A COMPARATIVE STUDY ON INQUIRY ACTIVITIES WITH AND WITHOUT A COMPUTER SIMULATION

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By
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CERTIFICATION OF APPROVAL

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Dr. Catharyn Shelton Professor of Educational Technology	Date
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DEDICATION

This thesis is dedicated to my amazing supportive husband, Eduardo Soto Rivera. The thought of completing a thesis was always scary and seemed unattainable to me. He has been my biggest supporter motivating me to complete my Master's Degree and this thesis study. Thank you for your unconditional support and instilling in me motivation when I needed it.

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ABSTRACT

This study compared inquiry-based learning with high school students with and without computer simulation. The treatment group completed a guided-inquiry activity using the PhET Build an Atom simulation ($n = 29$), whereas the control group completed a Process Oriented Guided Inquiry Learning (POGIL) activity on the atomic structure ($n = 30$). Both groups learned about the same main topics and completed a Post-Inquiry Assessment and Post-Inquiry Reflection after their inquiry activities. The mean of the Post-Inquiry Assessment for the two groups did not differ significantly. Qualitative data from the Post-Inquiry Reflections revealed the majority of participants in both groups perceived the inquiry activity as beneficial to their learning. The reflections also revealed that both groups were able to learn abstract concepts and a few participants felt like they needed more practice. A few participants in the control group demonstrated an ability to use similar information in different contexts, since the participants mentioned how they were able to make connections between using information in the periodic table and writing an isotope symbol. Some participants in the treatment group perceived the game component of the computer simulation to have benefited their learning. Overall, this examination of inquiry learning with and without a computer simulation revealed that in the context of a high school chemistry lesson on atomic structure, both types of activities have learning benefits.

CHAPTER I

INTRODUCTION

Science is a study where we can explore countless phenomena. The method taken to discover these marvels requires the use of inquiry skills. The National Institute of Health, Office of Science Education recognizes inquiry as a teaching method that can be used in multiple ways. In an inquiry lesson students can ask questions, design an experiment, interpret gathered data, and analyze data (National Institute for Health, 2005). Learning through inquiry and learning through critical thinking is considered an essential 21st century competency (Smith, 2014).

A number of recent studies have suggested that inquiry-based lessons within middle school and high school science classrooms are associated with improved performance and engagement. Oliveira, Wilcox, Angelis, Applebee, Amodeo, and Snyder (2012) compared teaching practices in higher performing middle schools versus average performing middle schools through a mixed methods study. In the study, teachers at the higher performing school more often carried out hands-on inquiry lessons. These teachers believed it was a method to make science more engaging and applicable to their students.

Smith (2014) also studied student engagement when students used a 3D simulation game in which inquiry was observed in the classrooms 84% of the time. In a student engagement survey, 90% of the students in this study stated they were engaged during the activity. In this study, the action of inquiry was used to cognitively challenge the students, but the technological component was also considered a possible factor in the high rating for student engagement. The authors concluded that if this technology were more readily available in more classrooms, more students would be able to benefit learning from an interactive 3D education game.

A case study conducted by Dudu and Vhurumuku (2012) compared two teachers with different ideas of teaching inquiry. Teacher A had a more close-ended inquiry lessons in his classroom where students followed directions that guided them to the inquiry goal. Teacher B implemented open-ended inquiry lessons where students had more time to plan out their research questions, critique, and revise ideas. Dudu and Vhurumuku considered open-ended inquiry as a higher level of inquiry. Teacher B carried out a higher level of inquiry in the classroom due to students having to revise and critique their ideas for their research. The teacher may have received different training or education on what best practices for teaching inquiry looks like in the classroom. With different levels of inquiry in mind, it is important to know which level benefits students the most, so teachers can use the inquiry levels that benefit students the most in their lessons.

In Indonesia, Hardianti and Kuswanto (2017) studied different levels of inquiry practice at a high school to determine if there was a difference in effectiveness between three different inquiry learning levels and their effect in improving students processing skills. The study compared inquiry levels 2, 3, and 4. In an inquiry level 2 experience, the teacher proposed the lab problem and carried out the lab. After the lab, the level 2 group had to supply answers, conclusions, and inferences about the lab. Students who experienced inquiry at a level 3 carried out the lab instead of the teacher and carried out the post-lab inquiry, just as the inquiry level 2 experienced. In the inquiry level 4 environment, students were able to design the procedure, carry out the lab, and carry out the post-lab inquiry. In a lower level inquiry, the teacher had a more active role in providing information to their students, and the student had fewer opportunities for inquiry learning. The results led to the discovery that some inquiry learning levels can improve processing skills with a different level of effectiveness when you compare levels 2 and 4 or levels 3 and 4. The results also revealed that the inquiry level 3 was the most effective in improving the students' processing skills. Overall all the inquiry levels 2, 3, and 4 helped improve the students' processing skills with a different level of effectiveness.

When students experience inquiry-based learning the amount of guidance a student receives may have a relationship with how well a student will be able to go through the critical thinking process in an inquiry lesson. Ku, Ho, Hau, and Lai (2014) discovered that direct instruction was a complementary method to implementing interventions through inquiry-based instruction. Students who experienced both direct and inquiry-based instruction demonstrated an improvement in critical thinking. This study exhibited how critical a teacher's role can be in inquiry instruction. It is important for the teacher to self-reflect in order to determine if students are receiving too much or too little teacher support.

A pilot study I conducted on eighty-two high school chemistry students explored student perceptions after they completed a guided-inquiry activity using a computer simulation. When students were asked on a survey “What could be improved about this simulation activity?” three themes were found amongst the responses: directions, teacher instruction, and questions. The Students who mentioned directions as a need for improvement mainly wanted more specific step-by-step instructions for the activity or more thorough directions. The need for better directions was the more prevalent theme in the question “What could be improved about this simulation activity?” About 27 percent of those surveyed wanted better directions to suit their needs. When students mentioned questions in their responses, they wanted to have questions that were more clear and easier to understand. The results in this pilot study conflict with the process of inquiry. Although students sought for more directions and more clear questions, the inquiry process usually requires students to grapple with information and try to learn concepts as they carry out an inquiry task.

In a recent qualitative study, teacher reflections brought to surface suggestions on how to effectively implement inquiry lessons when students struggle with grappling information. One teacher suggestion from Zhou and Xu’s (2017) study was to have a discussion prior to the inquiry activity with students, so students can discuss the inquiry question and possible investigation designs before an inquiry experiment. This could inspire some ideas for the scaffolded learning they will carry out later in the inquiry lesson. Another teacher thought the pacing was important in the inquiry lessons. If the teacher moves on before the students can understand the concept then class time is not strategically consumed since students could be left misunderstanding instructions and concepts. It is critical for a teacher to be receptive and adaptive in their teaching practice, so they can meet their students' needs while challenging them with an inquiry lesson. The teacher needs to know when to adjust the pacing, the inquiry level, and provide students with enough opportunities to experience multiple levels of inquiry.

Statement of Problem

The merging of inquiry and computer simulations in a classroom have the potential to improve student learning in the classroom. Hardianti and Kuswanto's (2017) research revealed how inquiry activities can benefit a learner's processing skills. Smith's (2014) study revealed that the use of computer simulations could result in a high student engagement rate. If computer simulations and inquiry-based learning are incorporated in the same activity, would students benefit more than the use of inquiry-based learning without a simulation?

Although inquiry activities can be beneficial to student learning, these types of activities can be expensive if materials or chemicals are required to carry out the inquiry task. It is no secret that teachers may spend their own money on classroom materials. SheerID and Agile Education Marketing (2017) reported from the 674 teachers surveyed that on average they spend $468 annually on classroom expenses including instructional materials. A teacher usually has to gather many materials together conduct different science inquiry lessons involving hands-on experiments, use manipulatives, or a project where students design and construct a device. Some teachers have to make the decision whether they will spend their own money or spend extra time to fill out paperwork for school and/or board approval to purchase necessary instructional supplies.

