between known information and that to be discovered. In other words, inquiry-based lesson planning requires teachers to analyze what their students know and what must be done to get them to the learning goal. Inquiry-based curriculum does not mean teachers issue an assignment and expect the students to develop a satisfactory product without guidance. As with cooperative work in the science community, the classroom becomes a community of learners.

The advent of computer use in the classroom has encouraged many educators to implement lessons and discovery opportunities only feasible with computer programs. Inquiry-based education requires students and teachers to complete multiple trials, interpret patterns, predict outcomes, and develop hypotheses. Computer programs provide the opportunity to run multiple trials in a short period of time. In turn, the students and teacher may develop explanations for scientific phenomena in standard classrooms rather than expensive laboratories. Moreover, the practice of using computer
programs encourages the reflective processes imperative for learning complex processes, such as those encountered in inquiry-based instruction (Soderberg and Price, 2003). As a result, the classroom begins to feel more like a laboratory of data collection, hypothesis building, and reflective analysis.

The emergence of standards-based testing and the No Child Left Behind Act has left many educators, parents, and school districts wondering what method of instruction benefits students most, inquiry-based or teacher-centered curriculum? Inquiry-based instruction encourages students to participate in discovering, developing models, and communicating their ideas with peers. In addition, inquiry-based curriculum promotes multiple attempts for reflective discovery, thus increasing the depth of understanding. Teacher-centered coursework generally follows the pattern of lecture, worksheet, the “see what I mean” lab, and assessment. The former method follows ideals of scientific discovery whereas the latter resembles an assembly line of instruction. Do students in science classes experiencing lessons via inquiry-based curriculum retain learning objectives longer than students in classes that are teacher-centered? What role does the utilization of computer software in inquiry-based classrooms enable student success? It is the hope of this study to determine that reflective practices of inquiry-based curriculum strengthens, with the use of computer programs, student depth of understanding and retention of models used to explain scientific phenomena.

Key Terms

Teacher-centered curriculum: Lessons designed with the teacher as the central figure in the classroom. The teacher plays the role of knowledge purveyor.
Inquiry-based curriculum: Lessons designed with the students as the focus of the classroom. The teacher plays the role of mentor throughout the scientific process while students engage in authentic scientific observation and model development.

Scientific Model: An idea used to explain naturally occurring phenomena

Computer Programs: An instructional tool used on a computer that may simulate lab activities and allow the students to collect data.

Information Questions: Questions with a right or wrong response.

Wonderment Questions: Questions concerning phenomena observed by a student. These questions cannot be answered with a yes or no response.

Scaffolding: An educational model that uses instructional supports designed to meet the current needs of the student and encourage them to develop further.

Research Questions

1. Do students in science classes experiencing lessons via inquiry-based curriculum retain learning objectives longer than students in classes that are teacher-centered?

2. What role does the utilization of computer software in inquiry-based classrooms play in enabling student success?

Variables

This study focuses on how student achievement is affected by experiences in teacher-centered versus student-centered classroom environments. The same learning objectives guide both classrooms; however, one classroom aligns itself with inquiry-based curricula while the other follows a standard teacher-centered curriculum (hear the information, read the information, and see the information).
The independent variable of the study is the implementation of an inquiry-based classroom utilizing computer programs, lab investigations, and wonderment questions to promote reflective scientific processes by the students. Dependent variables in this study include a survey to gauge student interest, a pretest/posttest comparison, and the utilization of a second posttest. The results of the assessments will be compared with those of students from a teacher-centered classroom, also known as the control of the investigation.
Literature Review

The literature review that follows discusses the role of informal education, wonderment questions, student-centered classrooms, inquiry-based education, and the utilization of computer programs in successful learning environments.

As babies become toddlers, and toddlers become children, the world around them becomes a playground for the mind. At this age, it is common for children to question the world around them. For instance, the child may ask questions like, “why does daddy have to go to work?” Or, “why can’t I stay at grandma’s one more night?” As it turns out, the “terrible twos” mark a time in an individual’s life when they truly begin to ask the most difficult and common scientific question, “why?”

The informal education of an individual contributes greatly to his or her personal ideology of education and learning. As discussed by Gerber, Cavallo, and Marek (2001), once a student has completed high school, the individual has spent approximately 11,000 hours in an academic setting. In contrast, the same student will have spent around 65,000 hours involved in other activities within the same duration. Obviously, the activities of the student outside the classroom will have a profound effect on the individual’s development as a learner. The activities the student is part of outside the classroom constitutes the individual’s informal education.

Informal learning experiences may have strong links to student success in the scientific classroom. Informal learning situations encourage individuals to develop questions, promote hypotheses, and reflect upon conclusions. This practice fosters traits of scientific reasoning ability that may be useful for understanding scientific processes and concepts in the classroom (Gerber et al., 2001). Therefore, the lessons outside the
classroom not only contribute greatly to our understanding of the world around us, the facilitated process of understanding also prepares us for scientific inquiry in the classroom.

