Using Inquiry-Based Learning to Improve Student's Critical Thinking and Problem-Solving Skills in Science

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A capstone paper submitted to the Department of Education and Human Development State University of New York (SUNY) Brockport in partial fulfillment of the requirements for the Degree of Master of Science in Education December 2023

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Chapter 1: Introduction

Problem Statement

Society has reached a point where innovation, discovery, and change are happening all the time. This is especially true in the field of science, technology, engineering, and math (STEM). As we continue to see the growth of STEM, teachers need to adapt their practices to best prepare students. Traditional methods, that are teacher centric with passive learning completed by students, are no longer feasible. These methods are not engaging and do not interest the students in the learning method. One type of teaching that has grown in prevalence and usage is inquiry-based learning (Makamu et al., 2022). With the implementation of inquiry in classroom and laboratory settings, learning becomes more active for the students as they are engaged in more real-life examples and can try multiple methods rather than trying to reach one set answer (Jeon et al., 2021). The students are now at the center of learning, which allows for greater depth of knowledge and overall growth.

As innovation in STEM continues, factual knowledge should no longer be the sole focus in science education. Students need to develop skills that can be applied both in school and once they exit school. These skills, describe as 21st-century skills, are highly important as they include critical thinking, problem solving, communication, collaboration, creativity, and technology use (Baran et al., 2021). By developing these skills and many others in science class, Panjaitan (2020) shares that students will be able to work with others in all disciplines to create effective solutions. By implementing hands-on inquiry learning students will have the opportunity to develop a wide range of skills and in an environment that has room for improvement. An additional way to create even more authentic skill development is the use of inquiry that has real-life connections. The development of skills in a vacuum with discrete segments of knowledge is ineffective. By implementing socio-scientific issues (SSI), along with other real-world examples, the students must weight their knowledge as well as the implications of the final solution (Qamariyah et al., 2021). The ability to consider all solutions and critically examine not only the solution but also its short and long term repercussions is a vital necessity in the interconnected world we live in.

Teachers need not limit themselves when considering inquiry methods. Inquiry is an umbrella term that describes a broad range of methodologies. The first way inquiry can be broken down is into varying levels of student control. Inquiry can be constructed, guided, or free (Duran et al., 2016). In these approaches, the amount of freedom and opportunity to lead their own learning varies. A teacher must decide which method is best for the content and age of the students, such that their learning and skill growth in highly supported. This means that the teacher must determine prior student experience with inquiry and possibly build their way up to free inquiry. An additional aspect of inquiry to consider is the methodology implemented. Some examples of inquiry include problem-based learning, project-based learning, simulation-based learning, and inquiry through hands-on local or real-life applications. These methods can be used in congruence as each method may work best for specific topics or applications.

Given the need for more hands-on, active learning in science with real-world connections, lessons and curriculum need to be developed to allow teachers to step away from traditional methods that are limited to textbooks and worksheets. This can be a daunting task and very time-consuming as it can be considered a revitalization of the way science is taught. The overall goal of this capstone project is to develop a set of lessons that implement inquiry learning methods in high school environmental science to help students grow in 21st-century skills, especially in critical thinking and problem solving.

Significance of Problem

This problem is significant as it can help both the teacher and the students in a classroom. Examining the teacher's perspective, the goal of teaching is to help students grow and develop. The purpose of teacher any science class is not for students to memorize material just to get a good grade. The teacher is striving to get students interested and engaged such that they can take their new knowledge with them and apply it to experiences they have had or will have. This strive to create a rich body of knowledge comes with the mindset that not all students will go onto become scientists and engineers, but having the deep body of knowledge and strong skill set can be a life-long benefit for all citizens of our society.

Considering the student perspective, there is often a hyper focus on just getting a good grade or just getting an assignment done to check off a box. This can be amplified when the students are passively learning. By being exposed to more active learning methods, the students can build interest and engagement with the topic as they are leading their learning. They have more say and control in the steps and outcomes. While at first, students may resist this new level of responsibility, as they may just see it as more work they have to do, through time and connection to the material they can become student scientists who come to class excited and ready to explore each day.

My overall goal is to help my students build connections and skills. I want to push my students to work hard and make discoveries such that they can see the benefits of science, especially when it may not be easy. Through engaging, active learning methods, the student's ability to think critically and problem solve can be developed. These skills are especially valuable in class but overall, in life and can help them prepare for whatever path they may follow.

Rationale

The rationale behind this project comes from my experience as a substitute teacher and as a full-time science teacher. In observations I have made, students often look at assignments almost like a check list that they must complete. This leads to them just getting it done because they must. Additionally, keeping in mind the check list idea, many students often struggle or ask for help if they cannot immediately find an answer. When questions do not ask for rote facts, they can struggle with connections and recalling prior knowledge. By implementing more student centric learning models, I hope to build student's critical thinking and problem-solving skills such that they have the power to persevere through any challenges to find an answer or reach their end goal.