Computer simulations can alleviate this monetary issue. The computer simulations in the PhET Interactive Simulations (University of Colorado, 2017) website provide an interactive experience of many different scientific phenomena. They provide visuals and real-time data to imitate the real scientific phenomena. PhET Interactive Simulations website has computer simulations that are available free of cost. It has numerous science and math simulations that can be used to implement inquiry-based learning. The Build an Atom simulation on the website has three different buckets of the particles that the atom consists of protons, neutrons, and electrons. In this single simulation, students are able to discover how the particles affect the mass of the atom, the isotope symbol, the atomic number, element symbol, and charge. This simulation also gives students the ability to see and interact with the particles in a way they would not be able to if they read about them in their textbook. The use of simulations in the classroom can make learning interactive and can help cut the cost of having to purchase instructional supplies for hands-on activities.

There are other benefits to using a virtual simulation in a high school science class. One is that carrying out hands-on learning can also be hazardous in science classrooms. For example, in a chemistry and biology lab, teachers are expected to teach lessons on lab safety at the beginning of the school year due to potential hazards students may run into. As a chemistry teacher in the Central Valley of California, I have my students and their parents sign a safety contract to notify them of the hazards and precautions in the science lab (Flinn Scientific, 2017) every year. We review how to handle accidents, how to handle hazardous materials, and what we do if any type of lab accident occurs. This usually takes over a week or two to cover well enough for students to know enough about lab safety so they could work with dangerous chemicals and be able to safely handle possible accidents.

Simulations could conceivably replace hands-on inquiry lessons, including experiments. They may offer benefits relating to cost savings and safety. It is unclear how virtual simulations compare to more traditional inquiry approaches due to the lack of comparative research between activities. Thus, the purpose of the study is to determine if there is a difference between student performance when students experience inquiry-based instruction with a simulation or without a simulation. I have noticed that some of my chemistry students are challenged when having to make inferences while completing an inquiry-based computer simulation activity. I have also noticed that when students conduct a hands-on inquiry activity they could end up with inaccurate observations and data if the activity directions are not followed carefully or if they are using contaminated lab equipment. Both of these dilemmas could lead to students developing inaccurate conclusions.

Significance of the Study

This study was designed to compare inquiry-based learning with and without a computer simulation in the context of a high school chemistry class. Participants carried out a POGIL activity to experience a more traditional inquiry activity without a computer simulation. Separate studies have suggested learning benefits from inquiry-based learning with a computer simulation or a POGIL activity. There is evidence that students believe simulation games helped them learn. Smith's (2014) previously mentioned study revealed that 80% of students either agreed a lot or agreed that they succeeded in the 3D simulation game where they experienced inquiry learning. Twenty percent of students reported they were succeeding in what they were doing; no students reported any level of disagreement to the statement.

Many positive benefits were linked to inquiry-based instruction in a review of over 200 research papers (Saunders-Stewart, Gyles, & Shore, 2012). Improved student achievement was a prevalent trend though multiple studies. Students improved their problem solving skills when they experienced inquiry-based instruction. Technology was found to assist inquiry with helping students develop an in-depth knowledge of concepts, where technology can be used to learn concepts in more than one way. This review also deliberated an outcome, engaging in inquiry resulted in the improved ability to see concepts as related in multiple applications. Students demonstrate this if they learned how to solve a math problem at school and they were able to apply the same math skill to a real-life math problem they had to solve at the home. The benefits of implementing inquiry instruction denotes the possibility of enriching the student's cognitive processes.

The study of science concepts via the use of computer simulations may help students add on to or enhance prior knowledge. A study on 21 fifth grade students established that the use of properly scaffolded procedural information during the simulation allowed students to correct or enhance their pre-conceptions of greenhouse gasses (Kukkonen, Kärkkäinen, Dillon, & Kinonen, 2014). The researchers found that students developed a more complex and in-depth understanding of greenhouse gases and the relationships connected to them. The researchers believe that it is possible that the simulation's ability to allow the learner to interact with different variables and cause and effect situations aided in the student's improved understanding.

Participants in the control group of this study completed a Process Oriented Guided Inquiry (POGIL) activity. POGIL activities guide the learner through learning a concept or problem by presenting data, information, or scenarios in order to make connections or make inferences. Walker and Warfa (2017) studied the implementation of POGIL activities and they found that incorporating POGIL activities resulted in a decreased chance of failing the course it was implemented in. On the other hand, courses that implemented normal lecture resulted in an increase of failing by 59%. These findings propose that implementing POGIL activities can increase the chance of more students passing that course.

A qualitative study found themes that emerged from the implementation of POGIL activities in an engineering class. These themes revealed how POGIL activities can potentially promote critical thinking, learning of cooperative skills, seeing things in multiple ways, and content retention (Douglas & Chu-Chuan, 2013). Although POGIL activities may be beneficial, the researchers of this study recommend the instructor have an active role as the facilitator so as to guide the students to discover the content.

Incorporating inquiry-based activities in the classroom allows educators to meet the expectations of the Next Generation Science Standards. The NGSS were designed in order for students to use science inquiry in the classroom. Since students are expected to learn in an environment where they learn inquiry methodologies they will be required to apply both content knowledge and inquiry practices along with other investigative skills in future science standardized tests (Next Generation Science Standards, 2013). Ideally, the results of this study can be used to determine how to best implement the Next Generation Science Standards in a 21st century classroom.

The NGSS called for teachers to incorporate inquiry learning in the classroom (Next Generation Science Standards, 2013). Multiple studies have suggested that the different types of inquiry activities may result in various learning benefits. Therefore, research that compares the result of inquiry-based learning with a POGIL activity versus inquiry with a computer simulation in the context of a high school chemistry course would be useful for science educators interested in inquiry approaches. If science teachers knew more about these different types of inquiry learning methods they would be better able to determine what type of inquiry activities are best suited for their students.

Research Question

The purpose of this study was to compare inquiry learning with or without the use of a computer simulation. To explore this, I compared the performance of two groups of high school chemistry students. The treatment group experienced a guided inquiry lesson while using a computer simulation to carry out the process. The control group completed a POGIL activity on the same topic. This study answered the research questions: How does student performance differ when inquiry-based instruction is delivered with or without a simulation? and What are students' perceptions of their inquiry learning experience?

Definition of Terms

POGIL Activity: activities from the POGIL activity books designed by Flinn Scientific and The POGIL Project. These activities were designed to create an interactive learning environment with guided-inquiry learning activities (Flinn Scientific, 2020)

Inquiry-Based Learning: a teacher facilitated pedagogical approach that engages students in investigations, gathering and analyzing data, and constructing evidence-based arguments (Voet & Wever, 2019).

PhET Simulation: interactive math and science online simulations provided by the University of Colorado Boulder that provide immediate feedback about the effect from changes users make on the simulation (University of Colorado, 2017)

CHAPTER II

REVIEW OF LITERATURE

Science educators can implement lessons that incorporate inquiry instruction in order to address the Science and Engineering Practices (SEPs). The Science and Engineering Practices are a key component of the NGSS (NGSS, 2013). The SEPs state that students should be able to plan and perform investigations, analyze data, use data as evidence, refine investigations, and use models to predict relationships. Inquiry instruction enables students to gather, process new knowledge, and form conclusions from the new knowledge (van DijK, Eysink, & de Jong, 2016). This literature review provided an overview of different inquiry teaching practices, then examined past research addressing whether and how simulations impact inquiry instruction, and finally, examined the observed effects of student performance after engaging in inquiry learning with a simulation.