It is the inquisitive nature of our youth that truly must be nurtured in today’s scientific classroom. “Wonderment” questions encourage individuals to assess and respond to the world around them. As Chin, Brown, and Bruce (2002) describe, wonderment questions encourage the learner to “hypothesize, predict, thought-experiment, and generate explanations” for phenomena. On the other hand, information questions seek a specific answer that is subject to being “right or wrong.” This classroom format mirrors the ideology that science is merely the transmission of fact. In addition, Wood and Wood (as cited in Chin et al., 2002) have exemplified how classrooms that revolve around teacher controlled information questions promotes student passiveness in the classroom. In essence, teacher-centered questions minimize the inquisitive nature and motivation of students.

Connections between the classroom and real-world observations promote better question asking by the students and increased depth of understanding. In the Chin et al. (2002) study concerning student questioning, the authors discovered that students began to connect concepts in the lab with phenomena they have observed outside the classroom through the development of wonderment questions. Once the students were placed in problem-solving laboratory situations, their questions moved from procedural to inquisitive. In turn, students began to develop their own scientific questions not only concerning the current lab but also the world around them. As Chin et al. (2002) discuss in the study, these questions may not be inherent to all students and all laboratory
experience; hence, teacher direction may be imperative to pique student interest and to create a connection with natural phenomena.

Student-centered classrooms not only promote inquisitive questioning, classrooms of this format also encourage student depth of understanding and processes of scientific thinking. The National Research Council (1996) describes a benchmark science classroom as an environment where students actively engage in the process of science, not an environment in which the teacher does science for the student. Many classroom activities/laboratories are formulated, thus restricting the freedom of students to develop questions that need to be answered and procedures to accomplish the goal. In turn, the student may feel that a particular answer is expected. However, such an experience does not operationalize the nature of science. Huber and Moore (2001) describe scientific inquiry as the process of “observing, measuring, classifying, communicating, making predictions and inferences, representing data, controlling variables, and experimenting.” This process requires students to engage in question asking activities (how will this experiment help me find an answer?) and partake in the true nature of science (how do my observations help me explain the observed phenomena?)

Student understanding benefits greatly from scientific inquiry and processes. As discussed previously, the number and quality of questions asked in the classroom increases with students who engage in scientific processes. The questions proposed by the students are in turn used for experimentation. As students formulate questions, the laboratories take on new meaning. Students begin testing variables based on their observations and predictions. Revision of laboratory variables and analysis of the results encourages students to assess their predictions and models. Reflection during this process
of experimentation not only involves the students in the scientific process, it also increases student depth of understanding (Lee and Butler-Songer, 2003).

Inquiry-based education strongly mirrors the thought processes that encourage meaningful learning. Science classrooms structured on lecture, worksheet, and recipe labs do not reflect the culture of learning. Instead, an environment such as this promotes a culture of transmitting knowledge, or schooling. White and Frederiksen (as cited in Lee and Butler-Songer, 2003) describe an effective inquiry-based classroom as one that consists of questioning, predictions, experimentation, model development, and application of findings. This cycle invites students to internalize the observations they have made, the experiments they have conducted, and the conclusions they have drawn. In addition, the final step in the sequence connects the models developed in the classroom with phenomena outside the classroom.

Inquiry-based education requires more than just hands-on activities; the activities must also be minds-on. Hands-on activities promote the participation of students in the classroom; however, many hands-on activities conclude prematurely, resulting in a lack of student understanding (Huber and Moore, 2001). In addition, many hands-on activities found in textbooks present the scientific method as a step-by-step process (Huber and Moore, 2001). On the other hand, inquiry-based education creates a classroom environment of procedure development, trial and error, and reflective analysis of observations. As discussed by Dalton and Morocco (1997), the teacher must become part of the scientific community and “coach” the students through investigations, not guide them.
Scaffolding lessons in an inquiry-base classroom plays an integral role for student success and understanding. Teachers must prepare lessons and present information to their students that will aid in the discovery process without promoting one particular result. Creating connections between “islands” of knowledge can be difficult for the learner; however, this step is necessary for students to resolve open-ended problems and creating long-term understanding (Reid and Yang, 2002). The teacher may have to create the bridges to link these “islands.” As such, inquiry-based curriculum must be focused on a unifying concept to create a “coherent conceptual network” (Dalton and Morocco, 1997). Inquiry-based lesson planning does not mean hands-off teaching for the instructor. The teacher must act as facilitator and scaffold the lessons based on student preconceptions and background understanding.

The advent of computer technology in the classroom strongly lends itself to the reflective practice and reflexive methodology of inquiry-based education. Teaching and learning are personalized processes that are complex; as such, teaching and learning require consistent reflective practices (Soderberg and Price, 2003). A computer program in which students control variables and run experiments at a much more rapid pace than in an actual laboratory allows students to collect more data, observe patterns, and develop hypotheses within a respectable timeframe. The ability of students to repeat experiments to test new ideas mirrors the ideology of scientific research. In addition, the reflective nature of the process promotes deeper understanding of concepts analyzed. Furthermore, the essence of inquiry-based education focuses on the explanation of phenomena via the analysis of student observations. The utilization of computer programs provides a medium for students to test a hypothesis, critique adequacy of the hypothesis, and
reformulate the hypothesis based on new observations. This behavior mimics that of scientists in the laboratory and the ideology of inquiry-based curriculum.

