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Effects of Inquiry-Based Learning on Science Students

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EFFECTS OF INQUIRY-BASED LEARNING ON SCIENCE STUDENTS

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Abstract

Inquiry-based learning is growing in popularity with educators seeking student-centric teaching methods. As with any method of instruction, evaluating the efficacy of the practice is essential. Through an extensive literature review, the data contained herein support inquiry-based learning as an effective practice across the elementary, secondary, and post-secondary levels; its effectiveness extends across a variety of science disciplines. The data also supported the use of inquiry-based learning in a variety of applications beyond the classroom, including camps and virtual settings. In this review, quantitative and qualitative data showed increased student achievement and engagement through the intentional practice of critical thinking and questioning skills further supporting inquiry-based learning.

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CHAPTER I: INTRODUCTION

The perspective of best practices in learning have constantly changed throughout the existence of modernized education. One approach that has recently moved to the forefront of the discussion is inquiry-based learning (IBL). The concept of IBL has changed greatly over time. Originally, IBL was designed to encourage students to interact with others, but it has morphed into a problem-solving model using, and honing, their inquiry skills (Suárez et al., 2018). This approach has the potential to be particularly effective in a scientific setting, where inquiry and questioning are central to a scientific approach. Effective use of inquiry-based learning benefits students of all backgrounds in a way that helps them grow in their current learning and develop long-term skills.

The entirety of science is based on asking questions and seeking answers, where "truth" has changed multiple times over the course of history. Fortunately, a benefit of the dynamic qualities of IBL is how well it applies to changing learning models and culture. Using an IBL approach can take multiple forms and fosters many areas of growth within a student. The inquiry can be synchronous or asynchronous, independent or collaborative, and can utilize many different learning styles (Suárez et al., 2018). This allows for the varied types of IBL to address students in many ways, encouraging students to be well-rounded learners. The foundation of IBL helps students develop their questioning skills, leading to a self-driven method of intrinsic motivation. Developing these skills and motivation supports students of all backgrounds, as it allows them to utilize their experiences and learning styles in their education. In the current technology-centered world, IBL can be as effective as ever.

Many schools now use various types of technology to benefit student learning. My current school district has provided high school students with their own personal Chromebook. One key point is to acknowledge that technology is a tool for learning, not the focus of learning. While it is no secret that students are becoming increasingly focused on technology and its benefits, many teachers actively seek practices to engage students and increase motivation. When technology is used properly, it can lead to even more opportunities to offer students to explore in a scientific setting. Fortunately, while many learning models struggle to realign when based on technology, the inquiry model is efficient at transferring skills (Suárez et al., 2018). As students develop additional skills through technology, it provides them with more paths to ask questions and seek understanding. This makes the impact and implementation of IBL a relevant point of research.

There are an increasing number of jobs available across the country in science-based fields (Skelton et al., 2018). In order to properly prepare students for future scientific settings, teachers must help build both content knowledge and skills for long-term use and implementation. Many students can become centered on memorizing science facts while ignoring the need to build the skills that students must have to be successful in the future (Feyzioglu & Demirci, 2021). Providing students with the space to practice questioning skills is not only beneficial but also necessary in helping students be prepared for the future. The inquiry-based learning model puts these skills in the spotlight of learning, building expertise in addressing problems and questions independently rather than relying on provided information.

Inquiry-based learning is a relevant approach to student-centric learning. Further research is needed to fully understand how the practice will impact student learners of all ages and from all backgrounds.

Rationale

It is a frequent occurrence in my classroom for students to seek out answers and not focus on the processes involved. Too often, their goal becomes a strong assessment grade rather than understanding the process of what they are learning. Students often have trouble accepting that learning is a process, and instead, they expect to be provided information to study and repeat on a test. The difficult question becomes: How do teachers get students to be comfortable with learning as a process that leads them to understanding a concept? In part, science seems to stand out from other content areas in its extreme focus on process and methods. It holds a unique place that utilizes the scientific method to gather and interpret data. One could even argue that the answer in science is the question and process itself, and in turn provides an outcome to match.

Definition of Terms

Below are terms key to this review. For the purposes of this thesis, inquiry-based learning will be defined in three ways.

Structured Inquiry

The teacher provides the scope and sequence for the activity. Students receive a question to answer which includes a step-by-step procedure. The structure provided leads students to a predicted outcome, but this outcome is only known ahead of time by the teacher. This style of inquiry learning is not a major focus of this research.

Guided Inquiry

Guided-inquiry is the most frequently addressed type of IBL in this research. It provides the students with scaffolding to prepare for the learning that will take place, but students are responsible for the goal and process throughout the inquiry process. This is the most common form of IBL found in this thesis.

Open Inquiry

This is a student-centric approach that starts with a student's question. A student or small groups design and conduct an investigation. In this method, the teacher mainly provides guidance through questioning.

Statement of Research Question

The guiding question for this thesis is: How does inquiry-based learning impact student mastery of content within a science classroom setting?

CHAPTER II: LITERATURE REVIEW

The studies included in this research originally covered applications in 5th through 12th-grade students, but was later expanded to include research from the university level. The research covered multiple school-based settings, including elementary, secondary, and post-secondary schools, as well as online learning and a study on a school-based week-long camp. There is a wide range of locations represented in this study. Many studies were completed internationally, while some were completed in the United States. Research with unclear definitions of inquiry-based learning were excluded from the study. The collection of applicable studies was completed through online keyword searches and the use of the Bethel Library database. Inquiry-based learning keyword searches focused on the following concepts: science labs, achievement, engagement, application, technology, and motivation. Studies focused exclusively on project-based learning were not included in the study. One study did compare project-based learning with inquiry-based learning and therefore was included (Panasan & Nuangchalerm, 2010). All studies included were focused on either the impact of inquiry-based learning on students or the effectiveness of its application across a variety of settings. Meta-analyses focusing on the general description of inquiry-based learning were not included in the study. To be included in the study, research must have taken place in an academic setting. One study was completed in a school-based week-long camp (Dolenc, Beaulieu, & Sheppard, 2020). The analysis prioritized quantitative data but also included qualitative data from participant interviews and observer notes. The analysis also focused on recently completed research, with all studies completed since 2000 and most completed within the previous five years.

Chapter Two is separated into three sections: 1) Academic Growth, 2) Student Engagement, and 3) Inquiry-Based Learning Utilization.

Academic Growth

A major question in the application of inquiry-based learning is how it impacts a student's academic growth. There are many measurements of academic growth, including not only achievement on assessments, but also building skills in higher-order thinking, interacting with peers, and literacy. Another important factor in academic growth in a science classroom is developing laboratory skills that include the scientific method process. Of the article reviews included in this study, 14 contained an academic growth theme.

Inquiry-based learning can impact many different aspects of scientific learning. The purpose of the study conducted by Gormally et al. (2009) was to determine the impact of inquiry-based learning (IBL) on scientific literacy as well as on the skills and confidence of the learner. They used data from the Fall semester of 2006 and the Spring semester of 2007 in a university setting. Each course was split in half for their lab sections, previously-used instructional content was used for one course, and newly created guided-inquiry lessons were used for the other. The researchers analyzed the data regarding participants and found that there were no significant differences in demographics between the two groups. The students registered for classes without prior knowledge of the study or the method of instruction used in each particular class. Data was collected from each group based on scientific literacy and skills, self-efficacy, course evaluations, and student interviews.

The study included both quantitative and qualitative data. The data regarding scientific literacy was measured quantitatively utilizing a multiple-choice question test delivered to each group in the same manner. To assure test reliability, Gormally et al. (2009) used a Cronbach Alpha analysis, which resulted in a score of $\alpha = 0.73$ for the spring of 2007 but a score of $\alpha = 0.63$ for the fall of 2006. This required the removal of the fall data as that semester's test did not meet reliability standards. To analyze the data, Gormally et al. (2009) compared a pre-test score to this post-test; there was no significant difference between pre-test scores for the two groups. The data showed a significant increase in correct responses ($*p < 0.05$) for the group that received inquiry-based instruction, with an overall 4% increase in correct responses. However, according to the student self-efficacy survey, students who learned using the traditional course material demonstrated a higher self-confidence score when describing and transcribing biological content. In the same self-efficacy survey, the inquiry-based learners reported higher confidence in problem solving and analytically conducting labs.

Inquiry-based learning was also studied in Abdi's (2014) research, which looked at the correlation between the effects of IBL and students' academic achievement, particularly in science. Abdi's (2014) study used the following research question: "Is teaching science with inquiry-based instruction supported 5E learning cycle more effective than traditional science teaching methods?" (p. 38). This research study echoes the importance of scientific literacy and its implementation in learning. The hypothesis for the study was that there would be no significant difference between test scores of the control and experimental groups. The study was completed in Iran, using 20 fifth-grade girls in each of the two groups. Students were placed in each group using the purposive sampling method. This sampling method was used in an attempt to create reasonably even groups based on GPA and student strength in content areas. The two groups were not statistically different from one another.