Inquiry Teaching Practices

Research from this past decade has brought to light the different ways inquiry learning can be implemented. Wang and Jou (2016) studied the differences in the beliefs of inquiry instruction among physics teachers from Chicago, Beijing, and Taipei. Qualitative data was collected through class recordings, open-ended questionnaires, and teacher interviews. The questionnaire asked the teachers to rank the level of inquisitiveness of the four observed recorded class sessions, where the levels ranged from 0 to 3. At a level 0 of inquisitiveness; the students were given the research question, method, and answer for their inquiry activity. At a level 1, the teacher gave the students the research question and experimental procedure to their students, but the students were asked to create the answers on their own. At a level 2, the teacher provided the driving research question, whereas the students design the research process to find the answer. In level 3, students were not provided the research question, procedure, or answers; they were engaged to independently determine the concepts and theories without guidance.

The results revealed different ratings on inquiry teaching elements. Teachers from Beijing focused more on the amount of knowledge students learned, the depth of knowledge, and training students with skills. Teachers from Chicago focused more on learning situations and student understanding as well as a students' ability to take control of their own learning during inquiry. Meanwhile, teachers from Taipei focused more on their students' overall grasp of knowledge and experiences that was gained from the scientific method.

Teachers from Beijing also demonstrated a different interpretation of inquiry teaching. Teachers from Beijing focused more on guiding their students through the inquiry process. Teachers from Chicago were more focused on the students' inquiry skills. They focused more on the students' awareness of the research problem, their ability to gather data, analyze data, explain data, bring up questions pertaining to the experiment, and being able to work collaboratively. Teachers in Taipei shared interests with teachers from Chicago and Beijing, but they were more inclined to adopt an inquiry approach like teachers from Beijing. The results from this study demonstrate how the implementation of inquiry instruction can vary greatly. Teachers from each city had a different focus on their ideal way to teach inquiry in their classroom. This study reveals how inquiry pedagogy can be implemented in a variety of ways.

Dalgarno, Kennedy, and Bennet (2014) conducted a study to determine if there was a difference in performance between students who experienced simulations with preset parameters (observation condition) and students who experience simulations with variables that could be changed (exploration condition). Students in the observation condition were provided with only a continue button to display predetermined data, whereas the exploration condition was allowed to change multiple variables in their simulation. The subjects in this study consisted of 158 education students enrolled at the University of Wollongong. The study compared student performance in two content areas, under different conditions. Each student completed the exploration condition of one content area and the observation condition of a different content. The two contents implemented were blood alcohol concentration (BAC) and global warming. Students were assessed before each simulation with a pre-test and after the simulation with a post-test.

An analysis of the pre and post-tests of both experimental conditions yielded two significant results. The observation participants performed significantly lower on the post-test than the pre-test. Students in the exploration conditions performed significantly better on their post-test. This data implies that the observational condition did not benefit the students performing the global warming content. The data also suggests that exploring a simulation without teacher prompting did not benefit students who experienced the BAC content in exploratory conditions.

The researchers analyzed the data of the exploration group to determine the underlying factors even further. They determined what method students used to explore the simulation. One method was a systematic method, where the subject only changed one variable, while they kept another variable constant. Another method, the unsystematic method, was when students changed multiple variables as they performed their activity in the simulations. Inferential tests were conducted with the students' pre-and post-test scores to compare the systematic and unsystematic approach. It was found that the students who had completed the BAC simulation in a systematic approach had significant gains from their pre to post-test scores (p-value 0.003).

Dalgarno et al.'s (2014) research suggests that being well equipped with a methodical approach or having background knowledge on experimental methods can benefit performance in science simulation activities. Teachers should plan ahead how they will prepare and support their students prior to a simulation activity.

Simulations and Inquiry

Previous studies have noted a benefit in learning when inquiry-based learning was done with a computer simulation. A study conducted on students enrolled in various extracurricular educational activities in mid-Atlantic City examined how the participants perceived the scientific method after engaging in science simulations (Peffer, Beckler, Schunn, Renken, & Revak, 2015). Data was collected on three different simulation activities titled: Seizing Sea Lions, Neural Tube Defects, and Unusual Mortality Events. Students from grades six to 12 participated on three simulations. After the simulation, students completed an anonymous survey. They were asked to rate on a five-point Likert Scale the level of difficulty; the amount of thought required to complete the simulation, and how much the student believed the simulation assisted them with learning the content. Students were also asked if the simulation changed their perception on scientific research and how science problems are approached by scientists.

The survey revealed that 67% of the students believed the simulation altered how they thought about research and how scientists approach problems, while 28% disagreed with this statement. The students' open-ended statements revealed a common response among students; they were surprised how challenging the scientific process is. The open-ended responses also revealed that 80% of the students who disagreed stated that their thinking did not change because they had prior knowledge of science practices before conducting the simulation. This study suggests that it is practical to implement simulations to integrate inquiry-based instruction. As the results show, students are able to follow the scientific process with the use of science simulations.

A comparison study sought out to answer two main questions (Olympiou, Zacharias, & deJong, 2013). First, should representations of abstract objects be incorporated in simulations? Second, is prior knowledge a factor needed to be considered when deciding to use representations of abstract objects in a simulation?

The study was conducted on 69 undergraduate students enrolled in a physics class implementing inquiry curriculum. The experimental condition consisted of 36 students, where they experienced simulations that included representations of abstract objects. The rest of the 33 subjects were assigned to a control group where they experienced a simulation with concrete objects. The students in each condition were also randomly assigned to groups of three.

The subjects took an individual test before, during, and after they conducted the inquiry simulation activity. The tests administered during the simulation, in order, were Tests 1, 2, and 3. The Light and Color (L&C) test was a summative test administered after the activity. A Mann-Whitney test revealed that in the case of comparing the improvement scores of both low and high prior knowledge favored the experimental group, with a p-value lower than 0.05. This implies that having the abstract representations in the simulation could be beneficial to student learning.

The comparison tests also demonstrated significant differences in favor of the experimental condition in regards to the performance of students with low prior knowledge. This implies that students with low prior knowledge may benefit from the abstract representations in the simulations. A statistical comparison also revealed significant differences in favor of the experimental condition in regards to performance of high prior knowledge students. This could indicate that students with high prior knowledge can also benefit from simulations that incorporate abstract objects. In general, this study reveals that students with differing background knowledge can benefit from simulations that have abstract concepts represented, therefore suggesting the use of simulations like the ones in this study benefiting student learning.

Inquiry with Simulations versus Traditional Instruction

Past studies that have compared traditional instruction and learning with a computer simulation suggest that inquiry learning with computer simulations may yield greater cognitive and learning benefits. Wang, Guo, and Jou (2015) were interested in comparing the learning effectiveness of scientific inquiry skills among high school students when they used a virtual physics lab, in other words, a simulation. Three high school physics classes (n = 145) were randomly selected to participate in this study. Each class experienced a different type of instruction; traditional physics instruction, model-based inquiry (MBI) physics instruction, and MBI instruction with virtual physics labs (MBI-VPL). In the traditional physics instruction, students experience traditional physics lectures and lab demonstrations performed by the teacher. The MBI approach requires the teacher to scaffold while teaching, include social opportunities for learning, and application of the inquiry process. The inquiry process in the MBI model had students generate, test, and revise the scientific model with the objective of forming evidence-based explanations. In the MBI-VPL condition, students were able to practice the MBI model by using a virtual physics lab created for this class.

Quantitative data was gathered via pre-tests prior to the semester commencing and via post-tests after the semester ended. Wang et al. (2015) compared student performance among the three groups to reveal complementary and divergent results regarding inquiry skills. Students from the traditional teaching approach only achieved improvements in descriptive skills and mathematical expression. Students from the MBI and MBI-VPL groups demonstrated significant improvements in descriptive skills, process skills, comprehensive skills, learning attitude, communication skills, reflection skills, mathematical expression, and experimental facts. In comparison, the students in the traditional teaching approach did not show significant growth in inquiry skills, as the MBI and MBI-VBL did. These results suggest that traditional physics lessons do not benefit students as much in the development of more complex thinking skills.

A comparison of the MBI and MBI-VPL revealed that students who experienced the VPL component were able to develop more in-depth practice in the scientific inquiry method. The technology was also found to be useful with facilitating independent reflection and evaluation among students. The results suggest the use of simulations can be a useful tool for students to be able to execute an inquiry activity and acquire inquiry related skills.