Significant Terms

Inquiry-based learning, defined by Abdi (2014), is a method that allows students to become more engaged and involved in their learning. Additionally, Mutlu (2020) explains that inquiry requires studetns to use their science skills.

21st-Century Skills are skills that studetns need to possess as the world continues to grow and advance (Baran et al., 2021). Many skills fall under this category, and they can be developed in many ways but through science education teachers can help students grow in these areas.

Critical Thinking Skills are one of the many 21st-centrury skills students need. Sutiani (2021) explains that critical thinking skills allow students to apply and transfer information and abilities to new subjects, problems, and examples. This ability of transference is critical to using knowledge that is developed in science classes.

Higher Order Thinking Skills are very similar to 21st-century skills and often include similar skills. Higher order thinking skills promote students to think both critically and creatively to solve problems (Qamariyah et al., 2021).

Chapter 2: Literature Review

Introduction

As the world continues to grow and change, teachers need to make sure that they are educating students to be the best prepared version of themselves. This means that education needs to shift from teacher-centric, passive learning where students are meant to absorb and take in knowledge to a model where learning is student-centric with active learning that allows them to grow in knowledge and skills. By developing skills, in conjunction with knowledge, students can apply prior knowledge and link new information to past experiences such that they can be successful in solving problems. The ability to connect new and old information is especially important as we continue to see societal innovation so that as citizens, students can continue to be lifelong learners.

One method that can be used to develop skills and knowledge through active, student-centric leaning is inquiry. Inquiry-based learning gives students the opportunity to ask questions, explore ideas, and collaborate. This is especially important in science classes as students can begin to learn through true scientific methods rather than memorizing a list of facts and figures. With inquiry, the students no longer have a fixed way of acting and thinking, they become the driver of their learning. Rather than following a list of steps, depending on the inquiry style, the students have to define their own questions and set up the procedure to be followed. This increase in student participation will take their thinking outside of rote facts and require the use of specific skills. An additional benefit to inquiry is that is not limited to one single method or set of steps. Inquiry can be changed and modified to fit the needs of the curriculum and use a variety of tools and materials. This diversity makes inquiry increasingly appealing to both teachers and students. This increase in diverse materials helps teachers expose students to a greater wealth of knowledge. For students, the diverse materials make learning less monotonous and different from day to day. Overall, the change in pace and materials make learning more engaging, interesting, and active. With this combination, two specific skills that can be developed with inquiry are critical thinking and problem-solving skills.

Critical thinking and problem-solving skills can be developed in the science classroom and transferred over to other academic areas as well as life in general. These skills allow students the opportunity to take their knowledge from discrete experiences and make it applicable and useful with new ideas and events. Problem-solving skills are closely linked to critical thinking skills, as they allow students to again connect old and new ideas, but this time to reach practical solutions. By using both these skill sets together, the student can discover deeper knowledge and meaning that makes learning more relevant and impactful. This dual development allows for the greatest possible growth for the individual skills as well as the combination of the two skills. Individuals, small groups, and the whole class can grow in these skill sets such that students have the power to succeed across a variety of settings, topics, and group sizes. Critical thinkers and problem solvers can make changes and solve problems in the face of adversity no matter the specifics of the situation and therefore are key skills teachers can help foster within their students.

Overall, by implementing inquiry-based learning methods in secondary science classrooms, teachers have the opportunity to promote the greatest chance for success of their students. The students will have a change in their mindset. Rather than looking at an assignment as a job that has to be done or a box to check off, the students can find more meaning and connection with inquiry. By shifting away from lecture and simple worksheets to a variety of inquiry methods, the current and next generation of students has the opportunity to grow into strong critical thinkers and problem solvers that will be lifelong learners and support the continuous growth of our society. Teachers who implement inquiry in the science classroom have the strongest opportunity to push students closer to their future success rather than just focusing on shorts term academic knowledge.

Research Methods

The research that has been completed on inquiry-based science education uses a variety of research methods and analysis. The method that stands out as the most common general research method is quasi experimental methods that utilize a pre- and post-tests. A benefit to this method is the fact that there is comparison data to look at student skill level before and after the implementation of the desired educational teaching method. With the two sets of data, the researchers can see firsthand how results changed after the implementation within the classroom. This method of pre- and post-testing can be one with a singular group or for both a control group and the experimental group. In the case when both a control and experimental group are used, the data shows very clearly how the new inquiry methods impacted the students versus more traditional methods. When looking at just one group that is experimental only, the results are weaker as there is no baseline data to stack the new inquiry method against. When this type of research is done, the work does not stand up as strongly as the lack of comparison factor makes it harder to definitively say if the inquiry methods truly led to the observed change.