The control group received the traditional teaching method, which mainly consisted of direct instruction with an emphasis on question-and-answer assessment. The experimental group was taught using a 5E learning cycle, where the teacher encouraged questioning and creative thinking. Each section was taught by the same teacher. A pre-test was used to provide comparative data for the completion of the study. There was not a statistically significant difference between two groups' pre-tests. The information collected as a post-test was focused on quantitative data, using a 30-question multiple choice test. The test was considered to have a Cronbach's alpha reliability score of 0.75, which is adequate for use. Based on an ANCOVA analysis, Abdi (2014) concluded that there was a significant difference between the experimental group and control group. Abdi (2014) claimed that this supports other previously conducted research, and concluded that effective instruction implemented by teachers should incorporate 5E methodology to increase student success.

The study completed by Panasan and Nuangchalerm (2010) also assessed the connection between inquiry-based learning activities and academic achievement. However, their study compared inquiry-based instruction to project-based instruction. Panasan and Nuangchalerm's (2010) goal was to determine whether there were statistically significant differences in academic success when incorporating the two strategies. Their study focused on potential variance in academic achievement, scientific literacy, and critical thinking. With these factors in mind, they hypothesized that there would be a statistically significant difference between the two groups. For this study, the population consisted of nine classes of fifth graders, totaling 296 students. Eighty-eight of these students were chosen for the study using cluster random sampling; half received project-based instruction, and the other half received inquiry-based instruction. A pre-test recorded initial data on student understanding for comparison with final post-test data.

Panasan and Nuangchalerm (2010) spent an equal amount of time preparing lessons for each group. One group of 44 students received instruction centered on project-based learning; the other 44-student group implemented inquiry-based learning. The authors explained that while the methods were similar, the project-based learning offered more upfront direction than the inquiry model, and it carried a focus on design. To assess the academic achievement of the students at the end of the study, they utilized a three-section multiple-choice test. The first section involved a 30-question multiple-choice test for achievement, which presented a reliability rating of 0.86. The second section of 20 multiple-choice questions focused on analytical thinking and carried a reliability score of 0.76. The final section was also a 20-question multiple-choice test that analyzed science process skills; it had a reliability score of 0.82. Results of the final post-test data showed that while project-based learning scored higher than inquiry-based learning, the difference was miniscule, represented by a 0.15% higher mean in test scores. After completing Hotelling's T2 analysis, the difference was not statistically significant. Panasan and Nuangchalerm (2010) concluded that both methods were effective for instruction and can be implemented successfully in a classroom setting to benefit student achievement, analytical thinking, and science processing.

Inquiry-based learning methods have come with many descriptions in the history of its use. Zhao et al. (2021) studied the impacts of Prediction-Observation-Explanation inquiry (POE) on fifth-grade students studying light refraction. The population consisted of 174 fifth grade students with two classes in each group (Zhao et al., 2021). The two groups were similar in participant demographics and contained approximately the same number of students. The control group consisted of 88 students while the experimental group consisted of 86 students (Zhao et al., 2021). The students participated in the study with consent, but it is not apparent that they were aware of the specific focus of the study. The same teacher taught both groups of students. The study covered four 40-minute class periods centered around the topic of light refraction. The control group received conventional instruction while the experimental group was taught using the POE method. To compare the student groups and assess validity, students were asked to take a pre-test. There were no statistically significant results when comparing the two groups.

After the data was collected, students were asked to complete a post-test to assess their comprehension. A t-test was used to compare the growth in pre-test to post-test scores. During analysis of the results, Zhao et al. (2021) found that the students in the experimental group had a higher mean score on the post-test than the scores of the students in the control group ($p<.05$). The results were broken down into four categories: source, certainty, development, and justification. Of those sections, there were statistically significant results in source and certainty ($p<.05$), while there were no significant differences in the categories of development and justification (Zhao et al., 2021). Zhao et al. (2021) claimed that this data suggests that POE inquiry-based learning is a more effective instructional strategy than conventional learning, but acknowledged that there are limitations to this application as the research covered only one topic in a class.

The application of inquiry-based learning goes far beyond a simple method to share information. It can establish critical thinking skills that help students process current-day events that can often be controversial. Qamariyah et al. (2021) researched the impact of inquiry-based learning on this type of socioscientific issue to see the effect on development of students' higher-order thinking skills. A group of 96 students were divided into three classes. Two classes received inquiry-based learning instruction (68 students), while one class experienced verification learning (28 students). First-year Chemistry students participated in the study. The study was completed during a time when students learned virtually. The experimental treatment included four asynchronous assignments and two synchronous assignments completed over a video call. Qamariyah et al. (2021) used a pre-test/post-test system to establish a comparative analysis. The pre and post test questions focused on measuring higher-order thinking skills. Qamariyah et al. (2021) had experts perform a validity test and approved 20 questions for use after revisions. An ANOVA test showed there was no statistically significant difference between the experimental and control groups on the pre-test.

The results of the post-test showed large differences between the control and experimental groups. While the pre-test scores were similar (control = 38, experimental = 40), the post-tests were drastically different (control = 40, experimental = 68). An ANOVA test showed statistical significance between the two groups ($p<0.05$). Qamariyah et al. (2021) stated that this difference was likely due to the fact that the experimental group was consistently practicing higher-order thinking skills, while the control group focused on memorization. Qamariyah et al. (2021) concluded that inquiry-based learning can strengthen students' higher-order thinking skills and prepare students to think critically about socioscientific issues.

Inquiry-based learning can be an effective tool to support long-term learning in a variety of settings. Korkman and Metin (2021) studied the impact of virtual inquiry-based learning on student success and permanent learning; they emphasized the collaborative aspects of inquiry in spite of the virtual setting. Their study collected data on 64 students evenly split between the control and experimental groups. Korkman and Metin (2021) used the stratified sampling method (effective for validity and reliability) to sort students into the groups. The control group received in-person inquiry instruction while the experimental group received online inquiry-based instruction. The demographics of the groups differed in gender ratio (control=20F/12M, experimental=15F/17M), but showed no other significant differences. Korkman and Metin (2021) completed their research in four stages: pre-test, application of the tested variable, post-test, and analysis of data. The pre-test showed no significant difference in student achievement. Throughout the study, the seventh-grade students received lessons on chemical bonds. Students worked collaboratively in-person on content for the control group, while the experimental group utilized virtual collaborative inquiry learning. Both groups used similar materials despite the differences in delivery. Students then completed the post-test to measure their academic growth. At a later date, the students received a retention test to compare long-term learning.

While the control groups pre-test scores were slightly higher, a t-test showed no statistically significant differences between the two groups ($p<0.05$). Both the control group and the experimental group showed significant growth when compared to their respective post-test scores. The experimental group scored higher on the post-test than the control group, but a t-test showed no significant differences. However, both groups showed a statistically significant increase in achievement compared to their pre-test scores. The results of the retention test showed slightly decreased scores for both groups, but a t-test reported no statistical significance. Korkman and Metin (2021) determined that collaborative inquiry-based learning is effective whether instruction is in-person or online. They recommended its practice for both achievement and retention.

Bezen and Bayrak (2020) tested the implications of inquiry-based learning in physics classrooms. They attempted to identify the growth in conceptual understanding of wave-related physics topics. The research model included four steps: “determining the research problem, data collection, data analysis and interpretation, and designing an action plan” (Bezen & Bayrak, 2020, p. 878). Their study, completed in the spring of 2018, included 58 student participants from 10th grade in Anatoli, Turkey. Participants included 30 girls and 28 boys; all were either 17 or 18 years of age. Thirteen selected students participated in interviews throughout the study. Bezen and Bayrak (2020) selected these students intentionally from varying levels of previous academic success from the previous two years; these students participated voluntarily. Prior to the start of the study, Bezen and Bayrak (2020) tested the effectiveness of the content on a pilot group. The study took participants through five inquiry activities over the course of two weeks. Researchers assumed the role of participant observer to collect data for the study. After completion of the inquiry-based instruction, Bezen and Bayrak (2020) administered a 17-question open-ended assessment. Experts validated the contents and methods involved in this assessment.

Bezen and Bayrak (2020) prepared a rubric to measure the students’ conceptual understanding. They then divided student responses into two categories: scientifically acceptable and scientifically unacceptable. Bezen and Bayrak (2020) then further categorized responses into themes with the consultation of experts in the field of physics education.

Qualitative data showed a significant change in students' conceptual understanding. Bezen and Bayrak (2020) acknowledged that students did not have a complete change in understanding. They identified the topic of "speed of the beat" as a particular area of difficulty for students. Overall, Bezen and Bayrak (2020) stated that the inquiry-based instruction model is effective in the physics classroom regarding the topics of waves. They identified students' critical thinking and enthusiasm as particular areas of growth.