Another study sought to compare student performance in an environment where students used simulations versus an environment where students learned from a lecture (Stieff, 2011). The study consisted of 460 student participants and four chemistry teachers. Eight classes, taught by four different teachers, experienced lessons using the *Discovering Matter!* Curriculum. The *Discovering Matter!* Curriculum required students to work with a partner and learn about the distinctions between different substances and how they behave. The same teachers taught different courses the same content using traditional lecture teaching methods, including illustrations that represent the molecules as they may be represented in the simulation. All teachers in the lecture group assigned textbook reading and textbook questions. Students were given a pre-and post-test to examine growth in the two groups.

An analysis of covariance (ANCOVA) test revealed a significant effect of curriculum, where the mean achievement for students in the simulation experience classroom was higher. The increase in achievement between the pre and post-test for each group was small. These results suggest that simulations have the potential to increase student achievement. Further research would be necessary to determine more information on the relationship between student achievement and inquiry with a simulation.

Stieff (2011) also discovered significant results that revealed that students in the simulation experience were more likely to be able to draw submicroscopic representations of molecules with better accuracy. This group was also more likely to create the same drawing that a chemistry teacher or a chemist would draw and they were more likely to communicate accurately how molecules are in motion under different conditions.

Summary

Studies reveal that science simulations can be used to practice inquiry-instruction in the science classroom, with the implication that the teacher provides their students with guidance that can scaffold the activity. Overall the studies suggest that simulations could affect performance and understanding in the content they are learning through the simulation, and help develop complex thinking skills. Research that compares inquiry-based learning with and without computer simulations is limited. This study seeks to expand the research available on inquiry and computer simulations by examining differences in high school chemistry students' learning and experiences in an inquiry lesson with or without a computer simulation.

CHAPTER III

METHODOLOGY

The purpose of this study was to determine if there was a difference in student learning and experiences when high school students in an introductory chemistry course completed an inquiry activity with a computer simulation in comparison to an inquiry activity without a computer simulation. This chapter will introduce how participants were grouped, the instrumentation used, procedures carried out, and the data analysis used.

Participants

The study consisted of a total of 59 students enrolled in five different chemistry sections at a rural public high school in the California Central Valley. I used a convenience sampling method, conducting the study with pre-existing groups of students enrolled in different sections of my chemistry class. Participants included high school sophomores (n = 23), juniors (n = 29) and, seniors (n = 7). The school I teach at was on an alternating block schedule. The three chemistry sections that were chosen to experience a computer simulation activity (n = 29) had chemistry on Mondays, Tuesdays, and Thursdays. Whereas the two chemistry sections that experienced a normal inquiry assignment without a computer simulation (n = 30) had chemistry on Mondays, Wednesdays, and Fridays. These blocks of classes were randomly selected to experience the assigned inquiry experience. The chemistry sections were also grouped by days to try to have a close number of participants. The group that experienced the inquiry activity with a computer simulation was considered the experimental group, whereas the group that experienced a traditional inquiry assignment was the control group.

Research Design and Instrumentation

On July 31, 2019 the University Institutional Review Board, protocol #1819-085, approved the research design and instrumentation of this study. This study collected quantitative and qualitative data. First, a Post-Inquiry Assessment (Appendix D) was used to collect quantitative data. The post-assessment consisted of seven questions about key concepts and conclusions students were expected to learn from completing the inquiry activity. Two Post-Inquiry Assessment questions were worth three points each and the other questions were worth one point. The answer key and grading guidelines are provided in Appendix D. Once the post-assessments were scored, the mean scores of the experimental and control group were compared with a one-tailed, independent samples t-test.

Second, qualitative data was collected using a Post-Inquiry Reflection (Appendix E). The participants were asked to share their learning experiences with an open-ended written response.

Procedure

The study began with the participants in the experimental and control group completing a self-paced inquiry activity. Students in the control group carried out a POGIL activity on the atomic structure. The POGIL activity was completed as a paper hand out, which had information and data on the structure of the atom. The

POGIL activity proceeded with asking participants guiding questions to help them make conclusions on the properties of subatomic particles, the atoms structure, and writing an isotope symbol.

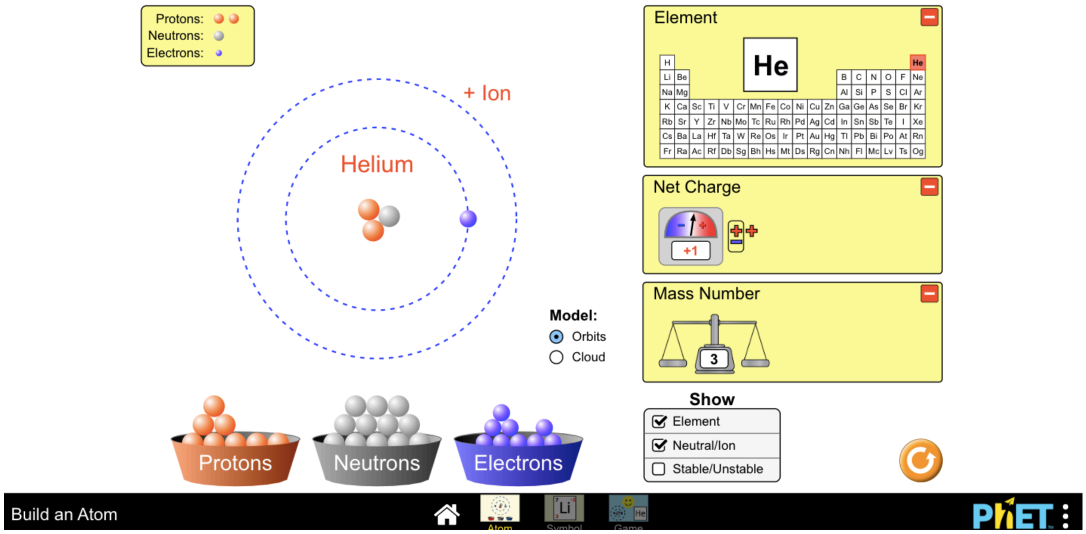

Figure 1. Example of the PhET (University of Colorado,2020) simulation the simulation group used.

Participants in the experimental group completed a guided inquiry activity with the PhET Build an Atom Simulation (Figure 1). This group completed the guided-inquiry activity with a paper hand out that guided them to discover the same concepts as the control group's activities. After the participants completed their inquiry activity they completed the Post-Inquiry Assessment on paper to determine how much they learned from the activity. Finally, participants hand wrote their responses for the Post-Inquiry Reflection.

Ethical Considerations

The participants in this study may have experienced some ethical issues. A problem to be considered is that students in the different learning groups experienced different learning situations, which may have led to a disparity in providing instruction in an equitable manner. This issue was remediated after the study by having the control and experimental groups complete the activity they did not experience during the study.

As the chemistry teacher of the participants, my role could have influenced my decisions as the study was carried out. This connection to the participants gave me background knowledge that may have influenced my decisions on how the procedure was carried out or how the data was analyzed. In order to avoid bias, I facilitated students to complete the inquiry activity the same method I have in my past years of implementing these activities. I also scored the Post-Inquiry Assessments using a key, for consistency. Also, names were omitted from the qualitative data when they were coded on the Qualtrics software. This allowed me to not make inferences on what students were trying to express based on my background knowledge of them.

Data Analysis

Each participant's Post-Inquiry Assessment scores were entered on a Google Sheet, which was also saved in a password-protected account. The control and experimental groups' mean scores were compared with a one-tailed, independent samples t-test with an upper p value set at .05. The t-test was used to determine if there was a difference between the classes who experienced the simulation versus the classes who did not experience the simulation.