Another method used is research focusing on the student data. All but one study focused on the student’s outcomes and perspectives. Of the selected research, one study looked at teacher's actions with the 5E method and did not examine student work (Makamu et al., 2022). Outside of this study, the 26 other studies focused on the students, the work they did, and the overall results and scores they achieved. By focusing on the student outcomes, the researchers have the ability to look directly at the effect inquiry has on the students in the classroom. In many cases, comments or feedback were collected with academic based information for an even bigger wealth of information. This information coupled with the specific framework and research methods used in each study allowed for data to be quantified and analyzed to the fullest extent and withdraw as many final conclusions as possible.

The final research method portion that must be considered is the characteristics of the students. This area is especially important in determining the viability of the research such that it can be beneficial to the upcoming capstone project. The research covered students from a wide range of ages, content areas and locations. In terms of age, the research examined covered students from middle school all the way through college. No matter the age, the bulk of the work was done with students during the normal school year with a select few studies being completed outside of schools over breaks in enrichment programs (Kim, 2016). Considering the conclusions that were discovered, if the work was done properly and was centric on the methods used rather than over relying on the topic being covered, the conclusions learned at the middle school, high school, or college level should be applicable to other grade levels with little to no modifications needed. This allows for the transferability of the work from the researchers to other teachers such that the work done can be applied across classrooms rather than in isolated instances. This transferability is highly important and limited the search for research to students between the age of middle school to early college which gives a range of 11-19 years old. Not every student, especially the college aged students fell into this range, but this range gives the best chance for transference as the methods that work with high schoolers will have a high chance of working with middle school students. Additionally, greater efforts were put in to find more high school centric work as time went on to better support future capstone work. Any work done with students under 11 years old was excluded and not used in the research process as the methods that work well with elementary age students are different than those used in middle and high school. By realizing the intended audience, modifications and systematic selections of research was possible. The same rationale of transference could be considered for content area as well. While small shifts and changes may need to be made to make a lab or method more feasible from physics to biology to chemistry, the use of inquiry methods should be feasible in any STEM discipline. By allowing for the opportunity to transfer methods and results from grade to grade and class to class, teachers have the opportunity to share the work the researchers have completed with a much wider audience. By allowing for a broader audience to use the work, a greater number of teachers, students, and schools can reap the benefits of the inquiry methods.

The last part of the research methods to consider is the location of the study. Of the 27 studies examined, very few were conducted in the United States. Through more detailed searching, a few studies were found with students in the USA, but the bulk of the work consistently showed up international. This fact shows that educational research may be more heavily funded or supported in other countries. Additionally, it highlights how the education system in the USA is heavily focused on testing and achievement such that teachers may not feel that they have the opportunity to complete research in K-12 classrooms. The work done by teachers and researchers is highly beneficial and can be applied in US classrooms, however the structures and functions of schools in other countries can differ and may require a greater level of modification to the work done to make the method fully transferrable to the US-based classrooms. With greater research in US-based classrooms, especially in STEM classrooms that are beginning to fully implement Next Generation Science Standards (NGSS), science teachers can see the full strength of inquiry.

Inquiry

Inquiry-based learning is an opportunity to change the way science is taught. Through inquiry learning, students are at the center of learning, rather than traditional methods where they are passively learning from the teacher (Esref et al., 2021). This active requirement changes the way students learn as they are not sitting on the sidelines. Given that this style of learning is more student-centric, the students are more active and engaged in the learning process (Jeon et al., 2021). Additionally, in inquiry-based learning the active nature makes it so that learning through phenomena creates an excitement and energy within the students that pushes them to be curious and aware metacognitively such that creating connections is at the forefront of their mind (Esref et al., 2021). With this boost in creativity and awareness for both prior and new knowledge, the students have opportunity for growth across many areas.

Another facet of inquiry-based learning is that it is not limited to one method. A variety of methods can be used in inquiry to help students learn. In most cases of inquiry, learning is not only hands on, but it includes more authentic and real-world connections (Maxwell et al., 2015). This pursual of more authentic work leads to application-based information and prompts (Omotayo et al., 2017). Through this application nature, teachers are helping students construct knowledge that can be useful for both themselves and others. Teacher can bring in socio-scientific issues to the classroom (Qamariyah et al., 2021). Additionally, the incorporation of lab work increases the application of knowledge and connection to authentic work. Through inquiry, labs lose their cookbook, stepwise nature (Huang, 2022). The removal of specific and compartmentalized steps allows for greater exploration and more authentic, real-world oriented lab work that better supports students. In science classrooms specifically, the connection to authentic examples can be seen all around us in the world and therefore helps to build connections both inside and outside of the classroom. The dual nature of authentic learning and active, engaging work makes inquiry a great method to use in science in both the classroom and lab setting.