While inquiry-based learning has been around for a long time, its implementation is still often misunderstood. The three types of inquiry (structured, guided, and open inquiry) can make defining the practice of inquiry quite challenging. Sarioglan and Gedik (2020) attempted to isolate the impact of guided inquiry learning on the outcomes of conceptual change and durability. To accomplish this, a population of 6th-grade students participated in a study in the western part of Turkey. For the purposes of the study, Sarioglan and Gedik (2020) defined guided inquiry as a teacher provides a goal and materials while the students design the process to come to a solution. This means that the instructor did not provide the answer to the problem or the precise steps to find a solution. The population of the study consisted of 26 students (12F, 14M). Test of Conceptual Understanding of Density (TCUD) assessed student growth regarding conceptual understanding of density. Sarioglan and Gedik (2020) piloted the TCUD using a group of 70 students who did not participate in the official study. They made adjustments to the TCUD based on the data collected from the pilot. The students took the TCUD before instruction and immediately following the instructional period. Sarioglan and Gedik (2020) also assessed students at the six and 24-week mark after instruction to determine conceptual durability. The assessment consisted of three open-ended questions all related to density. They then separated the responses into five categories: fully correct, partially correct, unacceptable, non-coding, and no answer. Professionals validated the reliability and effectiveness of the TCUD. The research's instructional period covered eight hours on the topic of density. Instructors used the 5E learning model to prepare content under the practice of guided inquiry.

The first question of the TCUD showed a 42% increase in correct responses. The partially correct response also saw an increase of 8%. The durability showed a slight decrease in the first durability test, but increased again for the second durability test. The second question showed similar results. Sarioglan and Gedik (2020) saw a 31% increase in correct responses after instruction. No students responded with a fully correct answer prior to instruction. The first and second durability tests showed an additional increase of 11% and a decrease of 4%, respectively. The third question also had no fully correct responses prior to instruction. Sarioglan and Gedik (2020) reported a large increase in correct responses, with 85% of students responding with a fully correct answer. The third question showed the largest decrease in durability. Fully correct responses decreased to 69% on the first durability test and further dropped to 62% on the second. Sarioglan and Gedik (2020) reported that guided inquiry learning was an effective practice for both conceptual change and durability.

Inquiry-based learning activities have deep roots in experimental processes and critical thinking. Shi, Ma, and Wang (2020) tested these inquiry practices compared to cookbook-guided laboratory experiments. The study, completed in China, included 78 participants. Shi, Ma, and Wang (2020) divided the students into a control group and experimental group. The control group included 40 students (14 female, 26 male) and the experimental group included 38 students (13 female, 25 male). A 5-point Likert-scale survey measured the students' epistemological perspectives. An expert and multiple student interviews confirmed the validity and reliability of the survey. The survey contained 30 questions, which Shi, Ma, and Wang (2020) tested with a pilot study of 34 students. An additional assessment measured student comprehension of the topics covered. Shi, Ma, and Wang (2020) administered the 20-point test multiple times in previously conducted classes to refine and approve its use for this study. The control group received instruction based on a cookbook laboratory experiment and the experimental group received instruction through open inquiry. For the experimental group, the instructor provided a list of questions to investigate but did not direct student practices. The instructor responded to student questions with instructive questions and did not inform the students when they accomplished their goal.

Statistical analysis completed regarding student epistemological perspectives showed significant results. Students who received the cookbook guided lab demonstrated a decrease in epistemology. The students who participated in the inquiry learning showed an increase in epistemology. While no statistical significant difference was found in the pre-test, both the control group's decrease and the experimental groups' increase showed statistical significance ($p<0.01$). A post-test administered to measure student comprehension showed growth for both groups. The control group scored slightly higher on the post-test than the experimental group, but a t-test showed no statistical significance. Shi, Ma, and Wang (2020) recommended the use of inquiry-based learning to benefit students' epistemological growth.

Nopiya, Hindriana, and Sulistyono (2020) claimed that teacher-centered instruction has no impact on students' scientific processing skills (SPS) or interpersonal intelligence (II). To work on these skills, inquiry-based learning is an effective instructional practice. Nopiya, Hindriana, and Sulistyono (2020) conducted a study with students participating from a high school in Jamblang, Indonesia. The 11th-grade students learned about the human respiratory system. Nopiya, Hindriana, and Sulistyono (2020) formed two groups of students, made up of two separate classes from the high school. The control group received standard instruction, while the experimental group received instruction through guided-inquiry. They utilized both a survey and pre-test/post-test to collect data. An observer took notes on the impact of each study throughout its implementation.

Nopiya, Hindriana, and Sulistyono (2020) categorized the survey data and observer notes into three themes: empathetic processing, giving feedback, and inquiry and questioning. The experimental group scored significantly higher regarding empathetic processing and giving feedback. The control group scored slightly higher for inquiry and questioning. The pre-test scores showed homogeneity between the two groups. The assessment included questions from four categories: control variables, formulate the hypothesis, experiment, and data interpretation. Both groups showed statistically significant growth on the post-test. However, the experimental group scored higher than the control group in all four categories. A t-test showed a statistically significant difference between the two groups post-test scores. Nopiya, Hindriana, and Sulistyono (2020) claimed that the biggest difference in data supported that students from the experimental group had better practice with curiosity and observation than those in the control group. The experiments conducted improved their critical thinking skills and experimental abilities. Nopiya, Hindriana, and Sulistyono (2020) claimed that inquiry-based instruction is effective in improving students’ scientific processing skills and interpersonal intelligence.

Sahintepe, Erkol, and Aydogdu (2020) attempted to measure the impact of inquiry-based learning on science processing skills. Their study included 40 7th-grade participants from public schools in Turkey. The study divided the students into two groups (control and experimental) of 20 students. The control group consisted of 11 boys and nine girls, while the experimental group consisted of 12 boys and eight girls. The control group's instructor used the curriculum from the previous year, while the experimental group received inquiry-based instruction. Pre-test scores showed no significant difference between the groups. Sahintepe, Erkol, and Aydogdu (2020) assessed the students using the scientific process skills scale (SPSS), which is considered valid. The SPSS is a 27 question multiple-choice assessment. Sahintepe, Erkol, and Aydogdu (2020) also collected qualitative data through student interviews consisting of eight questions. The two groups covered the same topics and assessed with the same questions.

Pre-test scores showed no statistically significant difference between the control and experimental groups ($p>0.05$). However, a Mann Whitney U-test showed a significant difference between the post-test scores, as the experimental group received higher scores on the assessment ($p<0.05$). The SPSS also showed a statistically significant difference in higher-level questions, whereas the experimental group received higher scores ($p<0.05$) The results suggested that the inquiry-based instruction had a greater impact on the students' scientific processing skills. The student interviews supported these findings, as students from the experimental group reported stronger confidence in forming hypotheses and performing experiments. Sahintepe, Erkol, and Aydogdu (2020) recommended that inquiry-based learning be implemented as their results showed that student achievement increased and students found confidence in completing the scientific process. They encouraged the use of inquiry-based learning for students of all achievement levels.

Kacar and Balim (2021) attempted to determine the effects of argument-driven inquiry on the conceptual understanding of middle school science students. The argument-driven inquiry is similar to the inquiry method with argumentation added in the middle section to help refine concepts and ideas. Their study included 64 participants which were divided into two groups. The seventh graders participated in either the control group (33 students; 16 female, 17 male) or the experimental group (31 students; 14 female, 17 male). Both groups learned about electrical energy. The instructor utilized the previous year's curriculum for the control group, while the experimental group experienced argument-driven inquiry instruction. Both groups met over a period of nine weeks for four hours per week.

Kacar and Balim (2021) collected data using the conceptual learning test, daily student journals, and research notes. Experts reviewed the conceptual learning test and a pilot group tested the assessment, which showed high validity. The 15-question assessment measured students' conceptual understanding. Kacar and Balim (2021) implemented the assessment as a pre-test and a post-test. An important factor in the research was that the instructor has been previously trained in implementing the argument-driven inquiry method in the classroom.

The pre-test showed a higher mean score for the experimental group when compared to the control group, but this difference did not show statistical significance. After the experimental group experienced the argument-driven inquiry, their post-test scores showed a significant increase ($p<0.05$). Control group data also showed a statistically significant increase. The experimental group did score higher on the assessment. The difference between the mean score of the experimental group and control group showed statistical significance in favor of the experimental group. Kacar and Balim (2021) concluded that the argument-driven inquiry method is effective and should be used to benefit students' conceptual understanding.

Critical thinking has been shown to benefit students comprehension and academic achievement. Maknun (2020) set out to find a connection between critical thinking skills and the implementation of the guided inquiry learning model. The study was completed in Bandung, West Java, Indonesia. Maknun (2020) identified the potential for growth as many students in the area had difficulty connecting concepts to the real world. The population of the study consisted of two groups of 28 students. One group received instruction through conventional learning (control group) and the other received inquiry-based instruction (experimental group). Maknun (2020) used a pre-test/post-test design to measure student growth. The 40-question assessment evenly covered the two topics studied in the unit (i.e., static fluid material, Ennis's indicators). The two groups displayed similar scores on the pre-test and showed no statistically significant difference.

Maknun (2020) used an N-gain score to determine the level of growth based on the assessment results. The implementation of a t-test compared the groups. The experimental group outperformed the control group in every topic assessed. The assessment showed a high level of increase in understanding for the experimental group (N-gain=0.71). The control group showed a low level of growth (N-gain=0.28). Maknun (2020) asserted that a likely reasoning for this change was due to the inquiry instruction's opportunities for students to actively and independently practice the steps of the scientific method and think critically about their process. This meant that students had to analyze and draw conclusions with support rather than direct guidance. Maknun (2020) claimed that inquiry-based learning showed a significant growth in student comprehension and critical thinking skills. The practice was recommended for use at the high-school level based on the growth shown in the study.