The responses from the Post-Inquiry Reflection were transcribed into a Google Sheet document, then imported into the Qualtrics software. The Qualtrics software was used for open coding (Ryan & Bernard, 2003). The participants' responses were first proof read after they were uploaded into the Qualtrics software as open ended questions with an essay text box. The text data analysis feature on Qualtrics was used to tag each response with repetitive key terms or ideas found along the responses. Common tags were automatically counted in the Qualtrics software. The codes and responses were reexamined to determine if any codes could be merged into a collective theme. The most prevalent themes from the participants' reflections were chosen as the major themes.

Summary

High school chemistry participants in this study carried out a self-paced guided-inquiry activity with or without a computer simulation. After the activity, participants completed a Post-Inquiry Assessment and a Post-Inquiry Reflection. The Post-Inquiry Assessments were scored based on accuracy using a grading key. Assessment scores between the two groups were compared with a t-test. The Post-Inquiry Reflections were coded to determine common themes in the participants' guided-inquiry learning experience with or without a computer simulation. Chapter IV will discuss this study's quantitative results and prevalent themes revealed from the qualitative data collected.

CHAPTER IV

RESULTS

The purpose of this study was to compare inquiry-based learning with and without the use of a computer-simulation. This study focused on tenth to twelfth-grade high school chemistry students at a rural high school in California's Central Valley. Post-assessment scores were used to compare if there was a significant difference in learning when students experienced inquiry learning with a computer simulation as opposed to students who carried out a POGIL activity in the classroom. Participants also completed a Post-Inquiry Reflection to collect data on the students' learning experience. The reflections were coded to identify common themes present in the Post-Inquiry Reflections. This chapter presents the quantitative and qualitative data gathered to answer the following three research questions:

1. How does student performance differ when inquiry-based instruction is delivered with or without a simulation?
2. What are students' perceptions of their inquiry learning experience?

Post-Inquiry Assessment

The group who experienced inquiry learning with a computer simulation (n = 29) had a mean score of 8.26 out of 12 points on their Post-Inquiry Assessment. The group who experienced the traditional inquiry lesson, POGIL (n = 30), had a mean score of 8.53 out of 12. The scores were compared, revealing no significant difference between the two inquiry groups.

Student Perceptions

The qualitative data gathered from the Post-Inquiry Reflection was analyzed for common themes. The themes that arose were: helped learn, atom structure, periodic table, games, and more time. Themes are reported by the computer simulation group, then the traditional POGIL simulation group.

Computer Simulation

The themes regarding the learning experience of computer simulation participants are presented in Table 1.

Table 1

Themes of inquiry group using a computer simulation

Themes	**Description**	**Examples**
Helped Learn	Students described varying levels of learning. Some students mentioned the simulation activity was very helpful. Others mentioned that the simulation helped them learn, but they did not achieve 100% proficiency of the content.	"This activity helped me extremely by providing a clear representation of how protons, electrons, and neutrons interact with each other."
Atom Structure	Students described different aspects of the subatomic particles like the charge, mass, or how they affect an element.	"Looking over the elements and their atomic masses, mass number, and how many protons or electrons they had helped"
Games	All students that mentioned the game component of the simulation thought it was helpful to some extent.	"I also found the games really helpful and fun."
More Practice	Some students mentioned needing more practice or not completely understanding everything they needed to learn.	"It helped me because it had visuals and I think that they are great help because in that way you are experiencing [a] way of doing it/learning but I would need to go over it a couple more times to understand it better."

The most prevalent theme identified from the computer simulation group was *Helped Learn*. Approximately 76% mentioned that the activity helped them learn or facilitated their learning to an extent. Some participants believed they highly benefited from this activity. One student stated, "This activity helped me extremely by providing a clear representation of how protons, electrons, and neutrons interact with each other." Others learned or improved their understanding of the topic, but did not achieve full mastery of the content. One student mentioned, "This activity didn't fully help me understand everything 100%, but I didn't know much starting off." Students' responses suggested that the use of a computer simulation for an inquiry activity was useful to students, but more practice and clarification was necessary to target any students who need more practice on the topic.

Another prevalent theme that arose from the computer simulation group's reflections was students showing knowledge about the *Atom's Structure*. The simulation allowed students to create an atom using protons, neutrons, and electrons, exploring how these subatomic particles affect the element and its mass, charge, or atomic number. One student mentioned, "Looking over the elements and their atomic masses, mass number, and how many protons or electrons they had, helped." This statement reveals how the interactive data in the simulation gave students the opportunity to collect information, so they could determine what variables were affected as the number of protons, neutrons, or electrons were changed in the atom. These responses suggested that the computer simulation gave learners the opportunity to explore cause and effect relationships.

The reflections from the computer simulation group also uncovered how the games in the simulation were helpful to the students. There were six from the 29 students in the simulation group that thought the games helped them in their learning. One student mentioned, "I also found the games really helpful and fun." Another student mentioned, "it required me to remember everything it has taught me" about the games in the simulation. These statements demonstrate how the use of games in a computer simulation can possibly be helpful to student learning and help with students checking their retention of the content.

The previously discussed theme, *Helped Learn*, brought to light how most of the simulation group thought the inquiry activity was helpful in their learning. However some students mentioned they did not feel they achieved mastery of the content. Five from the 29 students in the computer simulation group mentioned the need to practice the content they learned more or requiring more help. One student elaborated, “It helped me because it had visuals and I think that they are great help because in a way you are experiencing ways of doing it/learning it but I would need to go over it a couple more times to understand it better.” This inquiry activity was used to introduce students to the content, so students were not expected to become complete masters at the content after only one activity. Computer simulations can be useful tools to add context to a new concept they are learning, but additional learning activities may be used to further support students with learning the information on the topic they explore in the simulation.

Without a Computer Simulation

Table 2

Themes of inquiry group without a computer simulation

Themes	**Description**	**Examples**
Helped Learn	Students mentioned that the inquiry activity was helpful to a certain extent.	"I think this activity helped me learn a lot more about analyzing the isotope symbol and a lot more what its components."
Atom Structure	Most reflections involving this theme mentioned they had a good understanding of the subatomic particles regarding their charge, mass, proper representation, or location.	"This helped me understand the parts of an atom and where everything goes. It also helped me remember the atomic mass and where the protons and neutrons go."
Periodic Table	Students mentioned that they understood the periodic table better, using the periodic table was helpful, or that they needed more help using the periodic table.	"...I still need help on the periodic table." "The components of this activity helped me by being able to identify what part is which on the periodic table."
More Practice	Most responses in this category mention they had some learning to a certain extent, but admit they are still having difficulty or need more practice to master the content.	"I need help on the isotopes, I do kinda get it just need a little more help...I know that if we practice more I will get it."

Table 2 displays descriptions and student examples of each major theme coded form the control groups Post-Inquiry Reflections. These findings suggest that the control group had some similar learning experiences with the experimental group. One being, participants who experienced inquiry learning without a computer simulation also thought the POGIL inquiry activity was helpful. Ninety percent of the participants in this group mentioned in some way that the activity helped them learn.

One student mentioned, "I think this activity helped me learn a lot more about analyzing the isotope symbol and a lot more [about] its components." The POGIL inquiry activity had students read information, diagrams, and data on the atom, isotope symbols, and subatomic particles. The POGIL activity had students answer guided questions to help the learner make sense of the data and make connections. An inquiry activity similar to the one in this study could facilitate student learning.

The non-simulation group reflections also revealed the theme *Atomic Structure*. The POGIL activity this group experienced had a table with information on the charge and mass of the subatomic particles. The subatomic particles were also represented in a diagram denoting where the protons, neutrons, and electrons are located on the atom. The POGIL activity also had information on how the subatomic particles affected the element, mass number, and atomic number. The students digested this information by answering a series of questions that guided them to understand this information. Most students who mentioned parts of the atom or the structure of the atom mentioned that they learned about these main ideas. One student stated in their reflection, "This [activity] helped understand the parts of an atom and where everything goes. It also helped me remember the atomic mass and where the protons and neutrons go." This evidence suggested that a POGIL inquiry activity can potentially help students learn about science related structures and their relationships if presented in a similar technique to this POGIL inquiry.