Inquiry methods are also not limited just to curriculum specific content. Inquiry can be done to enrich and expand a student's mindset and skills. This enrichment can happen in the classroom as supplemental lessons or through specific enrichment programs and seminars (Kim, 2016). The work of Kim (2016) reveals the overall importance of inquiry education, especially for middle school age students. No matter the setting, in school or in other programs, exposing students to inquiry is a highly positive experience and should be done as much as possible.

Inquiry Methods

5E Inquiry Method

One specific application of inquiry is the 5E model. In the 5E model, students are asked to engage, explore, explain, elaborate, and evaluate information (Omotayo et al., 2017). These five steps give students the opportunity to have greater input and planning in the topics that are explored (Abdi, 2014). When considering the 5E model in comparison to other more traditional methods, researchers have discovered positive results. Students exposed to 5E saw greater learning benefits than those not exposed to 5E (Abdi, 2014). This greater benefit can be associated with the greater involvement of the students. This ability to have greater input as well as greater involvement during the actually learning makes this method very engaging. This increase in engagement makes learning more interesting for the students to take part in.

Throughout the five steps, students are busy exploring, investigating, and using evidence so that in the end they can apply evidence to support and prove their conclusions (Makamu et al., 2022). In the final two steps, elaborate and evaluate, the students can elevate their knowledge from simple ideas and facts to evidence that can be applied to the present and future examples. With this application, the student is no longer acting as a sponge, trying to absorb and take in the information, but rather they are searching out the information themselves such that it can be discovered and applied.

Project-Based Learning

Project-based learning is a second type of inquiry-based learning. In project-based learning, students are often exposed to meaningful and real-life topics (Syifahayu, 2017; Baran, 2021). The authentic element means that teachers can push students to connect the classroom with the real world. By pushing this angle, the students are able to shift from looking at information as discrete pieces of knowledge to seeing information all around them (Baran, 2021). This connection allows for deeper understanding and the opportunity to build new relationships with the knowledge. This building of new relationships leads to the use of creativity and critical thinking skills (Anazifa et al., 2017). The use of creative and critical thinking skills is important for long term life skills and is not limited just to science class. By developing skills that have broad reaches, science teachers can develop students who can be successful across any directions their life may go. Shifting away from facts and making work project oriented, such that it fulfills a task or begins to fill a gap in the world, is a way to push students to make connections to the world outside the classroom. Without such connections, inquiry loses meaning and connection to the students.

Problem-Based Learning

Similar to project-based learning, problem-based learning is another inquiry method. In problem-based learning, students have the opportunity to work on devising practical solutions that require students to consider time management (Alsarayreh, 2021). With practical solutions, especially for secondary students, the learning outcomes become less abstract. Additionally, the development of practical solutions allows students to grow in creativity and critical thinking. This goes hand in hand with reducing the abstract nature of knowledge as it builds more meaningful connections. Often times students will miss the connections between themselves and science. Science is all around us, students just need the tools and experiences to open their eyes to the connections. One field that can specifically benefit from problem-based learning is biology. Many applications of biology, especially connected to people, animals, and health, have some of the most easily visible connections. One area specifically is the connection between body systems and medical conditions people can have or develop (Wulandari et al., 2022). By introducing real life concepts with problem-based inquiry methods, the students can become experts on tangible ideas and topics that they can currently connect with or one day in the future connect with. The more teachers use real-life connections and examples, the greater the chance for development of student skills (Suprapto et al., 2017). Through inquiry methods like problem-based learning, students can be presented with direct examples of science on small and large scales. These direct examples will act as a launch point to help them take their classroom knowledge out to the real world.

Simulation and Technology Inquiry

As the world progresses, advancements are happening in science and technology at alarming rates. As advancements continue to arise, teachers must be aware of the growing demand for students to be able to use technologies for their benefit. One-way teachers can do this is through apps and simulations. Online simulations can be very beneficial in the classroom. For science teachers, two major benefits can be drawn out. The first benefit of simulations is the growth of skills and knowledge (Ogegbo et al., 2022). By using simulations, knowledge can be built as well as skills. Additionally, simulations in conjunction with specific inquiry methods can promote collaboration, connection building, and the use of prior knowledge (Makamu et al., 2022). The second benefit of technology is the fact that simulations can be used for content that is very abstract, in times when access to real equipment is not feasible or too expensive, or when there are not proper safety factors in place. Another approach teachers can use with simulations is combining it with specific inquiry methods. One specific method that can be completed with simulations is POGIL (Bennett et al., 2020). The use of guided inquiry methods such as POGIL with simulations can lead to even stronger benefits than inquiry through simulations alone (Bennett et al., 2020) In any of these scenarios, most other inquiry methods may be off the table when learning is more abstract and cannot be easily visualized, but with simulation inquiry the benefits can still be imparted onto the students. This opportunity makes simulations a great asset for teachers to pull upon.