Skelton et al. (2018) stated that job opportunities in science, technology, engineering, and math (STEM) are increasing significantly, for STEM-related jobs made up approximately one-fifth of all jobs in 2015 and an increase of 17% was expected by 2020. These statistics make scientific skills extremely important as students prepare to enter the workforce.

The study consisted of middle school students in Las Vegas, Nevada. Participants included six 6th-grade classes and five 8th-grade classes. Skelton et al. (2018) collected results from 88 6th-grade students and 43 8th-grade students. The study utilized a pre-test/post-test design. A panel of experts validated the pre-test, which found no significant differences between the two groups. The 6th-grade and 8th-grade students studied different topics, so comparative analysis was not viable. Skelton et al. (2018) completed comparative analysis separately for each grade level. Both grade levels used similar techniques to carry out the instruction, utilizing guided-inquiry practices throughout. The 6th-grade students learned about soil pH while the 8th-grade students focused on analyzing water chemistry. Each class received one week of instruction on background information. Instructors then divided the students into groups of three to carry out scientific processes through guided-inquiry. The student groups created their own hypothesis and procedures, then carried out their study. The students then took the post-test at the completion of the learning cycle.

Results from the post-test showed growth in all areas (i.e., scientific skills, scientific knowledge, and scientific reasoning) at both the 6th-grade and 8th-grade levels. The categories of science reasoning and science skill for 6th-graders showed statistically significant growth on the post-test. The 8th-grade students showed statistically significant growth in the science skill category ($p < 0.01$). Skelton et al. (2018) demonstrated that inquiry-based learning strengthens students' science skills, scientific knowledge, and scientific reasoning. This led them to recommend guided-inquiry learning for instruction in middle school science classes.

Student Engagement

For students to learn efficiently, getting them engaged in the learning is essential (Feyzioglu & Demirci, 2021). Student engagement and motivation builds the skills necessary to be successful in the classroom and beyond. The following 10 article reviews focus on the topic of student engagement.

Inquiry based learning can be particularly beneficial to students in STEM based courses. The impact on these courses was studied by Attard, Berger, and Mackenzie (2021), regarding students from years 3 through 8 in school from the Sydney area of Australia. Teachers were trained on how to utilize inquiry in STEM units and then implemented these units in their classrooms. Teachers of students from years of school other than 3 through 8 were involved in the training but did not participate in the research portion of the study. The research included students from five different schools. Of the five schools represented in the data, all five reported teacher interview data. One of these five schools did not report student focus group data. While Attard, Berger, and Mackenzie (2021) did evaluate additional courses, data from courses not related to STEM topics were not included in this data report. All participants, including both teachers and students, gave informed consent to participate in the study after receiving basic information about the study.

The data was largely qualitative, having utilized teacher interviews and student focus group responses.While the qualitative nature of the data made reliability testing difficult, deductive analysis was used to correlate responses and identify common themes. Attard, Berger, and Mackenzie (2021) turned these responses into a form of quantitative data by identifying repeated themes. Common themes included increasing relevance, connecting industry, and overall engagement. Overall, student engagement was the most recurrent theme.

Student motivation can be impacted by inquiry-based learning methods. Bayram et al. (2013) researched the connection between student motivation and inquiry-based learning methods among students attending the Faculty of Education at Hacettepe University. Thirty-seven students participated. Data was collected using the Motivated Strategies for Learning Questionnaire (MSLQ); the intent of the MSLQ is to focus on motivation and learning strategies. The portion of the MSLQ dedicated to motivation is broken down into 31 parts, including intrinsic goal orientation (IGO), extrinsic goal orientation (EGO), task value (TV), control of learning belief (COLB), self-efficacy for learning and performance (SLP), and test anxiety (TA). For the study, a lesson on chemical equilibrium was taught using inquiry-based methods. Considerations were taken in comparing MSLQ pre-test scores between the control group receiving procedure-based instruction and the experimental group receiving inquiry-based instruction. Bayram et al. (2013) found no significant difference between the two groups. The teacher performed a chemical equilibrium demonstration and instructed students to design experiments and deduce what was taking place.

Bayram et al. (2013) compared the MSLQ pre-test and post-test data for significance ($p<.05$). When analyzing the control group receiving procedure-based instruction, the

Mann-Whitney U-test identified statistical significance in the pre-test for extrinsic motivation (EGO). Statistical significance was not seen in any other portion of the MSLQ for the control group. However, when analyzing the experimental group that received inquiry based instruction, statistical significance was shown between pre-test and post-test data regarding motivation. Bayram et al. (2013) concluded from this data that inquiry-based learning led to an increase in extrinsic motivation in the students. They claimed the students evaluating the experimental process themselves increased their engagement and motivation as their comprehension of the process improved. Bayram et al. (2013) summarized the impact of standard procedure-based labs as lacking in student comprehension of process and purpose, while arguing that inquiry encourages students to think critically and ask questions.

The study conducted by Maxwell, Lambeth, and Cox (2015) focused on the impact of inquiry-based learning on academic achievement, attitudes, and engagement. They conducted their study using 42 fifth-grade students from two separate classes. The researchers formed two groups; the control group received traditional instruction and the experimental group utilized inquiry-based learning. Maxwell, Lambeth, and Cox (2015) described inquiry-based learning as introducing a problem to students and asking them to investigate and solve it with the provided materials. They defined traditional instruction as teaching through notes, worksheets, and procedure-led lab experiments. The administration separated the students into the two classes. These two classes were considered to be similar in demographics with no statistically significant differences between them. Maxwell, Lambeth, and Cox (2015) used the Criterion Referenced Competency Test (CRCT) as a pre-test to compare the average score between the two groups. While the experimental group scored slightly higher than the control group on the pre-test, the researchers found no statistically significant difference. The two groups participated over the first eight weeks of the school year, utilized the same learning targets for instruction, and participated in the same number of experiments. The control group received instruction through structured learning experiences, including procedure guided experiments and specific explanation of concepts. The experimental group learned using a problem or question to solve, usually collaboratively, and used provided materials. Small group thoughts were then shared out in a large group setting to come to a consensus.

For data collection purposes, an additional pre-test was conducted. The Physical Science Knowledge Assessment was given to all students at the beginning of the year and at the conclusion of the data collection period. This test allowed Maxwell, Lambeth, and Cox (2015) to gather quantitative data on the success of the students. A peer review team concluded that the test was valid and effective for the scope of this study. The instructors also recorded qualitative data throughout the experiment. The results of the study showed that the students from the inquiry group were more engaged than their peers in the traditional instruction group. When considering attitude and motivation, the data showed a statistically significant result in the control group when students responded to their enjoyment of learning about science. The students from the inquiry-based experimental group in this study reported a decrease in their interest in learning about science. Students also responded negatively when asked if science would help them understand the world around them. While there was a decrease in results, this data did not prove to be statistically significant. The data did show significant results in quantitative data regarding the academic success of the students in the inquiry group, suggesting that inquiry-based learning may have a positive impact on student engagement and comprehension (Maxwell, Lambeth, and Cox, 2015).

Laboratory experiments can be used in an inquiry-based learning environment. In their study, Smallhorn, Young, and Burke da Silva (2015) used the term “redevelopment” to describe the process of transforming traditional instruction into inquiry-based learning. They centered their research around the impact of this change on student satisfaction and achievement. To collect the data on student satisfaction, students took an open-response survey to describe their experiences and the instruction format’s impact on their learning. The research took place at Flinders University; roughly 800 students were in the traditional-instruction control group and 700 students were in the inquiry-based experimental group. The control group (receiving traditional instruction) took place in 2013. Redevelopment was then performed to teach the same concepts to the inquiry-based experimental group in 2014. Part of the redevelopment of the course included expanding on topics previously taught only in lecture by introducing new inquiry-based labs.

Survey responses were collected from 710 students to collect qualitative data on student experience and satisfaction. The students also were assessed using a multiple-choice test to quantify their achievement and comprehension. The multiple-choice questions were separated into two categories: lecture questions and lab questions. When analyzing the results, the mean scores of students were consistently higher in the experimental group that received inquiry-based instruction in addition to lecture. There were statistically significant results in the laboratory-related questions after redevelopment ($p=.000$) and the mean score on lecture-based questions ($p=.017$). The mean score on laboratory-based questions that were not redeveloped actually decreased for the experimental group. Smallhorn, Young, and Burke da Silva (2015) stated that these results showed a noticeable difference in student achievement and suggested that inquiry-based learning models are useful and effective in their implementation. They acknowledged that inquiry-based models effectively mirror the scientific method and recommended its use to teach scientific principles.

Inquiry-based learning is supported by the constructivism learning theory. Baldock and Murphrey (2020) supported these practices in their research in high school agriculture classrooms. They claimed that agriculture classes lend themselves to inquiry-based practices despite the learning curve of implementation for students and teachers alike. The researchers used a phenomenon-based approach in planning the unit content. The study used the same instructor for all courses. The study included 67 students, 24 of which consented to be interviewed. Participants included sophomores, juniors, and seniors. The class utilized both student-led and teacher-led inquiry activities throughout the eight-month study. Baldock and Murphrey (2020) collected qualitative data through individual interviews. The instructor also collected field notes for analysis. The student interview included the same six questions regarding student experiences and potential improvements. Quantitative data was not collected in the study.