The use of computer programs in the inquiry-based classroom does not negate the necessity for scaffolding by the teacher. Reid and Yang (2002) explain the necessity for students to create links between “islands” of knowledge in order to develop deep and meaningful understanding. The role of the teacher may be to create these links through scaffolding of lesson content and use of computer programs. As Lee and Butler-Songer (2003) witnessed, a main difference between students and experts (scientists) is the students’ ability to draw connections between variables and manipulate multiple variables during an experiment. As a result, teachers may have to provide activities before the inquiry-based research to create connections between “islands” and activate prior knowledge of the students. In addition, the students need to understand the basic procedure of the computer program, the variables of the program (what they are and how to change them), and how results are presented. As one can see, the use of computer programs still requires strong participation from the teacher and scaffolding practices to encourage success of the students and long-term understanding of concepts.

The goals of the previous studies concentrated on the ideology of inquiry-based education, methodology of the curricula, and necessity to provide scaffolding for students to connect ideas of lessons. All of the above aim to improve student depth of understanding and connection of ideas to promote long-term retention of scientific concepts. In addition, many of the studies focused on the thought processes of students partaking in inquiry-based education. The reflective nature of the students during inquiry lessons mirrors that of scientists, and more importantly, active learners. Furthermore,
research concerning the use of computer programs as an educational tool aids in the
development of inquiry-based science curricula because of the repetitive nature of data
collection and analysis in order to develop a hypothesis. This study strives to discuss how
student learning is affected through inquiry-based education programs versus teacher-
centered programs. In addition, an analysis of how the repetitive nature of science
laboratories and associated computer programs affects student understanding and model
development shall be discussed. Findings of this research aim to assess how well all of
the aforementioned observations effectively create an environment of scientific inquiry
and academic achievement.
Methods

Research Design

The quasi-experimental design of this study resulted from the non-intrusive nature of the research. Students were enrolled in classes far before the implementation of this study. As such, the nonrandom assignment of the students into groups was the product of scheduling the year prior to the study. The analysis of inquiry-based science curriculum in conjunction with the use of computer programs compared to that of a standard science classroom lended itself nicely to a two group comparison: one with the experimental program, the other acting as a control group. The format of the study required two nonrandomly assigned groups, an observation prior to the implementation of the program, the implementation of the study, and an observation concluding the research. The diagram of the design was as follows.

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N \rightarrow O \rightarrow X \rightarrow O
\]

\[
N \rightarrow O \rightarrow O
\]

The first observation of both groups prior to the program resulted from a pretest containing multiple-choice and short answer questions. The questions focused on the learning objectives of the unit. The program contained the characteristics described in the literature review. Students of the program group involved themselves in an inquiry-based curriculum that encouraged question asking, experimental design, development of hypotheses, sharing of ideas, and the use of computer programs to gather information and test ideas. The posttest was two-fold. First, the students retook the pretest upon conclusion of the lessons. To avoid test threats to internal validity, a second assessment was also utilized. The second assessment, while still focusing on the learning objectives,
was more open-ended and required students to extend what they had learned in the classroom to a less structured, more realistic problem-solving environment. Scores from the pretest were then compared with those from the posttests.

Procedure

The study began with the control group and experimental group taking a pretest (Appendix A), which was focused on the learning objectives of the unit. The pretest (Appendix A) contained both multiple choice and short-answer. The control group proceeded through a unit that did not differ from the “normal” science classroom. The students took notes, read from the text, and completed a lab (Appendix B) to demonstrate the ideas expressed in the unit. The experimental group, however, began the unit with essential questions to answer, many of which the students themselves wrote. The experimental group also read from the text, but did not receive lecture notes in the typical fashion. Instead, students completed a lab utilizing computer software (Appendix C) to develop ideas to share with the class. The students then entered the lab to test the hypotheses derived during classroom discussion. Upon the conclusion of this reflexive laboratory experience, the class-developed hypotheses concerning the phenomena observed and began to answer the essential questions. Both groups completed the unit and retook the pretest (Appendix A) and a new posttest (Appendix D).

Measures

The pretest (Appendix A) at the beginning of the unit focused on the learning objectives of the unit. The format of multiple choice and short-answer allowed for the analysis of basic knowledge acquisition (multiple choice) and the underlying understanding and processes of thinking the students possess (short-answer). The open-
ended nature of the short-answer questions encouraged the students to link and explain concepts from the unit.

Video observations and clipboard record keeping also provided the study with evidence of student discussion and question asking. Part of inquiry-based education required students to share ideas. As such, a video camera allowed the teacher to analyze how groups were working through problems via discussion, reflection, and question asking. In addition, since only one teacher was in the room, a video camera allowed for the observation of more than one group.

At the completion of each day’s lesson, the experiment students recorded questions, responded to teacher prompted statements, and described their understanding of learning objectives through journal entries. The instructor collected the journals to assess student progress throughout the unit. This tool allowed the researcher to gauge the progress of the students. Furthermore, since motivation may be a key component to student success, the journals provided the teacher with feedback from the students with regard to motivational levels as the unit proceeded. In addition, the journals encouraged the students to reflect upon the lessons, a major component of inquiry-based lesson planning.