Another technological inquiry opportunity is apps. The introduction of apps gives way for more engaging and interactive learning in the classroom (Baharom et al., 2020). Students are exposed to app-based technology in many ways throughout their lives and often from a young age. By incorporating them into the science classroom, this is not only a familiar technology, but it is also a skill that can be carried on with them as they get older. Drawing on their prior experiences, bringing apps into the classroom can cut down on the learning curve that may be associated with other technologies that students have less experience with. This means that the relative understanding and familiarity of apps can be a simple and effective application to incorporate with students where they are taking the lead on their education. Another emerging technology that is making its way into the personal and educational lives of students is alternate reality and virtual reality games and devices (Liang et al., 2021; Tsivitanidou et al., 2021). Through these realities, students can experience apps in new and more immersive ways. This immersive technology can be utilized at home, in schools, and in community educational locations, such as museums, to help students grow and learn (Liang et al., 2021). This can be especially helpful in physics where "seeing" what is going on is not always possible as the content becomes more intense (Tsivitanidou et al., 2021).

As technologies advance, the use of apps, simulations, games, and technology-based tools and devices will be critical for students. Through exposure in educational, inquiry-based settings, students can see the connection between learning and fun. Teachers can bridge the gap the exists between learning and fun activities more easily. Rather than seeing school as boring and stuffy and apps as mindless games to play, linking the two entities together can lead to many benefits for both teachers and students such that learning can advance as the world advances.

Impacts of Inquiry on Students

Impact of Inquiry on Achievement

Achievement is an area of schooling that is constantly examined by schools and governments. Each year data is collected to check achievement scores across content areas and grade level. Additionally, countries are ranked based on their student's achievement scores. When countries do not succeed as they expected, changes may be made to curriculum or standards. On an even smaller scale, when a teacher notices that his or her students did not perform as well as expected on an assignment or an assessment, more time may be spent on the topic or new techniques may be used. This practice of changing curriculums, standards, and using new techniques in the classroom to improve achievement has happened with inquiry-based learning. After traditional methods have shown poor results, pushes have been made to go to more inquiry-based methods.

Abdi (2014) compared results of achievement in science after the use of inquiry and traditional methods. It was determined that using inquiry, specifically the 5E model, showed higher achievement levels in students (Abdi, 2014). The results received greater confirmation when Omotayo et al. (2017) also found that the 5E model had significant impact on student achievement, this time in math. These results highlight the benefit the 5E model can have on student achievement. 5E is not the only method to show positive impacts with achievement. The use of technologies, including apps, has shown positive impacts on achievement in science and gives researchers the confidence to recommend the use of apps and other learning technologies in the classroom as it supports greater achievement than non-inquiry-based methods (Baharom et al., 2020). The use of multiple inquiry methods has shown that achievement can be bolstered in greater capacity than with traditional methods. For teachers, schools, and curriculum setting boards, an increase in the use of inquiry methods is an opportunity to see higher achievement that is consistently being pushed for.

Another inquiry method that has shown positive impact on achievement is simulations. Using interactive simulations has shown to significantly impact achievement results when compared to traditional method (Ogegbo et al., 2022). Not only was this impact significant but it was also large (Ogegbo et al., 2022). Bennett et al. (2020) also noticed the positive impact simulations had on students. By using PhET simulations with POGIL, the students exhibited large growth in content knowledge (Bennett et al., 2020). With the implementation of PhET and

POGIL the students have the chance to learn with multiple representations that include the opportunity to interact with the pictures and visuals that are provided (Bennett et al., 2020). This highly interactive and manipulative method allows students to become more fully immersed in their learning which promotes greater content knowledge. This use of technology can increase the ability of students just like the 5E model and apps can. This highlights the success of inquiry as there are many methods that can provide the same type of benefits in the classroom. This gives teachers variety in the methods they can employ and choice in the method best suited to the students and the content that is being covered. In times when 5E is not feasible, simulations or apps can be used to improve achievement.

Another area of learning and achievement to consider is scientific literacy. Scientific literacy is a critical area of learning and achievement. With strong scientific literacy, students can recognize where they can convert their high achievement to application of information. An additional facet of literacy is that it allows for the development and use of other skills in science (Duran et al., 2016). With the study of environmental issues, inquiry through project-based learning has the opportunity to make students increasingly aware and literate on topics in their community and the world (Syifahayu, 2017). By exploring through real life projects, the students can take their strong background and apply it through collaboration and teamwork. Without the combination of achievement and literacy, the students would have trouble transferring knowledge. By implementing inquiry, both achievement and literacy can improve such that students can explore and connect with meaningful, world science topics.