The implementation of the study was successful. Common themes developed from the student responses. Many students reported satisfaction in performing the activities themselves and learning from their mistakes. Other themes included improved critical thinking skills and collaboration. The students were divided on whether background information should be shared before or after the inquiry activity. Students who preferred information prior to the activity wanted to apply the information shared. Students who did not want background information until after the activity argued that the activity is not truly inquiry if the information is shared beforehand. Baldock and Murphrey (2020) recommended that inquiry-based learning is effective and can be implemented in higher education settings. They stated that inquiry practices benefit many learning skills.

Feyzioglu and Demirci (2021) studied the impact of inquiry-based learning on learner autonomy and student conceptions of learning. The practice of inquiry can take different forms and their study used structured, guided, and open inquiry activities. They felt this research was needed as many students feel the goal of learning about science is to answer test questions correctly. As a result, their study focused on students developing scientific skills. Feyzioglu and Demirci (2021) highlighted the importance of student-led practices that placed students in the lead role. To do this, 70 students from Bursa, Turkey, received instruction that utilized traditional instruction (i.e., control group) or inquiry-based instruction (i.e., experimental group) that aligned with the regular science curriculum. Both groups engaged in 40-minute class periods held three times per week. Each 4th-grade class was randomly selected from the school. There were no significant differences in achievement scores between the groups; age, gender, and socioeconomic demographics also showed no significant differences. The same instructor taught both groups. Feyzioglu and Demirci (2021) used interviews to collect qualitative data; interview questions targeted the concepts of learner autonomy and conceptions of learning.

Feyzioglu and Demirci (2021) categorized learner autonomy responses into the themes of “receiving,” “participatory,” and “constructive.'' When analyzing the “receiving” responses, Feyzioglu and Demirci (2021) found that student responses focused on what the teacher had done or shared. “Participatory” responses showed a slightly higher level of student-led work, but still centered on what the teacher instructed students to do. The “constructive” responses showed a high level of critical thinking skills and a focus on asking questions. Interview questions regarding conceptions of learning showed the highest level of student-centric learning when students applied and inquired about topics. Feyzioglu and Demirci (2021) found that students from the experimental group successfully moved past the participatory role and into the constructive role of learning. They acknowledged that this transition of roles took time, but eventually these led students to learner autonomy unrestricted to memorized information.

Inquiry-based learning has a significant impact on student engagement. In addition, higher-order thinking skills are developed through student reflection and integrative learning. Archer-Kuhn et al. (2020) utilized a qualitative study to determine the impact of inquiry-based learning on student engagement in a collegiate setting. They used a seven-cohort mixed-methods study with participants from all levels of collegiate study. They cited previous research connecting inquiry-based learning to both increasing student engagement and developing critical thinking skills. Archer-Kuhn et al. (2020) acknowledged that it is difficult to find an exact definition of inquiry-based learning. The most effective definition may break inquiry down into three categories: structured, guided, and open inquiry. Archer-Kuhn et al. (2020) decided to scaffold the independence of the students, starting with more structure and working toward open inquiry. The study included 69 participants ranging from undergraduate to doctoral students. Fifty-two of the participants completed the post-course survey; then Archer-Kuhn et al. (2020) established focus groups with 19 participants each.

The study started with a 4-point Likert scale pre-test survey. This determined student engagement and identified any previous exposure to inquiry-based learning. Previous studies found the survey reliable. The groups' demographic data revealed no significant differences. Archer-Kuhn et al. (2020) then gathered qualitative data from the focus groups to better determine participants' perspectives. They separated the student experiences into five common themes: "(1) a new kind of learning, (2) increased awareness of learning, (3) freedom in learning, (4) honoring uniqueness of students, and (5) instructor in the trenches (Archer-Kuhn et al., 2020, p. 195)."

An ANCOVA test measured the change in higher-order learning. There was a statistically significant result regardless of gender or level of study ($p<0.05$). The ANCOVA test also showed significant improvement in the students' integrative learning ($p<0.01$). This demonstrated a significant growth across all student groups regardless of age, gender, level of study, or collegiate GPA. Archer-Kuhn et al. (2020) recommended the utilization of inquiry-based learning across all collegiate levels to benefit students' higher-order and integrative learning.

A major goal of inquiry-based learning is to help students establish skills related to critical thinking, questioning, and laboratory procedures. To test these skills, Kaya and Avan (2020) developed an inquiry activity on the topic of fish respiratory systems. Students engaged in a hands-on lab activity which was completed over the course of two hours in a 7th-grade classroom. Participants included 28 students from the Kastamonu province of Turkey. Kaya and Avan (2020) divided students into groups of four for the activity. To begin the activity, the instructor asked the students a series of questions. They intended for these questions to lead students to think critically and converse about different topics and possibilities. Students then designed a model to float, sink, or suspend in a pool of water using balloons, straws, and a two liter bottle. Many groups had similar designs, but each contained unique pieces. After the students tested their models, students held a discussion about what they learned and developed. Kaya and Avan (2020) then conducted student interviews about the process. The interview questions focused more on student perspectives and less on accurate comprehension, although student examples did show a successful level of comprehension.

Qualitative interviews conducted revealed consistent themes from student perspectives. The students frequently mentioned their enjoyment of the investigative process. Students accurately paired the parts of their model with the parts of the fish respiratory system. Other students described feeling pride and success in sharing their developed model. Students identified areas that required problem solving and felt confident in their success in overcoming issues. Kaya and Avan (2020) considered the activity a success in both implementation and student growth. They recommended the utilization of similar activities to provide students with opportunities to share in the process of learning.

Self-generation plays a major role in student motivation. Streich and Mayer (2020) attempted to measure the impact of inquiry-based learning on self-generation. They used a mixed-factorial design with 98 participating students. The students' average age was 13 years old. Streich and Mayer (2020) divided the students into three groups; each received a different variable (i.e., self-generation, self-generation with feedback, rereading). They also tested students for retention at two time intervals (i.e., 10 minutes, one week) using the same questions. All groups focused on the topic of biological adaptation.

The three groups began with identical lessons to share background information on the topic and given identical inquiry activities. The instructor required the self-generation groups to create and test a hypothesis and then analyze results on their own, while the instructor provided the information for the rereading group. The self-generation with feedback group then received feedback on what they had accomplished and were given time to revise their answers. Streich and Mayer (2020) provided feedback that was identical to the rereading group, meaning that the self-generation with feedback group and rereading group were provided with the same information at different times. Students completed an assessment immediately after they completed the inquiry activity. The students then took the same assessment one week later to gauge retention. Experts approved the reliability of the assessment with a Kappa statistic test ($p<0.001$).

The retention tests showed significantly higher scores for the self-generation with feedback and rereading groups immediately following the activity ($p<0.05$). The rereading group scored higher than the self-generation with feedback group, but not at a level of statistical significance. During analysis of the one week retention test, only the self-generation group showed a statistically significant decrease in score ($p<0.05$). Streich and Mayer (2020) point out that reading competency was a strong predictor of success for the rereading group. The results of the study showed that feedback in some form was essential for student success. Streich and Mayer (2020) encouraged instructors to utilize inquiry learning with feedback in the science classroom.

Sever and Guven (2015) studied the impact of inquiry-based learning on student resistance in a science and technology class setting. Their study included 95 7th-grade students and 14 teachers. Researchers divided participants into control and experimental groups. A pre-test/post-test design measured academic achievement. Sever and Guven (2015) also used surveys and interviews to collect qualitative data. The control group received instruction through traditional methods while the experimental group received inquiry-based instruction. Sever and Guven (2015) recorded the number of students in each group that showed resistance behaviors. This included seven students from the control group and nine students from each experimental group. Sever and Guven (2015) used the pre-test/post-test method to measure the academic growth of the students. The interviews conducted allowed for analysis of resistance behaviors and ideology.

Sever and Guven (2015) analyzed the results at the completion of the study period. The analysis showed statistically significant increases in academic achievement for both the control group and experimental group. The experimental group did show a higher mean score on the post-test, but the difference between groups was not statistically significant. Sever and Guven (2015) prioritized the analysis of changes in resistance behaviors through the qualitative data. The teacher interviews exhibited the common theme of a decrease in resistance behaviors. Students were reportedly less likely to disengage from content and more likely to respect the teacher and provide feedback. Interestingly, teachers were surprised that the resistance behaviors seemed to return after a relatively short period of time after the conclusion of inquiry-based learning. Based on the results, Sever and Guven (2015) recommended that teachers utilize inquiry-based learning methods to help students who exhibit resistance behaviors.