The assessment of student understanding in both the control and experimental groups resulted from two posttests. The first test mirrored that of the pretest (Appendix A). The multiple-choice questions were used to assess student achievement with respect to basic learning goals. The short-answer questions gauged how the students processed the information, used ideas gained from the unit, and derived responses based on understanding of the learning objectives. The second posttest (Appendix D) assessed the
students’ ability to formulate responses to questions that are more open-ended. In essence, the students had to extend what they had learned throughout the unit and apply it in a setting that was not as structured as that presented in the first posttest (Appendix A). The use of two posttests was to alleviate possible test threat in the study.

Subjects/Participants

The participants in the study were high school chemistry students. A majority of the students were sophomores, juniors, or seniors. At the high school used in this study, almost all students are encouraged to take chemistry. As such, the ability levels of the students varied greatly within the classes; however, scheduling conflicts also influenced the composition of the classes. The block scheduling of the school only allowed for four class periods per day. Thus, students who took higher-level math together may have also found themselves in the same chemistry class. As such, analysis of the classroom demographics may have resulted in the apparent overloading of some classes with highly motivated and achieving students. Thus, when the results were compared, it was important to map the demographics of the classes as well.

The overall demographics of the school district represented that of a small, blue-collar town. The school population was approximately 600 students. Cultural diversity was low and the economic status of the community was mainly low to middle class. Furthermore, the school district was landlocked by surrounding districts. As a result, the general population of the district has changed very little.

Data Collection and Analysis

The independent variable of the study was the incorporation of an inquiry-based curriculum compared to a standard curriculum that was already in place. The dependent
variable of the study was student achievement with respect to intended learning outcomes of the unit. Data collected throughout the unit came via a pretest (Appendix A), observations during the lessons, and two posttests (Appendices A & D).

The pretest (Appendix A) served as a benchmark for comparing student understanding before and after the respective units. In addition, the pretest (Appendix A) also allowed for comparison of the two groups prior to any program or lesson. This was important for gauging the ability level of both classes. Without this base level, it would have been hard to determine if the program used for this study had any effect on student understanding.

Observations in the classroom included videotaping, clipboard assessment, and exit journals. The videotapes documented student discussion in laboratory settings. This was vital because the teacher could not be with all groups at once. In addition, the video documentation allowed the teacher to reflect on the student growth during the lesson and any changes that may improve the lesson in the future. The clipboard assessment was a quick note-taking tool used to record observations during the class period. Using the clipboard, the teacher documented student questions and achievements quickly. The exit journals, as described earlier, encouraged the students to reflect on the lesson of the day. Once submitted to the instructor, he assessed student understanding, questions, and motivation level of the students throughout the study. This feedback from the students also allowed the teacher to gauge student involvement in the class.

The posttests, one similar to the pretest (Appendix A) and the other an extension of the learning objectives (Appendix D), served as a tool to gauge student progress through the two different units. The score on the first posttest (Appendix A) was
compared to that of the pretest (Appendix A). The data for the two groups was analyzed to determine the progress of the students in both classes. The second posttest (Appendix D), subjectively scored by the teacher in some instances, was used to gauge depth of understanding. Although there was not a pretest to directly compare with this posttest (Appendix D), the responses to the questions provided insight into how well the students from respective groups understood and applied concepts learned via the standard classroom curriculum versus that of the inquiry-based classroom.

Use of Human Subjects

Prior to the start of this study, approval of its intention and content was gained from district administrators, parents (Appendix E), and colleagues in the science department. However, the ideology of assessing the progress of students based on the implementation of different educational strategies was not new to the district. Nonetheless, to avoid complications with administrators, approval was sought.

The students were subjected to the same learning outcomes in each program. As such, there was not any issue with students, parents, or administrators with respect to learning varying content. In addition, many of the students have several different science teachers throughout the semester (a result of block scheduling). As a result, the students were prepared for changes in instructional strategy.
Analysis of Results

The groups were determined randomly via the choice of cards. The demographics of both groups are relatively consistent. All students were sophomores, juniors, or seniors. All had completed similar science programs prior to the chemistry course. Furthermore, all students in the study met the prerequisites for enrollment in the chemistry course. One difference in the composition of the two groups was that the experimental group contained a special needs student. Again, said student matched the previous characteristics; however, as was indicated in the students individualized education plan, the student’s cognitive abilities were slower than the average student in this sample.

The topic of this lesson focused on Boyle’s Gas Law. Boyle’s Gas Law describes the relationship of a gas’ volume to the pressure placed on the gas. For example, if the pressure on a contained gas increases, the volume the gas occupies will decrease. In turn, the law also describes how the pressure of a gas changes in relation to changing volume of the gas’ container. Thus, if the volume of the gas’ container increases, the pressure exerted by the gas on the container’s walls will decrease. The indirect relationship is summarized with the following equation (P $\rightarrow$ Pressure, V $\rightarrow$ Volume).

$$P_1V_1 = P_2V_2$$

Students mimicked the Boyle J-tube experiment in the respective lessons to demonstrate the previously explained relationship. One end of a bent glass tube (shaped like a J) was closed and the other was open (see diagram in Appendix B). Water was added to the open end of the tube, thus trapping air in the closed end. As water was continually added to the open end of the tube, the pressure on the trapped gas increased
from the resulting weight of the water and atmospheric pressure. As the pressure increased, the volume of the trapped gas decreased.