The *Periodic Table* was the next theme in the non-computer simulation group. Students completing the POGIL assignment needed to refer to the periodic table to determine an element or its atomic number. There were 8 from the 30 reflections in this group that mentioned the periodic table being helpful in their learning, that they understand the periodic table better, or that they needed more help using the periodic table. One student stated, “The components of this activity helped me by being able to identify what part is which on the periodic table.” Whereas, another student mentioned, “I still need help on the periodic table.” This revealed how an inquiry activity structured like this one provides students the opportunity to discover connections between different sources of information. On the other hand, some students may find this task more challenging, so they may need more guidance during the activity to increase student understanding.

The reflections from the non-computer simulation group revealed its fourth largest theme, *More Practice*. Four of the participants from the non-computer simulation group revealed in their reflections the need for more practice on the topic they were learning about. Some mentioned they had learned, but still needed more practice or help. One student mentioned, “I need help on isotopes, I do kinda get it just need a little more help.” Another student stated, “I’m not quite sure how it helped but maybe if we could get a little more practice it would help improve my skills.” Whether students learned more than one another, they recognize the need to further explore the topic they learned. This theme reveals the need to support students with more activities involving this topic after an inquiry activity, so they can master the content.

Common Themes

The qualitative findings were also analyzed together to compare commonalities and differences across the experimental and control groups. Figure 2 compares the percent frequency of the inquiry groups with and without a simulation.

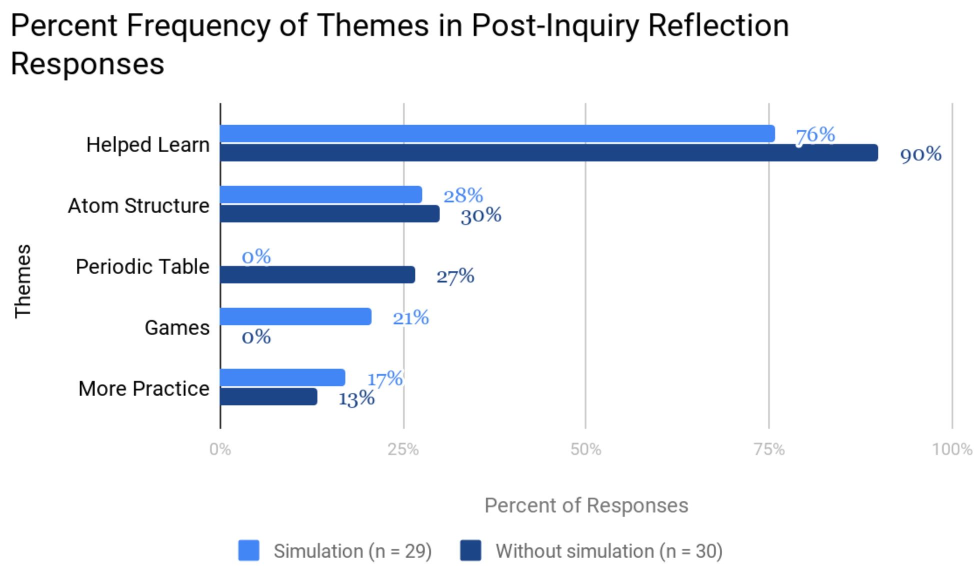

Figure 2. Percent frequency of themes in the Post-Inquiry Reflections in both inquiry groups.

Helped Learn was the most frequent theme in the experimental and control groups' Post-Inquiry Reflections, where students who experienced inquiry without a computer simulation mentioned more often that the inquiry activity was helpful. Also the two inquiry group reflections had a marginal 2% difference in the frequency of the atom structure theme. Similarly, there was only a 4% difference among the inquiry groups with the more practice theme. Although the control and experimental group had different inquiry experiences, based on the common themes these two groups do seem to have similar learning experiences.

Summary

This chapter presented the quantitative and qualitative data collected from a group who experienced inquiry learning with the use of a computer simulation, in comparison to a group that experienced inquiry learning without a computer simulation. The quantitative data from the Post-Inquiry Assessment revealed that there was no significant difference in the learning of computer simulation and non-computer simulation groups. The qualitative data revealed that student experiences with the computer simulation group and the non-computer simulation were similar in that both: helped students learn, they gained specific knowledge about atom structure, and valued the opportunity for more practice. The majority of students in both inquiry groups mentioned that the inquiry activity helped them learn or they demonstrated with their knowledge that they learned from the activity in their Post-Inquiry Reflection. Some mentioned how they were able to learn about the parts of the atom and make connections about the relationships among different representations of the structure of the atom. The theme *More Practice* revealed that students expressed or demonstrated the students' need for practicing the content more. This was due to some students being confused about concepts that they practiced or their expression of not feeling confident that they fully understand the concepts.

The themes from the qualitative data also revealed that the computer simulation group benefited from the interactivity of having a game embedded in the simulation. Students in the computer simulation group who mentioned the games in their reflection thought the game was helpful to their learning experience. Whereas in the non-computer simulation group, many students who mentioned the periodic table in their response learned how to utilize the periodic table for information they need, so they were able to learn the relationships among different sources of information.

CHAPTER V

DISCUSSION

This study explored potential differences in student learning and experiences when engaging in inquiry learning with or without a computer simulation. Participants completed an inquiry activity with or without computer simulation. Then participants in both groups completed the same Post-Inquiry Assessment and a Post-Inquiry Reflection, where they elaborated on their learning experience by responding to open-ended reflection prompts. This chapter will discuss the findings, implications, limitations, and need for further research.

Discussion

The findings from the quantitative data answered the research question, How does student performance differ when inquiry-based instruction is delivered with or without a simulation? The mean of the experimental group's Post-Inquiry Assessment scores were not significantly different from the control group's mean scores. Previous research has suggested that simulations have the potential to increase student achievement (Stieff, 2011). However, this current study revealed when traditional inquiry instruction was compared to inquiry instruction with a computer simulation there is no significant difference between the two groups' performance.

The qualitative findings aligned with the quantitative results. The majority of students in both inquiry groups thought the inquiry activity helped them learn. However, 76% of students who experienced an inquiry activity with a computer simulation shared that the activity helped them learn. Whereas 90 % of students who experienced an inquiry activity without a computer simulation stated that the activity helped them learn. Smith's (2014) study found 80% of students either agreed or agreed a lot that they succeeded in a 3D simulation game. In the current study, 21% of the students in the computer simulation group mentioned that the game component of the simulation was beneficial to their learning. This finding, along with Smith's study suggest that students perceive inquiry learning with and without computer simulations as beneficial to their learning, and simulation games can contribute to the benefit as well.

The qualitative data also revealed that students were able to learn about the structure of the atom. Coding of the Post-Inquiry Reflections revealed that 28% of students in the simulation group and 30% of the students in the control group mentioned learning about the structure of the atom. A study conducted by Olympiou et al. (2013) proposed that having abstract representation in a computer simulation could be beneficial to student learning. This current study coincides with what Olympiou et al.'s study suggests. In addition, the current study postulates that inquiry activities, like POGIL activities, can also help students learn about abstract content like the structure of the atom.

A few participants in the non-computer simulation group mentioned that using the periodic table was beneficial to their learning or they understood the periodic table better after the POGIL activity. Douglas and Chu-Chuan (2013) shared how their qualitative study revealed how POGIL activities can help with seeing information in multiple ways. The use of the periodic table in this current study gave students in the traditional inquiry group the opportunity to understand the use of atomic numbers, and element symbols in the periodic table, in contrast to an isotope symbol.

Finally, a few students in each inquiry group mentioned their need for more time or practice to learn the content in the inquiry activity. Zhou and Xu's (2017) study suggested the importance of teacher pacing in inquiry lessons when students struggle with grappling information. It is important for teachers to be able to adapt to their student's needs during an inquiry lesson. The teacher should be receptive to when students need more help or guidance to be able to successfully learn in an inquiry activity.