To fully understand and implement any practice, it is necessary to consider how it will impact students. Nunaki, Kandowangko, and Nusantari (2019) studied the differences between male and female students in developing metacognitive skills through inquiry-based learning. They claimed that metacognition is highly correlated to academic achievement. Students who have strong metacognitive skills are more likely to succeed individually or in groups. This study was conducted over multiple years in a high school in Manokwari, Indonesia. One group of 70 students participated in the study (35 male, 35 female); the participants were 15 and 16-year-olds. Nunaki, Kandowangko, and Nusantari (2019) used a 4-D research and development model. A pre-test and post-test system compared student growth. A t-test determined validity of the groups and measured growth of metacognitive skills. Experts validated the pre and post-test materials. Nunaki, Kandowangko, and Nusantari (2019) made two comparisons in their research: general growth and compared growth between male and female students. The Corebima rubric measured students' metacognitive skills on an eight-point scale (0-7; 0 = low, 7 = high).

The average pre-test score for all students was 43.00. Males (42.06) and females (43.94) scored similarly with no statistically significant difference. The post-test scores showed growth for both male and female students. The overall average score increased to 71.56, while males (72.11) and females (71.00) continued to exhibit similar scores. The t-test determined that the overall increase in test scores was statistically significant ($p<0.05$), but no significant difference was found between males and females. Nunaki, Kandowangko, and Nusantari (2019) recommended inquiry-based learning, having determined that the method benefits the development of students' metacognitive skills, regardless of gender. They cited collaboration and critical thinking as beneficial practices to support metacognitive skills.

Sarioglan (2021) attempted to create a reliability scale to track the validity and reliability of inquiry-based practices. The application of the scale focused on the middle school level. The population of the study included 765 students (364F, 401M) from the 5th through 8th grade level. These students attended 11 schools spread out over five cities. Sarioglan (2021) argued that instruction that directly shares content does not teach students questioning skills. As such, Sarioglan (2021) produced a 5-point Likert reliability scale to track and measure the instructional approaches that help students develop questioning and critical thinking skills. Survey scoring prioritized environmental factors that are found in an inquiry-based learning environment. Professionals approved a 37-question survey for use. The survey included 25 positive statements and 12 negative statements. Sarioglan (2021) flipped the scoring of the negative statements. Sarioglan (2021) included seven topics in the scale: 1) student participation, 2) paying attention to ideas, 3) collaboration, 4) learning, 5) asking questions, 6) observation, and 7) focusing on problems. Cronbach-alpha reliability coefficients determined the reliability of varying factors in the study; the Pearson Correlation coefficient revealed connections between factors.

Two tests, the Kaiser-Meyer-Olkin sampling adequacy test and the Bartlett Sphericity test results test, showed statistically significant results that show the scale is viable for exploratory factor analysis ($p<0.01$). Based on the exploratory factor analysis, Sarioglan (2021) found multiple statistically significant relationships (see table 1, $p<0.001$). Only one relationship result did not show statistical significance (2 and 3). Some relationships showed a negative correlation (1 and 3, 3 and 4, 3 and 5, 3 and 6, and 3 and 7). Interestingly, collaboration showed a consistently negative relationship with the other factors.

Inquiry-Based Learning Utilization

To trust the utilization of inquiry-based learning, it is essential to assess the impact of its use in many settings. The following eight article reviews contained the theme of effective utilization of inquiry-based learning to determine its effectiveness in a variety of settings.

In a study conducted in the southwest US, examined the outcomes of teachers who went through an inquiry-based learning and teaching training program. In this program, 14 teachers participated in the study. Eight of the teachers taught middle school while six taught high school. As a part of the training, teachers participated in the Inquiry-Based Demonstration Classroom program (IBDC). The teachers had a wide range of experience and were evenly split between males and females. The program taught teachers how to implement inquiry lessons while also providing space to analyze and reflect on the impact of the lessons. These inquiry lessons included extended inquiry cycles which lasted at least three days each. During the 18-month training period, teachers implemented these practices across a variety of grade levels and scientific content areas. As such, the teachers were aware of the purpose of the study and consented to participate in the research.

To gather data on the study, the researcher used both qualitative and quantitative data analyses. Qualitative data was collected through a standardized interview process made up of 50 items. Teacher responses were analyzed for common themes and impacts on their methodology towards instruction. Luft (2001) also considered the context of each teacher's location and content area in this analysis. Quantitative data was gathered through application of a rubric-based pre-test and post-test system, which were compared using t-tests. Based on the quantitative data, there was statistically significant data in topics surrounding collaborative learning, questioning and experimental design, and assessment ($p<.05$). The teacher interviews were less conclusive, as the majority of teachers involved held a student-centric approach to teaching prior to joining the program. There were slight changes to the participating teachers' beliefs, but none of the results were statistically significant. The changes in teachers' beliefs trended toward student-centered instruction which utilized the teacher as a guide than direct instructor. Luft (2001) claimed that while the implementation of inquiry activities did not significantly change the teachers' pedagogical beliefs, inquiry-based learning did show student achievement growth that continued to strengthen through multiple extended inquiry cycles.

Inquiry-based learning is often implemented in an in-person setting and frequently uses hands-on lab experiences. However, inquiry practices can also be utilized in virtual lab activities as well. Putri et al. (2021) studied this practice and its implementation in an online learning environment. Putri et al. (2021)'s participants were eighth-grade students from Indonesia. The topic of the learning cycle was light and optics, to which these students had not been previously introduced. Included in the study were 40 students (26 = female,14 = male); all 40 students were from the same class. The analysis of the study centered around the impact of a virtual inquiry-based learning activity on the students' scientific literacy regarding the topic of light and optics.

Putri et al. (2021) used a pre-test and post-test design, which consisted of 30 questions. The test was made up of 18 questions that focused on scientific competency and 12 questions that demonstrated scientific knowledge. The tests were administered to a separate group of students to determine validity and difficulty level. After analysis by an expert, the test was considered valid and effective for the scope of the study. As a pre-test and post-test system was used, the entire class of 40 students was the experimental group. The study compared the difference between pre-test and post-test results (Putri et al., 2021). Students participated in two virtual inquiry lab activities, with one introducing geometric optics and the other offered the topic of lenses and mirrors. The learning cycle included seven sessions, with the pre-test and post-test occupying the first and last meetings, respectively.

When analyzing the data, Putri et al. (2021) compared the pre-test scores to the post-test scores. They broke the analysis down into scientific literacy and scientific knowledge scores, as well as an overall analysis of assessment results. The average overall score increased by 17.98 (pre-test = 63.27, post-test = 81.25). The section of the test regarding scientific competency saw a greater increase in score (66.5 to 83). The scientific knowledge portion also increased (60 to 74) on the respective pre and post-tests. It is significant to note that the distribution of scores on the pre-test regarding scientific competency were not normally distributed, while the post-test scores showed normal distribution. Scores addressing scientific knowledge were not normally distributed on either the pre-test or post-test. Both portions of the test showed statistically significant differences in pre-test and post-test scores (Wilcoxon signed-rank test). Using an N-Gain test, students showed a medium improvement in both scientific competency and knowledge. Based on the results, Putri et al. (2021) concluded that virtual inquiry activities are effective in teaching scientific concepts and recommended their incorporation into both in-person classroom instruction and completely virtual instruction.

Bernard, Dudek-Rózycki, and Orwat (2019) defined inquiry-based learning as "(a)n intentional process of problem diagnosing, carrying out a critical analysis of experiments and searching for alternative solutions, planning research, testing hypotheses, searching for information, constructing models, discussions with colleagues and formulating coherent arguments" (p. 184). To accomplish this in an impactful way, students need to be involved in the construction of the learning process. According to the authors, a large part of this can be accomplished through the 5Es learning cycle: engage, explore, explain, elaborate, evaluate . During their research, Bernard, Dudek-Rózycki, and Orwat (2019) tested the integration of inquiry-based learning using formative assessment in Chemistry classrooms. The teachers had to have met specific requirements to participate in the study: a certificate in inquiry-based teaching, a MSC and PhD degree in their subject, and at least a decade of experience. From a pool of 75, two Chemistry teachers met the criteria; both attended a training to establish consistency in content delivery. Of note, as the two teachers taught at different levels, the content of the lessons was not identical. The teachers did, however, deliver content using similar inquiry methods.

The study was completed with small class sizes, including eleven students in one class and five students in the other. All students experienced this format of learning for the first time. Students and teachers were informed of the qualitative data that would be collected throughout the study.

Throughout the collection of data, some consistent themes emerged. The biggest challenge for the teachers was using assessment effectively in an inquiry-based setting. However, the teachers did succeed in implementing the inquiry model and the students accurately accomplished their task. Since the ages of the two classes were different from one another, a comparative analysis was not viable. Bernard, Dudek-Rózycki, and Orwat (2019) also pointed out that the teachers involved in the study were exceptionally educated and experienced. They point to this as a potential bias in their study as the data may not apply to less experienced teachers. Both students and teachers were hesitant at first, but large growth was seen in student engagement and skill acquisition. Bernard, Dudek-Rózycki, and Orwat (2019) recommended inquiry-based learning as an effective practice, but cautioned its utilization by less-experienced teachers.