Prior to the division of control and experimental groups, all students completed a pretest to serve as a benchmark for this study. The pretest (Appendix A) focused on the fundamentals of Boyle’s Gas Law and includes qualitative and quantitative responses. As the collected data indicated (Appendix F), there was not a significant difference in understanding prior to the lesson as indicated by a t-value of 0.22 (95% confidence is above 2.11). As a matter of fact, when the mean, median, and mode of the scores were analyzed, the control group scored slightly higher.

### Analysis of Pretest Data

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<tr>
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<th>Experimental Group</th>
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<tbody>
<tr>
<td>Pretest out of 5 possible points (Before)</td>
<td>1.7</td>
<td>1.44</td>
</tr>
<tr>
<td>Mean</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Median</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Mode</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.67</td>
<td>0.88</td>
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The control group received introductory explanations of Boyle’s Gas Law and an introduction to Boyle’s J-tube lab, all via lecture. The control group then entered the laboratory to complete Boyle’s J-tube lab (Appendix B). Subjective teacher analysis of the lab write-ups exhibited weak conceptual understanding of the process and meaning of collected data. The detail of explanations was weak and many did not use data to solidify responses. The teacher used the following question from the Boyle’s Law Lab as an
example: “Given the following two equations, which better describes the relationship of pressure and volume of a gas. Use your data to back-up your decision.” The student circled the first equation ($P_1V_1 = P_2V_2$) and explained, “You showed us the answer!”

Furthermore, few provided a real-world application of Boyle’s Law when prompted to do so. One student explained Boyle’s Law using a balloon in the following manner. “Here’s an example, putting air in a balloon, more air it gets in balloon higher pressure and lower the volume (sic).” As indicated in this response, the observation in the lab of higher pressure resulting in lower volume in a gas was not transferred to a real-world application. Overall, the lab seems complete only in a superficial manner.

The experimental group began with a computer simulation, not with a lecture, (Appendix C) concerning the J-tube experiment that included similar questions to those found on the laboratory version. In addition, the experimental group completed reflection questions of the laboratory goals upon completion of the lab. Even though the data collected in the computer simulation did not accurately support Boyle’s equation, the other portions of the simulation seem to be a great success.

Through subjective analysis by the teacher, the responses to the lab questions and goals contained a greater amount of detail than that found in the control group. For example, this was a student’s explanation of the relationship between pressure exerted on a gas and the resulting volume of the gas, “If the pressure is increasing you would predict the volume of a gas to be decreasing. If the pressure was decreasing, you would predict the volume to be increasing.” Compared to the, “you showed us the answer!” response, this student demonstrated a deeper conceptual understanding of the relationships found in the data.
The experimental group then moved to the laboratory to complete the same J-tube lab as the control group (Appendix B). The students received a brief introduction to the lab. This included set-up and review of the experiment from the day prior. Once the lab was completed, the students again reflected on the lab goals and how they are related to what they witnessed in the lab. Both the lab goal reflection and completion of the lab packet demonstrated a deeper understanding of not only procedure, but also the data collected and calculations completed. When asked to choose an equation and explain the relationship in the collected data, one student not only chose the correct equation ($P_1V_1 = P_2V_2$), but also described the selection with this statement, “the product of pressure and volume is almost the same in every trial, making PV a constant, or nearly a constant. This proves that $P_1V_1 = P_2V_2$.”

After completion of the lab, both groups retook the pretest. As was evident in the data, the experimental group’s mean score of 4.78 (out of 5) exceeded that of the control group’s mean score of 3.90. The difference in these results is significant with a 95% confidence level ($t_{\text{calc}} = 3.73$). Most notably, all students but one in the experimental group scored perfectly on the reassessed pretest.

In the assessment activity (Appendix D), once again the experimental group scored notably higher than the control group. The mean score for the experimental group was 5.5 out 7. On the other hand, the mean score for the control group was 4.25 out of 7. The data collected for this assessment was significant at a 90% confidence level. However, as discussed previously, one student in the experimental group had special needs and was cognitively slower than the average student. When the score of this
student was removed from the results of the experimental group, the difference in the
mean scores between the two groups was significant at a 95% confidence level.

In the assessment activity, the control group scored very poorly in calculations
using Boyle’s Law. Approximately half could use supplied data to support Boyle’s Law
and only two out of ten could correctly answer both of the calculations predicting
pressure change in a closed system when the volume was altered or volume change in a
closed system when pressure was altered. Moreover, the conceptual descriptions of
Boyle’s law provided by the students, based on subjective analysis by the teacher, lacked
depth of understanding. Four out of ten students could not explain how pressure was
added to the gas in the J-tube experiment. This was an example response: “The water on
the gas causes the pressure.” As is evident in the next paragraph, this response may be
regarded as correct, but it lacks detail and pertinent elements.

On the other hand, the experimental group scored significantly better in both
calculations using Boyle’s Law and the accompanying conceptual understanding. In the
calculations using Boyle’s Law, all but one student successfully determined the resulting
pressure change in a closed system with a variance in the volume and volume change
with a variance in pressure. When asked to sketch a graph of the relationship between
pressure exerted on a gas and the resulting volume, all students successfully sketched the
graph. Only two of the experimental students did not describe the relationship the graph
depicted. Moreover, all but one student adequately described how pressure was added to
the gas in the J-tube, thus, demonstrating a stronger understanding of the laboratory
procedure and resulting data. This was an example response: “When you pour more
liquid into the J-tube it exerts more pressure on the gas in the closed end because the force of gravity and the air pressure in the room exert pressure on the gas in the tube.”