Impact of Inquiry on Student Attitude

Teachers have many goals for their students. Each of these goals is not purely academic. In science class, teachers want to draw their students in to see the wonderful world of science that is all around them. Often times, especially in middle to high school, as science courses become more specific and detail oriented, students can start to experience hardships and consider science to be too hard. As teachers, the goal is to keep students interested and invested such that they can grow up to either work in a scientific field or simply be a lifelong learner open to sharing and discovering. To foster future scientists and lifelong learners, teachers need to build up student's overall attitudes and opinions of science.

Inquiry-based learning has been shown to increase student attitudes toward science (Omotayo et al., 2017). Mutlu (2020) found in their work that over the course of inquiry-based work students became more favorable to science and concluded with positive statements. Additionally, even in groups that experienced high levels of stress in inquiry, the majority of the students reported positive opinions and attitudes towards science and inquiry methods (Jeon et al., 2021). This high level of positivity, especially in the groups that were very stressed, shows how strongly inquiry impacts student opinions. The ability to engage and work through the process such that they are driving their own work is a big factor in this conclusion. The ability to have a say and be involved gives a greater sense of control and power which allows for a greater feeling of satisfaction when the work is done. Through the power of engagement, inquiry can turn tides and make students more positively inclined to science.

Another portion of attitude that is important to acknowledge is student consensus or agreement. Isdianti et al. (2021) examined the level of consensus among students after exposure to inquiry. In the questionnaire data that was collected, it was revealed that agreement between students ranged in value from 77 to 95 (Isdianti et al., 2021). These values reflect percentages of students who agreed to the questions on the questionnaire. With the lowest score falling at 77, this shows that even in times when there was not complete consensus, the responses still show

how the majority of students were in favor or agreement on the topic. Additionally, on the high end, 95% of students agreed and therefore shows almost full consensus of results. Taking this number range into consideration, teachers can see that inquiry is a highly favored method from the student perspective. Not only can teachers reap the academic and skill benefits of inquiry, they can also benefit from students who are engaged and interested in the methods being implemented. This level of engagement and interest can be challenging to instill and maintain, especially as secondary science classes become more intense and challenging.

A third attitude related portion to consider is that not all students hold the same attitudes towards science and prior experiences can influence attitudes. Huang (2022) examined novice and experienced learners to see how inquiry-based lab work impacted the outcomes for the two types of learners (Huang, 2022). It was determined that prior experience can impact attitudes. The novice students who held prior negative views saw greater changes in attitude and other growth areas than the experienced learners with inquiry (Huang, 2022). This highlights how inquiry can be helpful for teachers in helping narrow the gap between students with rich levels of experience and those with moderate or weaker levels of experience. Now it is important to note that the two groups of students saw different gains. Tsivitanidou et al. (2021) also examined attitudes between different groups of students. In their work it was discovered that with the implementation of virtual reality that all students experienced gains, but the gains differed based on the students preestablished notions on STEM (Tsivitanidou et al., 2021). Those who entered with higher positive attitudes saw a greater degree of growth than those who originally had lesser opinions of STEM (Tsivitanidou et al., 2021). While this is not surprising, as even outside of inquiry students with more interest typically see higher performance or enthusiasm for a class, it is important to note. While all students have the chance for attitude growth with virtual realities, the impact is universal in the positive direction with varying magnitude of growth. These notes highlight the need to have scaffolding and differentiation built into inquiry (Huang, 2022). By using inquiry and building in support for all learners, teachers can build up the attitudes of all students. While growth will vary, growth in attitude in the positive direction is a benefit inquiry can produce across individuals as well as small groups and whole classes. This growth in attitude can help contribute to bringing all students to their highest level of success, as growth is a personal journey for all students.

Impact of Inquiry on 21st-Century Skills/Science Skills/Higher Order Thinking Skills

A major area of development for students is in their skills. The development of knowledge is important, but the development of skill will allow students to be successful in both the short and long term. These skills can be described as 21st-century skills, science skills, or higher order thinking skills. No matter what title these skills are given, promoting and instilling these abilities into students can follow them out of school and into the workforce (Anazifa et al., 2017). Fuad et al. (2017) suggests that critical thinking is one of the most important skills a teacher can promote. This sentiment is seconded by Alsarayreh (2021) and Samba et al. (2020) who both suggest the development of critical thinking as well as creativity.