This study's control and experimental group both experienced a guided-inquiry activity, where they were given a set of information or followed general guidelines to collect data and make conclusions. Hardianti and Kuswanto (2017) found that an inquiry level similar to the conditions of this current study were most effective at improving a student's processing skills. The inquiry level in Hardanti and Kuswanto's study that is similar to my study was a middle inquiry level. In Hardianti and Kuswanto's study, students who experienced the middle inquiry level carried out an inquiry lab instead of the teacher and carried out the post-lab inquiry. This middle-inquiry level was similar to the conditions in my study since the participants in my study carried out the inquiry activity and made conclusions of the concepts on their own. Lower inquiry level activities, where the teacher completes the inquiry activity for students to collect data, were less effective at improving students' processing skills. A higher inquiry experience, where the student designs the inquiry activity, were also less effective at improving students' processing skills. Hardianti and Kuswanto's study reveals how researchers and educators must be cautious how scholars and educators interpret research involving inquiry activities at different levels.

Implications

This study has implications for teachers. Teachers may not be sure if computer simulations enhance the inquiry learning experience. As the capacity of technology evolves, computer simulations could potentially provide students with an interactive learning experience regular class activities may not be able to do. This study provided insight into how inquiry activities with and without a computer simulation may differ within the context of a high school chemistry lesson on atomic structure.

This study suggests that inquiry with or without a computer simulation can *both* benefit student learning. Given this finding, teachers should use learning objectives as a guide to decide if they want to incorporate an inquiry activity with or without a computer simulation. The teacher should consider which type of inquiry experience is best suited to facilitate learning the objectives. If teachers are equipped with inquiry activities that require and do not require the use of a computer simulation they can consider giving students the choice of selecting the type of inquiry activity they prefer to experience.

Some students in this study expressed their need to practice more or continue learning the topic. Teachers should consider how they pace an inquiry activity. Teachers should allow students to pace their own progress through an inquiry activity and closely monitor student progress. The teacher should be receptive to how well students are doing throughout the inquiry activity, so they can further guide any students who may need a more guided approach to the inquiry activity. Teachers should be careful with this technique, so as to not remove the inquiry experience from the activity. Teachers can guide their students by asking students guiding questions or direct them to data or information they can consider during the process.

The game component of the computer simulation was thought by some students to be helpful in their learning. One student even mentioned the game made learning more fun. The game students experienced in this research also gave students feedback, which let them know how accurately they understood the content. Simulation designers should consider gamifying a learning simulation or incorporating a game component to benefit student learning and also to give students the opportunity to check their understanding.

Limitations

The conditions of this study lent some limitations. A convenience sampling method was used with my chemistry students, which meant the participants did not represent a general student population. However, using a small sample size helped with making the data collection and analysis process more manageable for a study conducted by only one researcher. Factors beyond my control also came into play.

For example, I was limited by how many students gave consent to participate ($N = 59$). Additionally, some participants were also absent from school one or more of days the inquiry activity was done. Absent participants experienced the study differently than those who were present all days, so the data from absent students was not used in this study, since similar experimental conditions were needed to consider their data as analogous to students present for the entire study.

Another limitation is that the results of this study cannot necessarily be extended to other computer-based inquiry programs. The Build an Atom simulation utilized in this experiment was highly interactive. This simulation gave students multiple controls over the conditions they needed to observe. The simulation also gave students immediate data once they changed a certain condition. Other simulations may not be as interactive and may limit what the learner can do. For example, the Atomic Structure Simulation from the PBS Learning Media website (2020) walks the learner through an experience to learn about the atom. This PBS simulation provides more narrative to the learner, instead of more interactive capabilities. Interactive simulations in comparison to less interactive simulations could possibly yield different learning results that we may not know about.

A final limitation of this study was the Post-Inquiry Assessment. The Post-Inquiry Assessment only focused on the main concepts participants in the two inquiry groups should have learned. This assessment could have been enhanced to detect differences among the group by increasing the rigor of the questions or designing questions to more specifically determine subtle differences in learning. For example, I could have included a question that asked students to draw an atom to demonstrate how the proton, neutron, and electron were organized. I could have explored the responses to that question to investigate if participants from different inquiry groups depicted the structure of the atom differently. I could have also included questions that used higher levels of thinking, to test if the two inquiry groups performed differently on more difficult questions.

This study examined student perspectives about their learning experience by exploring themes presented in their Post-Inquiry Reflections. This device was used to capture the participants' perceptions of their experience, but the data was limited by what participants were willing and/or able to share about their experiences. Thus, this research could have been extended with student interviews to probe students on their reflections or learning experience, which could have led to more details regarding the participants' learning experiences. Another approach could be to have students answer Likert scale questions where they rate their learning experience across a consistent set of items that could be compared quantitatively across groups. In spite of these limitations, there were strengths in the mixed methods approach used in this study. Instead of only comparing assessment scores between the experimental and control groups, the mixed method design allowed me to explore beyond the quantitative data to further and more completely understand the participants' learning experiences.

Further Research

Given the interesting findings in the student reflections within this study but the inherent limitations in the reflection instrument, future research could probe the student experience for more detail. Researchers could use interviews, so students could elaborate more on their learning experience. Future studies could also ask more specific questions using a Likert scale, to gain more numerical data on how students perceived their inquiry learning experience.

Most participants in this study thought the inquiry activity was beneficial to their learning. A future student perception study could further explore what specific aspects of the inquiry activity were beneficial in their learning. Such information would help teachers and computer simulation designers better understand aspects of this learning experience that were most valuable. In a similar vein, future researchers could have the students rate the effectiveness of the questions they were asked in their learning process. They could also ask students how they would rate the visuals the inquiry activity provided. This information would help teachers to tailor future instruction around questions and visuals that students find most useful.

Another way to further explore the application of guided inquiry activities would be to compare the same conditions in this study with a hands-on experiment. Hands-on experiments potentially present the challenge that if the experiment is not done precisely, the experiment can yield unexpected results. This type of comparative study could explore the effectiveness of hands-on inquiry experiences, technology-based inquiry experiences, and traditional inquiry experiences.

Prospective research may also examine inquiry learning in a longitudinal study. Researchers could compare the longitudinal effects of a class that implements inquiry learning for a year with a class that implements traditional learning. The researcher could compare the performance of each group on state tests where NGSS is implemented. This research could determine whether or not inquiry learning has the potential to raise a student's state test score where NGSS is implemented. Another approach to this comparative study, could assess the inquiry group and traditional learning group with an post-assessment that gauges the students skills on higher-order thinking, experiment design, data analysis, and making inferences. This method could shed light on which learning experience results in improving higher-order thinking skills.

Finally, future research should also consider the teacher's perspective. For example, studies probing a teacher's readiness and ability to implement inquiry learning experiences in their classroom may be helpful. Teachers could be asked to rate in a survey how prepared they feel to implement an inquiry activity and follow up with open ended questions that ask what support and resources they need to improve their ability to implement inquiry learning in their classroom. This information could give credential programs and administrators in education an idea how they could provide support to teachers so they are better prepared to enact inquiry lessons effectively.

Summary

This study sought to determine if there was a significant difference in inquiry learning with or without a computer simulation, while also exploring the student learning experience involving these conditions. High school chemistry students experienced a guided-inquiry activity involving the atomic structure with or without a computer simulation. Post-assessment scores of the experimental group and control group revealed no significant difference in learning levels between these two groups. Coding of Post-Inquiry Reflections revealed three prevalent themes in the student responses: helped learn, atom structure, and more practice. Some students in the experimental group shared the learning benefit of utilizing a game embedded in the computer simulation. Whereas, some students in the control group shared how an outside resource like the periodic table could be beneficial in the inquiry process or helpful with understanding different representations of related concepts.