One question in the final assessment asks students to explain the relationship between the kinetic theory of matter and Boyle’s law. Both groups scored low with regards to this question. However, in comparison, the experimental group still scored higher and answered the question in greater detail.
Discussion

The control group of this study received an educational experience similar to most science classrooms in this country: lecture, lab, and assessment. Similar to most science classrooms of which the teacher has been a part, the labs and discussion questions lacked analytical depth and reflection. In turn, scores on assessments were low and overall understanding of the scientific process remained unnurtured. In addition, observation of the laboratory environment reflected an attitude of nonchalance and lack of interest.

The experimental group experienced a learning environment that nurtured discussion, creative thinking, and reflective practice. All of these ideals lie at the heart of the scientific process. Other than an introduction on how to use the computer simulation (Appendix C), this group began the unit with very little instruction. The experimental group completed a computer simulation (Appendix C) and accompanying packet to guide understanding but not force it.

When reviewing the videotape of the experimental group working on the computer simulation (Appendix C), a movement from solitary work to that of cooperative group work was evident. One person, however, did not control the group work. When an individual became stuck, others either offered help or the individual sought out more information via the simulation. In other words, the students had taken control of their respective understanding. This was important because the students were innately reflecting on personal accomplishments and shortcomings; thus, guiding their future path of learning.

The simulation (Appendix C) mimicked the J-tube lab that students completed the next day; however, the simulation encouraged the students to collect data quickly and
assess how the data related to the lab goals. In other words, the students had more time to process information gathered rather than contemplating laboratory set-up. Allowing more time to assess collected data may have encouraged students to reflect on personal understanding of the experiment. For example, when the students were confronted with two possible equations to model Boyle’s Law in the computer simulation, neither worked. In turn, a discussion broke out involving the instructor. Students and the instructor discussed the graph of pressure v. volume and what relationship was displayed. From this point, students determined the correct formula to model the relationship in the data. Even though, the simulation did not work as planned, students identified the mistake and ultimately determined the correct relationship to model the data collected.

The second portion of the laboratory simulation (Appendix C) for the experimental group involved practice calculations using Boyle’s Gas Law. Students practiced the calculations and immediately received feedback regarding the answer. If the students determined the wrong answer, they were immediately presented with another calculation. If the students determined the correct answer, they could continue to practice until they reached an acceptable level of mastery. Providing the opportunity for students to reflect on personal understanding with immediate feedback encourages an environment that promotes intellectual growth and understanding.

In the laboratory (Appendix B), following the simulation, the experimental group demonstrated a solid understanding of laboratory set-up and procedure. The data collection and set-up were well understood. Given the data collected on this day, the students successfully explained Boyle’s relationship of volume and pressure given the data they collected. In addition, the responses to the analysis questions in the lab
demonstrated a greater depth of understanding. Furthermore, the experimental group completed calculation problems at a much higher level of success than that demonstrated by the control group.

Returning to the analysis of the data, it was apparent that all of the students in the experimental group, except one, scored higher than the individuals in the control group. The student that scored lower than the others in the experimental group was a special needs student. As such, the less restrictive learning environment may have been more difficult for him than the standard format of the science classroom. However, it should be noted that this student did improve his score from pretest to post-test in this unit.
Conclusion

The very nature of science embodies reflection upon personal understanding of the world around us. Unfortunately, many science classrooms do not nurture this ideology. In this study, the standard teacher-centered science classroom was compared to one that promoted inquiry and reflection in a laboratory setting. It was apparent that students thrived not only on assessment activities but also in understanding labs and personal progress. As such, the inquiry-based nature of science should be more strongly asserted in science classrooms. Furthermore, the use of computer simulations strongly encouraged the students to assess personal understanding of concepts, laboratory procedure, and calculations, all of which carried over nicely to the hands-on laboratory experience. The science classroom needs to move from an arena of knowledge transfer to one of knowledge development. As this study has indicated, students are capable of such a task via reflective practice and the use of computer simulations.
References


Appendix A

Boyle’s Law Pretest

Answer the following questions to the best of your ability. Circle one response for multiple-choice questions. Explain your responses fully for short answer questions.

1. The variables analyzed via Boyle’s law are
   a. Temperature and pressure
   b. Temperature and volume
   c. Volume and mass
   d. Volume and pressure

2. Which of the following data sets would you expect when analyzing Boyle’s law?
   a. 100 mm Hg:100 mL → 200 mm Hg:75 mL
   b. 100 mm Hg:100 mL → 200 mm Hg:125 mL
   c. 300 mm Hg:50 mL → 200 mm Hg:25 mL
   d. 300 mm Hg:50 mL → 400 mm Hg:50 mL

3. Which graph best represents the relationship between pressure and volume of a gas? Explain why you chose that particular graph.

![Graphs](image)

*Explanation:*
4. Complete the following calculation using Boyle’s law. The colored chamber contains a gas at initial volume and pressure. Calculate the final pressure after the gas is allowed to fill both chambers.