With inquiry, Samba et al. (2020) discovered that critical thinking increases with graphics organizers and experiential learning. Project-based learning has also yielded skills benefits as Baran et al. (2021) discovered that using this inquiry method in STEM resulted in positive post-test results in favor of skill development. Panjaitan et al. (2020) saw that students grew in process skills and creativity and that the usage of process skills caused students to implement greater levels of creativity. Additionally, Sutiani et al. (2021) discovered that inquiry-based learning led to students having very good classifications across multiple critical thinking skills in both portfolios and when comparing pre- and post-test scores. The ability to portray this skill across methods and assessment types reflects highly on the inquiry methodology. Duran et al. (2016) expands on why inquiry impacts critical thinking skills so strongly. The ability for students to become so involved and ask questions, without having to simply accept facts at face value, like they often do in passive learning, gives inquiry-based learning an edge over other methods (Duran et al., 2016). This ability to ask questions, get involved, and apply critical thinking grows even more with real life applications. Bringing in real life medical conditions when studying the circulatory system and its function proved to successfully impact critical thinking skills (Wulandari et al., 2022). The use of guided inquiry methods allowed students to successfully grow in critical thinking skills in the work they completed.

Another inquiry pathway that has shown success with critical thinking skills is alternate reality games. Liang et al. (2021) found that alternate reality games coupled with concept mapping promoted greater critical thinking skills than the games without the concept mapping portion. This combination shows that giving students the opportunity to explore and then use concept maps to organize their ideas allows for greater connections than those who just had the game (Liang et al., 2021). By taking a new piece of technology and coupling with a tried-and-true learning tool of concept mapping, the students can see that games can be fun and help them grow in skills. School work does not need to be limited to projects and inquiry-based worksheets, it can be immersive and engaging through multimedia sources. This promotes the ability to critically think and apply knowledge across mediums. Looking at the results combined, the use of inquiry has a high positive impact on student skills, with critical thinking as a skill of great emphasis as the student have the ability to highly engage with the material, A second skill of high importance that is often connected to inquiry is problem-solving skills. Baran (2016) discovered that the use of project-based learning helped the development of problem solving. Through struggles and challenges, students must work together to reach practical solutions. This struggle and extra effort allows for the development of problem-solving skills (Baran, 2016). Suprapto et al. (2017) also reached the conclusion that inquiry can improve problem solving, however the methods used were problem-based instead of project-based inquiry. By incorporating problem-oriented work, students performed higher than those who were exposed to conventional methods (Suprapto et al., 2017). This difference in performance was very large and highlights how real-world oriented examples motivate students to use problem-solving skills in a collaborative setting (Suprapto et al., 2017). Both these inquiry methods, of project- and problem-based learning, are an especially strong ways for inquiry to develop problem-solving skills as real world problems and applications are not always simple and easy. By working through challenges in the classroom setting, the students have a chance to develop these skills in a closed environment rather than needing to develop them on the fly when they are in a real-life situation.

21st-century skills may be the strongest area for teachers to focus on in hopes of pushing their students to be successful in their future endeavors. By using inquiry, the benefits are wide and immense, but show the highest promise in the area of higher order thinking skills which can be used for the rest of the student's lives. By using socio-scientific issues the connections begin in the classroom (Qamariyah et al., 2021). These beginning connections will only continue to grow and develop through greater inquiry and experiences in life.

Conclusion

Inquiry-based learning is a method that can be incorporated into education to better prepare students for future success. Examining the methods traditionally used in classrooms, with a specific focus on science classrooms, the traditional methods used for a long time no longer cut it. The shift to inquiry is needed across all levels of secondary science education.

Inquiry is a hands-on method of learning that actively involves the students. Through a variety of methods of inquiry, teachers can integrate many strategies and benefits. Some highly beneficial methods include 5E, problem- and project-based learning, and online and digital technologies with inquiry. In all these methods, the student is not passive in their learning. They can take the wheel and direct the process they follow. This ability to be engaged with applications and real examples leads to a long list of benefits. These benefits are also not limited to one inquiry method. Each inquiry method can be used based on the circumstances of the students, content, and the school to elicit more than one benefit. No matter which method or which combination of methods is implemented, the teacher and students will see positive growth.

Two major benefits of inquiry include increases in achievement and attitude. Achievement and attitude are areas that can wane for secondary students, and they are often interconnected. As a student progresses further into harder course work, achievement may slip and difficulties may lead to negative feelings. However, with greater implementation of inquiry, teachers can help students maintain and also improve their success and interest in science. The hands-on nature allows science to feel more personal rather than generic and disconnected. This will help students to continue to strive towards personal success and interest. By seeing the connections that are present between classroom content and the world around them, the classroom opens up right in front of the student’s eyes. These two benefits are major wins to keep students interested in science even as it gets harder, but there is one other area that exhibits even larger gains from inquiry.