In a changing landscape of education, it can be difficult to keep up with producing inquiry-based learning activities. Dolenc, Beaulieu, and Sheppard (2020) studied how teachers kept up with creating student-centered inquiry activities during the COVID-19 pandemic. In their study, teachers created lessons for students attending a week-long camp. The camp was conducted online due to the COVID-19 pandemic. The lessons related to outer space topics spread out over four rotating classrooms. Dolenc, Beaulieu, and Sheppard (2020) conducted an interview with each teacher (eight total) after the conclusion of the week of camp. The interviews included open-ended questions about lesson development and how it compared to preparation in an in-person classroom. Interviewers also asked the instructor to describe the lesson and its utilization. The last interview topic centered on advice for future teachers attempting to teach online. Dolenc, Beaulieu, and Sheppard (2020) categorized responses into two categories: 1) creating an inquiry-based learning environment and 2) challenges to teaching science online.

Based on interview results, teachers described positive feelings toward creating inquiry-based activities despite being online. While one teacher described the process as learning how to teach again, most teachers felt confident in their ability to successfully create and implement student-centered activities in an online environment. Teachers identified asking questions, collecting data, making observations, and discussing conclusions as important pieces of a successful lesson. The teachers involved did acknowledge that lesson planning took longer for a virtual environment. One teacher pointed out that a virtual setting opens many doors for future implementation as inquiry can apply regardless of a student's location; this would allow for more areas for research and study applicable right where they live.

The possibility for more diverse student experiments utilizing materials from in and around their home proved to be a common theme among teachers. Themes of barriers and challenges also appeared in the results. Many teachers shared concerns about students from low socioeconomic backgrounds having the ability to access online platforms or have materials to create experiments at home. Teachers also shared hesitation over losing the interpersonal aspects of in-person teaching. Scientific integrity also emerged as a concern. Overall, Dolenc, Beaulieu, and Sheppard (2020) found that changing inquiry-based learning activities to fit an online format can be accomplished successfully. In their estimation, while there are challenges that accompany a shift to virtual learning, the practice itself can be effective outside of a traditional classroom.

One of the difficulties of inquiry-based learning is coordinating instruction with technology. The online activities may not align properly with inquiry-based instruction, which may contribute to a decreased likelihood of their implementation. As a result, few studies have investigated the correlation between technology and inquiry-based learning. In 2020, Dunn and Ramnarain attempted to measure this correlation through their study in a South African school. They included two groups of students consisting of 34 students each. The control group received teacher-directed instruction while the experimental group learned through inquiry-based online simulations. Dunn & Ramnarain (2020) used a pre-test/post-test design with additional survey and interview responses. The pre-test data showed no significant difference between the control group and experimental group. The eighth-grade students learned about atoms and molecular structures throughout the study. At the end of the instructional period, both groups were given an inquiry activity centered on the structure of atoms and molecules. The experimental group's inquiry activity took place online using a simulation.

The pre-test data showed no statistically significant difference between the achievement of the two groups. When analyzing the quantitative data, the post-test data revealed a statistically significant difference. The experimental group scored significantly higher on the post-test than the control group ($p<0.05$). The qualitative data also reflected the benefits of the inquiry-based instructional practice. Dunn & Ramnarain (2020) utilized a five-point Likert survey, through which students spoke highly of their experience. Common themes in responses included the visual nature of science and an increase in learner autonomy. Students also enjoyed the use of virtual manipulatives and suggested they be used more frequently to support learning in the future. Students identified an increase in their ability to visualize abstract concepts through the virtual simulations. Dunn & Ramnarain (2020) recommended the use of inquiry-based simulations in a science setting, as their data showed benefits in achievement and learner autonomy.

Open-inquiry is a type of inquiry where students have less direct guidance from the instructor. Some instructors have shown concerns over the implementation of open-inquiry and the potential for difficulty in classes with students showing a wide range of learner autonomy. Rahmat and Chanunan (2018) studied the impact of open inquiry on metacognitive skills when comparing low and high academic ability. The study included 60 11th-grade Biology students in Indonesia. Rahmat and Chanunan (2018) divided students into two groups (control and experimental). Each group consisted of 15 students showing high academic achievement and 15 students showing lower academic achievement. An achievement test taken prior to the study provided categorization for high and low academic achievement. The achievement test served as a pre-test for the study. The control class received instruction through a conventional method while the experimental group learned through open-inquiry and a learning journal. At the conclusion of the experimental period, Rahmat and Chanunan (2018) administered a post-test to measure growth. The assessment focused on metacognitive skills within the achievement test. Rahmat and Chanunan (2018) also collected experimental group student journals.

At the conclusion of the post-test, Rahmat and Chanunan (2018) analyzed the data comparing growth between both groups as well as between students showing high and low academic achievement. Researchers found significant results when comparing the two groups as a whole. The mean score for the experimental group was 57.9, while the control group scored 33.9. This result showed a statistically significant difference between the two groups ($p<0.05$). Rahmat and Chanunan (2018) also compared growth between the groups of students who showed lower academic achievement on the pre-test. The students in the experimental group scored 46.9, while the control group scored 22.6. This result also showed statistical significance. These results strongly supported the use of open-inquiry learning in benefitting metacognitive skills for students with a wide range of previous academic achievement. Rahmat and Chanunan (2018) recommended the use of open-inquiry regardless of a student's previous academic achievement.

CHAPTER III: DISCUSSION AND CONCLUSION

Thirty-two inquiry-based learning studies were reviewed; they focused on student achievement, engagement and motivation, and proper utilization of inquiry practices. The comprehensive review proved inquiry-based learning to be an effective practice for all student populations studied. These results revealed a statistically significant improvement for inquiry-based learning students when compared to the control group in nine of 12 academic achievement comparative analysis studies (Abdi, 2014; Gormally et al., 2009; Kacar & Balim, 2021; Korkman & Metin, 2021; Maknun, 2020; Nopiya, Hindriana, & Sulistyono, 2020; Qamariyah et al., 2021; Sahintepe, Erkol, & Aydogdu, 2020; Zhao et al., 2021). Two additional studies researched the impact of inquiry-based learning on student achievement but were not fit for comparative analysis (Sarioglan & Gedik, 2020; Skelton et al., 2018). However, all 14 achievement-related studies showed significant achievement growth for students that learned through inquiry. The three studies that did not show a statistically significant difference when compared to the control group still found inquiry-based learning to be an effective approach (Bezen & Bayrak, 2020; Panasan & Nuangchalerm, 2010; Shi, Ma, & Wang, 2020). One study demonstrated a statistically significant growth in student epistemology (Shi, Ma, & Wang, 2020). The studies were further divided to measure the effectiveness of inquiry-based learning at different educational levels. For the purposes of this review, elementary school was categorized as kindergarten through fifth grade, secondary school represented grades six through 12; any following education was designated as post-secondary. At the elementary level, only fourth and fifth grade classes were included in this review. These levels were appropriately adjusted for international descriptors of school level.

Elementary Implementation

This review included five studies occurring at the elementary level (Abdi, 2014; Feyzioglu & Demirci, 2021; Maxwell, Lambeth, & Cox, 2015; Panasan & Nuangchalerm, 2010; Zhao et al., 2021). Three studies researched the impact of inquiry-based learning on academic achievement and showed statistically significant growth for the population (Abdi, 2014; Panasan & Nuangchalerm, 2010; Zhao et al., 2021). The study conducted by Panasan and Nuangchalerm (2010) was the lone study in this section of the research that did not demonstrate a statistically significant difference when comparing student growth to the control group. There may have been underlying significance, as this study compared inquiry-based learning to project-based learning. Panasan and Nuangchalerm's (2010) study was unique in that regard; the data showed the effectiveness of inquiry-based learning on the academic achievement of elementary school science students.

The other two elementary studies were conducted to measure engagement and to determine the best utilization of inquiry-based learning (Feyzioglu & Demirci, 2021; Maxwell, Lambeth, & Cox, 2015). Feyzioglu and Demirci (2021) determined through qualitative data that student engagement increased when inquiry practices were implemented. Maxwell, Lambeth, and Cox (2015) found that students' attitudes toward science improved when practicing inquiry. The combined elementary studies were conducted using life science and physical science topics.

Secondary Implementation

Secondary science studies also showed significant growth following the implementation of inquiry-based instruction. The majority of the studies included in this review were conducted at the secondary level. In fact, 22 studies in this review involved the content areas of agriculture, STEM, Chemistry, Physics, and Biology. Nine of these studies measured the impact of inquiry-based learning on the academic achievement of students (Bezen & Bayrak, 2020; Kacar & Balim, 2021; Korkman & Metin, 2021; Maknun, 2020; Nopiya, Hindriana, & Sulistyono, 2020; Qamariyah et al., 2021; Sahintepe, Erkol, & Aydogdu, 2020; Sarioglan & Gedik, 2020; Skelton et al., 2018). Of those nine studies, six showed statistically significant differences between an experimental inquiry group and the control group (Kacar & Balim, 2021; Korkman & Metin, 2021; Maknun, 2020; Nopiya, Hindriana, & Sulistyono, 2020; Qamariyah et al., 2021; Sahintepe, Erkol, & Aydogdu, 2020). The only comparative analysis study that did not show statistical significance between compared groups was the study conducted by Bezen and Bayrak (2020). However, this study did show a statistically significant level of growth for students who learned through inquiry, but the results were not significantly different from data that measured the growth of students in the control group. The two remaining studies were not conducted using comparative analysis, but also reported effective use of inquiry practices (Sarioglan & Gedik, 2020; Skelton et al., 2018).