Initial Pressure = 1 atm

Final Pressure:

Provide one real-world example of Boyle’s law at work. Explain why the observation is related to Boyle’s law.
Appendix B

Pressure v. Volume
(Boyle’s Gas Law)

Background
You are enveloped in a sea of gas. However, did you ever think about how these gases change when under pressure? How do the molecules react under varying pressures? Does pressure affect the temperature of the gas? Hopefully, through this lab investigation, you will be able to answer and explain some of these questions.

During the 1700s, many scientists began analyzing the relationship of pressure, temperature, and volume on the behavior of gases. Charles Boyle is known for having developed a relationship between pressure and volume of an ideal gas. Boyle utilized a piece of glass tubing sealed on one end and open on the other (known as a J-tube). Boyle added mercury to the open end of the tube, trapping a gas in the closed end. As he added more mercury to the tube he recorded the volume change of the gas on the sealed end. Through analysis of the data, Boyle developed an equation to explain the relationship between pressure and a gas’s volume.

Lab Goals
- Describe how pressure changes affect volumes of an enclosed gas (conceptual).
- Analyze data to formulate a relationship between pressure and volume on a gas (equation).
- Predict changes in gas volumes as related to changes in pressure.
- Explain a real-world gas pressure relationship using Boyle’s law.

Procedure
1. Record the temperature and pressure of the room.
2. Slowly add water to the open-end of the J-tube until the water rises to a level that you can measure on the ruler.
3. Record the position of the upper-end of the enclosed tube to the nearest mm (0.1 cm) (A).
4. Record the level of the water in the closed arm (B).
5. Record the level of the water in the open arm (C).
6. Add enough water to fill the open tube about 1/4 of its length.
7. Record the new levels of B and C.
8. Level A should stay the same throughout the experiment.
9. Repeat step 7, filling the tube half way.
10. Record your data.
11. Repeat step 7, filling the tube 3/4 of the way.
12. Record your data.
13. Complete the table (Calculations)
14. Create a graph of pressure (x-axis) and volume (y-axis).

**Data Table**

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<table>
<thead>
<tr>
<th>Trial</th>
<th>A (top of closed arm)</th>
<th>B (water level, closed arm)</th>
<th>V (volume of air = A-B)</th>
<th>C (level of water in open arm)</th>
<th>p (pressure due to water = C – B)</th>
<th>P (total pressure = barometer reading + p)</th>
<th>PV (product of P and V)</th>
</tr>
</thead>
<tbody>
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**Conclusion Questions**

1. As the pressure increases, what happens to the volume of the gas?

2. Describe the graph of this relationship (Pressure on the x-axis and volume on the y-axis.)

3. Are pressure and volume directly or indirectly related? Explain.

4. Describe what you notice about the product of pressure and volume in each trial.
5. Given the following two equations, which better describes the relationship of pressure and volume of a gas. Use your data to back-up your decision.

1. \( P_1V_1 = P_2V_2 \)
2. \( \frac{P_1}{V_1} = \frac{P_2}{V_2} \)

6. As the pressure increases on the gas, do the molecules get closer together or further apart? How does this affect the pressure the gas is exerting on the walls of the j-tube? Draw a picture to explain.

7. Given the following situation and the equation you decided upon above, predict the resulting pressure when the gas from the left bulb is allowed to spread throughout both bulbs.

a. Initial Pressure = 1 atm

   \[ \begin{array}{c}
   \text{i. Final Pressure:} \\
   \end{array} \]
b. Initial Pressure = 4 atm

Final Pressure:

8. Research and describe a real-world application of Boyle’s law.

References
Appendix C

Pressure v. Volume
(Boyle’s Gas Law)

Background
You are enveloped in a sea of gas. However, did you ever think about how these gases change when under pressure? How do the molecules react under varying pressures? Does pressure affect the temperature of the gas? Hopefully, through this lab investigation, you will be able to answer and explain some of these questions.

During the 1700s, many scientists began analyzing the relationship of pressure, temperature, and volume on the behavior of gases. Charles Boyle is known for having developed a relationship between pressure and volume of an ideal gas. Boyle utilized a piece of glass tubing sealed on one end and open on the other (known as a J-tube). Boyle added mercury to the open end of the tube, trapping a gas in the closed end. As he added more mercury to the tube he recorded the volume change of the gas on the sealed end. Through analysis of the data, Boyle developed an equation to explain the relationship between pressure and a gas’s volume.

Lab Goals
- Describe how pressure changes affect volumes of an enclosed gas (conceptual).
- Analyze data to formulate a relationship between pressure and volume on a gas (equation).
- Predict changes in gas volumes as related to changes in pressure.
- Explain a real-world gas pressure relationship using Boyle’s law.

1. Describe how the volume of the three states of matter changes under pressure. Provide an example for each state of matter.
   a. Solids

   b. Liquids

   c. Gases

2. Describe, on the molecular level, why each of the states of matter reacts differently under pressure.
   a. Solids

   b. Liquids
3. Visit [http://www.chm.davidson.edu/ChemistryApplets/GasLaws/BoylesLaw.html](http://www.chm.davidson.edu/ChemistryApplets/GasLaws/BoylesLaw.html) and complete experiments 1 and 2. In addition, answer the following questions.

   a. Pressure of the Atmosphere:

   b. Height of mercury:

   c. Height of trapped air (green color):

   d. Volume of trapped gas (diameter = 4.286cm)

   e. Pressure (atmosphere and mercury):

   f. Complete this data table by changing the amount of mercury and create a graph.