The results of this study revealed no significant difference in learning levels with experiencing a guided-inquiry activity with and without a computer simulation. A majority of participants in the experimental and control groups stated a benefit in learning from their inquiry learning experience. These findings suggest that educators should structure student-inquiry experiences with or without a computer simulation, since both learning experiences may yield positive learning benefits. In order to increase student learning, educators must be receptive of their students' learning process during an inquiry learning activity and be ready to guide struggling students when necessary.

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APPENDICES

APPENDIX A

PRINCIPAL CONSENT

Gustine High School

Principal – Adam Cano; Assistant Principal – Manuel Bettencourt
Counselors - Melissa Estacio, Horacio Mercado

RE: IRB Letter or Support

March 13, 2019

Dear Institutional Review Board Chair and Members,

I, Adam Cano, give consent to Araceli Soto to collect data for her Master's thesis research concerning guided inquiry with and without computer simulations. I ask that the name of our students be kept confidential.

Sincerely,

Adam Cano

APPENDIX B

PARENT CONSENT FORM

California State University, Stanislaus
Informed Consent to Participate in Research
Comparative Inquiry Study with or without Simulations

Purpose of the Research
The Principal Investigator, Araceli Soto, is a faculty member at Gustine High School conducting research for a Master's degree thesis in Education Curriculum and Instruction. Your child is being asked to participate in this study.

The purpose of this research is to learn more about student performance after learners complete a science inquiry activity with or without a computer simulation. This could help the researcher improve how she uses guided inquiry activities with her students.

Procedures
The activities for this study will take place during Chemistry class at your child's school and involves normal class activities. Your child will be involved in the following activities during their participation in the study:

- Before the activity, your child will be asked to briefly write about any prior knowledge they have on the subject they are learning.
- Your child will carry out a guided inquiry activity, which is an activity where they will gather/learn new information and answer questions to guide their learning. The guided inquiry activity will take approximately 2 days to complete. Your student will complete the inquiry activity using a computer simulation or through regular class activities.
- After the activity, they will demonstrate what they learned by taking a post-assessment and also share their experience and thoughts on the activity in a reflection.

Potential Risks or Discomforts
There are no known risks to your child's participation in this study. However, this activity could challenge their learning abilities. The teacher is prepared to support your child if they need extra support. The learning activities carried out in this research are normal classroom activities most students should have familiarity with.

Potential Benefits of the Research
Your child's participation will be helpful for scholars and educators. The participants in this research will help scholars and educators understand the impact of guided inquiry activities in a high school science classroom. This information can help science teachers better design inquiry lessons.

Confidentiality

The information collected for this study will be kept confidential. All information collected in this study will be saved in a password protected computer that only the researcher has access to. The data collected in this study will be deleted in a timely manner.

The researcher **will not** keep your research data to use for future research or another purpose.

Costs
There is no cost to your child to participate. Participation in this study is voluntary.

Compensation
There will be no compensation for participating in this research. There is no anticipated commercial profit related to this research.

Participation and Withdrawal
Your child's participation is voluntary. You may refuse to participate or stop participation at any time without penalty or loss of benefits.

Questions
If you have any questions about this research, you may contact me, **Araceli Soto**, at **XXX-XXX-XXXX**or my faculty sponsor, **Catharyn Shelton** at **XXX-XXX-XXXX or cshelton1@csustan.edu.**

If you have any questions regarding your rights and participation as a research subject, please contact the IRB Administrator by phone (209) 667-3493 or email IRBadmin@csustan.edu.

Consent
I have read and understand the information provided above. All of my questions, if any, have been answered to my satisfaction. I have been given a copy of this form.

Please Check One below and fill out below:

______ I give consent to have my child participate in this study.

______ I do not give consent to have my child participate in this study.

____

Participating Child's Full Name (printed)____

Parent/Guardian Name (printed) ____

Parent /Guardian: ____________________________________ Date: _________________

APPENDIX C

STUDENT ASSENT FORM

California State University, Stanislaus

Student Assent

Dear Participant,

You are being asked to participate in a study to learn if there is a difference in student performance when students complete an activity with a computer simulation versus without.

The research will take place in your chemistry class. The activities you do will be class activities you would normally do in class.

The activities involve sharing what you already know about the subject before the simulation activity begins. Then you will complete the activity with or without a computer simulation. Then you will be asked some questions after to see what new things you learned and share your experience on the activity. **Students who decide to participate and those who decide not to participate will complete the same activities and assignments in class.**

The difference between a participant and a nonparticipant in this study is that the participant will have the information they provided during the activities used as data for the research. A student not participating will not have their information used as data.

You are welcome to ask about the research at any time.

Future students can benefit from the findings of this research.

Your participation is voluntary. If you agree to participate, but change your mind, you can withdraw from participating in this study at any time without penalty or loss of benefits.

If you have any questions please contact me, Araceli Soto, at **XXX-XXX-XXXX**or my faculty sponsor, **Catharyn Shelton** at **XXX-XXX-XXXX or cshelton1@csustan.edu.**

If you have any questions regarding your rights and participation as a research participant, contact the IRB Administrator by phone (209) 667-3493 or email IRBAdmin@csustan.edu.

Sincerely,
Mrs. Araceli Soto

Consent:
I have and understand the information above.
All of my questions, if any, have been answered to my satisfaction.
I assent to take part in this study.

I have been given a copy of this form.

Please Check One below and fill out below:

______ I agree to participate in this study.

______ I do not agree to participate in this study.

Participant/Student Signature: ________________________________ Date: ____________

Participating/Student's Name
(Printed): ____

APPENDIX D

POST-INQUIRY ASSESSMENT SCORING KEY

Reaction Rates Inquiry Post-Assessment - KEY

1. How many protons does a Carbon atom have?

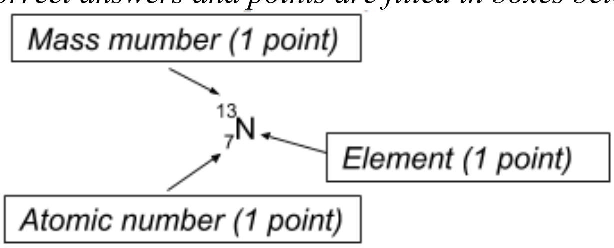
   **Answer:* *1 point for any of the following answers: 6 protons, six, or 6*

2. Mark an x in the following boxes to demonstrate which particles help determine the following. More than one can apply for each.

	protons	neutrons	electrons
a) Mass number *(1 point total or ½ point each correct x)*	x	x	
b) atomic number *(1 point total)*	x		
c) charge *(1 point total or ½ point each correct* x*)*	x		x

3. Label the following image as either mass number, element, atomic number:

   **The correct answers and points are filled in boxes below.*



4. What is the difference between the following three isotopes shown below?

$^{7}_{4}Be$	$^{8}_{4}Be$	$^{9}_{4}Be$

   **Mentioning either of the bulleted answers for one point maximum:*

   - *different number of neutrons*

     or

   - *different mass number*

5. Write the isotope symbol for Oxygen with 8 protons and 9 neutrons.

   **1 point for all three components are correct. ½ points if 2 of the components are correct*

   - $^{17}_{8}O$

6. Write the isotope symbol for a Helium atom with 3 neutrons.

**1 point for all three components below that are correct. ½ points if 2 of the components are correct*

- $^{5}_{2}He$

7. Describe how two fluorine atoms can be different isotopes. What would the two atoms have in common? What would be different about the two atoms?

   **Each major requirement below is worth one point for a maximum of 2 points possible in this question.*

   - *If they mention any of the following for what they have in common 1 point will be added:*
     - *the same number of protons,*
     - *the atomic number, or*
     - *element.*
   - *If they mention any of the following for how they are different 1 point will be added:*
     - *the number of neutrons are different, or*
     - *the mass numbers are different.*

APPENDIX E

POST-INQUIRY REFLECTION

Post-Inquiry Reflection Question:

This inquiry activity was designed to help you learn about the particles in an atom and how to express what the atom is made of in an isotope symbol. Reflect on your experience and if you think this activity helps you improve your skills involving analyzing information. What components of the activity helped or hindered this process?