This review also included five studies focused on the effectiveness of inquiry-based learning in engaging students (Baldock & Murphrey, 2020; Kaya & Avan, 2020; Luft, 2001; Sever & Guven, 2015; Streich & Mayer, 2020). The studies centered on inquiry implementation showed a common trend of a learning curve for the teachers in how to effectively implement inquiry-based learning. Baldock and Murphrey (2020) acknowledged that students self-reported the benefits of inquiry-based learning. Common themes included critical thinking, problem solving, and engagement. The remaining eight studies were conducted to determine proper utilization of inquiry-based learning practices (Attard, Berger, & Mackenzie, 2021; Bernard, Dudek-Rózycki, & Orwat, 2019; Dolenc, Beaulieu, & Sheppard, 2020; Dunn & Ramnarain, 2020; Nunaki et al., 2019; Putri et al., 2021; Rahmat & Chanunan, 2018; Sarioglan, 2021). Impactful results centered around the implementation of inquiry-based learning for students of all achievement and engagement levels, as well as determined effectiveness across gender and cultural differences. One major point of study was to determine whether the implementation of inquiry-based learning in virtual settings was effective. Three studies were conducted on this topic (Dolenc, Beaulieu, & Sheppard, 2020; Dunn & Ramnarain, 2020; Putri et al., 2021). All three studies found that inquiry-based learning was still effective in the virtual setting. These findings included fully online courses as well as virtual labs conducted in person. Two final studies measured the effectiveness of inquiry-based learning on different student groups (Nunaki et al., 2019; Rahmat & Chanunan, 2018). Nunaki et al. (2019) found that inquiry-based learning remained effective across gender differences using both quantitative and qualitative data. Rahmat and Chanunan's (2018) study showed benefits across all academic achievement levels.

Post-Secondary Implementation

This review also includes five studies conducted at the post-secondary level (Archer-Kuhn et al., 2020; Bayram et al., 2013; Gormally et al., 2009; Shi, Ma, & Wang, 2020; Smallhorn et al., 2015). These studies were conducted in the science disciplines of biology, physics, and chemistry. One study conducted in a social work course was also included to measure engagement and motivation. The studies conducted by Gormally et al. (2009) and Shi, Ma, and Wang (2020) determined the effect of inquiry-based learning on achievement. Gormally et al. (2009) found a statistically significant difference between the control group and the inquiry-based experimental group. Shi, Ma, and Wang (2020) did not find a statistically significant difference between their control and experimental groups, but both groups did show a statistically significant increase in achievement. This suggests that both methods used were effective in their implementation, but neither stood out as being more effective.

The study conducted by Archer-Kuhn et al. (2020) determined the effectiveness of inquiry practices on engagement and motivation at the post-secondary level. Their qualitative results identified that students increased both their reflective and integrative learning as well as stronger higher-order learning skills. The two remaining studies were conducted to determine the ideal utilization of inquiry-based learning at the post-secondary level (Bayram et al., 2013; Smallhorn et al., 2015). Both studies identified the benefits of redeveloping curriculum to fit an inquiry-based learning environment. Smallhorn et al. (2015) discussed the significance of developing student-centered learning that focuses on forming and asking questions related to evidence. The studies agreed in their recommendation of implementing inquiry-based learning in science courses. Bayram et al. (2013) claimed that inquiry is particularly effective in cultures with a constructivist approach. Smallhorn et al. (2015) added that the inquiry-based principles may be effective across disciplines due to the questioning and higher-order thinking skills developed.

Professional Application

A student-centered approach to learning should focus on preparing students for their future ahead. STEM-based jobs are increasing significantly (Skelton et al., 2018). This makes the need for scientific skills important in preparing students for the world ahead. Studies have shown that inquiry-based learning can be used to strengthen students' STEM-based skills in a classroom setting (Attard, Berger, & Mackenzie, 2021). This is logical, as the facets of inquiry-based learning allow for genuine practice of skills central to the scientific method. The impact of practicing the scientific method along with critical thinking and questioning should prepare students for a global society increasingly reliant on STEM-based professions.

Many districts, including my current district, have increased their utilization of technology. Any new practice must be analyzed to measure its effectiveness in the current educational setting. Inquiry-based learning has been found to be successful in technology-based classroom settings (Dunn & Ramnarain, 2020; Putri et al., 2021; Sever & Guven, 2015). For an evolving society, inquiry-based instruction is adaptable to fit the needs of students. There are an increasing number of virtual labs and activities that can be utilized in science classes that allow students to experience topics that they may not otherwise be able to experience. There can be difficulty in creating inquiry-learning opportunities through virtual labs, but the benefits of this practice are still present. Differentiating instruction to meet the needs of all students is another difficulty. Inquiry-based learning has shown the ability to support a variety of student needs (Rahmat & Chanunan, 2018; Sever & Guven, 2015). It has been utilized effectively to benefit student engagement, lower the number of negative behaviors, and provide growth for students of all prior achievement levels. While implementing an inquiry-based lesson to support a variety of student needs takes preparation, the needs of many students can be met.

Limitations

The studies represented many different backgrounds, content areas, and student needs. Students included in the studies ranged from late elementary school through graduate-level studies. Multiple scientific content areas were also represented in the data. However, this variety did not represent all groups. The studies included were mainly conducted in eastern Europe and eastern Asia, with few studies conducted in the United States. The studies in the United States were completed in a limited geographical area that may not be representative of the US population as a whole. The practice of inquiry-based learning may be represented differently in the unrepresented groups. Additionally, only six studies were conducted using Biology topics (Abdi, 2014; Gormally et al., 2009; Nopiya, Hindriana, & Sulistyono, 2020; Rahmat, & Chanunan, 2018; Smallhorn et al., 2015; Streich, & Mayer, 2020). Of these six, only three were conducted at the high-school level (Nopiya, Hindriana, & Sulistyono, 2020; Rahmat, & Chanunan, 2018; Streich, & Mayer, 2020). While the approach and implementation of inquiry-based learning is equivalent in other science courses, they are not represented in the review.

Certain topics were excluded from the study. While there is a significant overlap in practices between inquiry-based learning and project-based learning, differences in the approach of project-based learning may have misrepresented inquiry-based learning. Project-based learning can often fall under the category of structured inquiry and with the focus on project rather than inquiry, inquiry-based practices may unintentionally be omitted. Project-based learning also has a tendency to focus on outcomes, while inquiry-based learning places the focus on process.

Implications for Future Research

Studies included in the research were conducted over periods of time typically ranging from one to eight weeks (Maxwell, Lambeth, & Cox, 2015; Skelton et al., 2018). One study included research over multiple years (Nunaki, Kandowangko, & Nusantari, 2019). It would have been helpful to have had studies that measured the long-term impact of inquiry-based learning on student achievement. Some studies did utilize retention tests, but these were typically measured over a shorter period of time (Korkman & Metin, 2021; Streich & Mayer, 2020). Future research conducted in a variety of regions in the United States would also be beneficial. The majority of the studies were conducted in eastern Europe or eastern Asia. While the practice of inquiry-based learning shows strong promise in the usefulness of its implementation, additional research is needed supporting its use in the United States.

Additional research is also needed to support the use of inquiry-based learning in different content areas. The majority of the completed studies were completed in chemistry and physics. While there are similarities between the content areas in their scientific approach, vocabulary across content areas is quite different and needs the support of additional research. Biology is one science course in particular at the high-school level that is underrepresented in the research. Research completed in different content areas may also lead to studies on the impact of inquiry-based learning on other content-specific practices. Research on the effective growth of scientific literacy or collaboration could also benefit the application of inquiry-based learning.

One major point of study in regard to inquiry-based learning is the impact of the three types of inquiry: structured inquiry, guided inquiry, and open inquiry. While the type of inquiry was included or implicit in each study, there was a significant void of research in comparing the utilization of the different types of inquiry. This avenue of research could open an entirely new approach in how inquiry-based learning is utilized in the classroom. If each type of inquiry shows different strengths and weaknesses, instructors could intentionally design class content around the needs of students that utilize the strengths of each inquiry style. This could lead to a streamlined inquiry model that provides students with the most effective approach for each learning goal.

Conclusion

The goal of this review was to measure the impact of inquiry-based learning on students in a science classroom. This research revealed three main points: academic growth, student engagement, and inquiry-based learning utilization. Overall, inquiry-based learning shows a positive relationship with students' academic growth and engagement. It encourages students to practice the innate scientific skills of critical thinking, questioning, and observation. This growth was consistently present across many ages and backgrounds. Results showed benefits in improving student engagement and limiting negative behavior. Studies that focused on proper application of inquiry-based learning showed that teachers may struggle initially with implementing inquiry practices, but successful implementation was achieved after practice. Once teachers felt comfortable with the practice of inquiry-based learning, they were encouraged by the growth in achievement and engagement. Inquiry learning in schools is becoming more common, but more research is needed to isolate the benefits of each type of inquiry. Future research can benefit students and instructors by improving the already existing strengths of inquiry-based learning and shaping inquiry instruction to fit specific student needs in a variety of settings.

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