<table>
<thead>
<tr>
<th>Pressure (torr)</th>
<th>Volume (mL)</th>
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</tbody>
</table>

   g. Describe the indirect or direct relationship between pressure and the volume of a gas.

   h. Using the data you have collected, which of the following equations best describes the data (hint: plug your data into both equations).

      i. $P_1V_1 = P_2V_2$
      ii. $\frac{P_1}{V_1} = \frac{P_2}{V_2}$

   i. Present your findings to the teacher.

   j. Describe the relationship of the equation and your data in a complete sentence.
Calculations Using Boyle’s Law: Using the equation you have developed above, practice answering several questions on the website. Then, respond to the questions below.

1. Initial Pressure = 1 atm

\[
\begin{array}{c}
.5 \text{ L} \\
5 \text{ L}
\end{array}
\]

Final Pressure:

2. Initial Pressure = 4 atm

\[
\begin{array}{c}
2 \text{ L} \\
10 \text{ L}
\end{array}
\]

Final Pressure:

3. Describe the general relationship between the pressure of a gas and changes in volume.

4. Explain a real-world example that utilizes the generalization you have written above.
Appendix D

Boyle’s Law Assessment

Answer the following questions to the best of your ability. Be sure to explain your responses and show all calculations where necessary.

1. Describe how pressure is added to the gas in the J-tube.

2. Describe how the volume of the gas in the J-tube changes as pressure is increased and decreased. Sketch a graph that represents this relationship.

3. Draw a diagram illustrating Boyle’s law.
4. Circle which equation best illustrates the relationship between pressure and volume on gases. Use the following data to solidify your decision.

\[ P_1V_1 = P_2V_2 \]
\[ \frac{P_1}{V_1} = \frac{P_2}{V_2} \]
\[ P_1P_2 = V_1V_2 \]

<table>
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<tr>
<th>Pressure 1</th>
<th>Volume 1</th>
<th>Volume 2</th>
<th>Pressure 2</th>
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<tbody>
<tr>
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<td>150 mm Hg</td>
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<tr>
<td>120 mm Hg</td>
<td>25 mL</td>
<td>10 mL</td>
<td>300 mm Hg</td>
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</table>

5. Using the equation you choose above, complete the following calculations. Initial pressure and volume are related to the colored chamber. Final volume and pressure calculation relate to both chambers being filled with the gas.

Initial Pressure = 1 atm

\[ \text{Final Pressure} = \]
Initial Pressure = 4 atm

Final Pressure:

6. Using the kinetic theory of matter, draw a diagram that illustrates how pressure of a gas changes when the volume of the gas changes.
Appendix E

Little Chute High School
1402 Freedom Rd.
Little Chute, WI 54140

May 17, 2007

Dear Parent/Guardian,

I am a science teacher at Little Chute High School and graduate student at the University of Wisconsin-River Falls under the supervision of Dr. Rosenthal. I am conducting a research study to determine the effectiveness of two different educational methodologies.

The participation of your son or daughter in this study will involve attending his or her normal class and completing assignments focused on learning objectives for the unit. No matter which methodology is used in your student’s classroom, the learning objectives will be exactly the same. Participation in this study is voluntary. As such, you or your student may withdraw from the study at anytime. Withdrawal from the study will not affect your student’s grade. The results of the study may be published; thus, your student’s name will not be used.

Learning objectives and goals are the same in both classroom formats. The only difference is the delivery of the information. The benefit of this study is twofold. First, your student’s understanding of science material may increase. Second, to better meet the needs of students, curriculum delivery may undergo alterations.

If you have any questions, feel free to call me at (920) 788-7600 or email me at echoudoir@littlechute.k12.wi.us.

If you have concerns about how you were treated in this study, please contact: Dr. William Campbell, Director of Grants and Research, 104 North Hall, UW-RF, 715/425-3195.

This project has been approved by the UW-River Falls Institutional Research Board for Protection of Human Subjects, protocol # __________.

Sincerely,

Christopher Choudoir
Science Teacher

I give my consent for _________________________ to participate in this study.

__________________________ (Signature)   _______________ (Date)
Appendix F

Original Class Data

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<td>4</td>
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</table>

| mean | 1.70 | 3.90 | 4.25 | 1.44 | 4.78 | 5.50 |
| s | 0.67 | 0.32 | 1.11 | 0.88 | 0.67 | 1.66 |

Test 1: Pretest prior to lesson (5 points possible)
Test 2: Pretest after lesson (5 points possible)
Test 3: Post lesson assessment (7 points possible)

t-Test Results

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<th>Section</th>
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</table>
Conclusions
A difference in Test 2 results was significant at the 95% confidence level.
A difference in Test 3 results was significant at the 90% confidence level.

Without the data from the special needs student, both Test 2 and 3 were significantly different at the 95% confidence level.
The calculated t values for Test 1, 2 and 3 were 0.22, 9.78 and 3.79 respectively.