The area that leads to the biggest inquiry benefits are 21st-century skills. These skills are crucial to developing the future of our society. Two of the most prominent skills that inquiry develops are critical thinking and problem-solving skills. By exposing students to active, collaborative, real-world applications of science, teachers help students build their knowledge and skills simultaneously. This simultaneous building will help students to become citizens who can make major contributions to the world. This is possible as students have the chance to build connections from a young age within an environment where mistakes are expected and accepted. By creating these experiences, the students no longer look at information in a vacuum and will have the necessary skills to transfer their knowledge to their future experiences. This ability to develop skills, rather than just knowledge, helps students grow in ways that will allow them to succeed in any pursuits they work towards. While not all students will go on to work in STEM fields, inquiry helps teachers promote students to be lifelong learners who can promote the continual betterment of themselves, others, their community, and the world.

Science teachers must immediately begin to implement inquiry-based learning methods such that their students are growing in skill and knowledge, rather than just knowledge. With the implementation of inquiry, teachers can support their students in their pursuit of becoming critical thinking and problem solvers. This is of incredibly high significance for teachers and students studying environmental science. With inquiry the ability to draw connections can be maximized in environmental science. Given the nature of environmental science, the need to draw connections and link the classroom to the outside world is present from the onset. With inquiry, these connections can be maximized such that environmental topics can be linked to prior science disciplines as well as the local, regional, and world-wide communities. With the continual advancement of environmental science, the need for strong leaders and scientists grows by the day. Inquiry is the opportunity to overhaul current methods to better support this growing need.

Chapter 3: Capstone Project

Overview

This capstone project will explore and examine the application of inquiry-based learning in a high school environmental science classroom. The goal of this project to examine if the use of inquiry-based learning in high school environmental science can allow students to grow in skills, especially problem solving and critical thinking, and not just knowledge. While these results have been observed and studied by other teachers and researchers, this study is being done to see if it is applicable in environmental science and across classrooms, not just the classrooms that have been included in the research studies.

This chapter will share the project design with explanation of how skills will be assessed, the inquiry-based labs and activities that will be used, and analysis and explanation of the results.

Project Design

This project will include the creation of a series of inquiry-based activities for a non-AP high school environmental class. Given the time frame of this study the goal is to produce and implement six to eight inquiry labs that correspond with the curriculum. The labs and activities will vary in their format, style, type of inquiry, and delivery of information.

The goal of this project is to examine the development of skills. The teacher will examine work for changes and growth in abilities, as well as observing students during the lab itself. A third method to assess skill growth that gives the students opportunity to reflect on their growth and greater feedback is through surveys. Through the use of surveys, prior to any lab work, in the middle of the implementation of the project sequence (after activity 3 or 4), and at the closing of the project timeline, the teacher can take the student's self-assessment of skill growth and responses into consideration to allow for further analysis and examination. The ability to assess this growth of skill could be challenging to freely observe during labs or through work comparisons, therefore the inclusion of student surveys is another avenue to allow a fuller extent of analysis.

While literature shows that injury-based learning can have many benefits in science classrooms, this project will focus solely on the skills of critical thinking and problem solving. If carried out properly with varying levels and styles of inquiry, the planned activities can make learning about much more than facts and simple knowledge. There is an opportunity to help students grow in skills than can be carried with them throughout their lives and strengthen their understanding to a deep understanding, rather than just surface level comprehension.

Student Population

The students involved in this capstone projects come from two high school environmental science classes. Between the two classes there are a total of 21 students, 12 students are in period one and nine students are in period four. In terms of the grade level break down, there is one sophomore, 12 juniors, and eight seniors. The students range in age from 16 to 18 years old. The male to female ratio is in favor of males. Of the 21 students, only six are females. A note to add in this regard is the fact that the school where this capstone is being conducted was a male only school for much of its history and has only been co-ed for about three years. This means that within the upperclassmen, there have been more girls attending with each year passing but the boys do still outweigh the girls at this point. In the lower grades, of sixth to ninth grade, the split is more even, with possibly more girls than boys in some grades.

Surveying Students

Within this project, outside of using teacher observations and student's work and grades, surveys will be given to see how students perceive their own growth and for the teacher to access the growth of their survey responses. The surveys will be given at three times. An initial survey prior to any inquiry-based work, a mid-project survey after the fourth inquiry activity, and a final survey after the seventh or eighth inquiry activity. The final survey date will be set at a later date to determine when the best time to assign this survey will be.

For the initial survey, the students were asked a series of 10 questions. Most questions were qualitative in nature with a focus on future goals, challenges that may arise in pursuit of such goals, skills students currently use and may need to use in the future, and asking about how students define critical thinking and problem solving as well as if such skills are needed in life. The last question was a set of two Likert scale questions to assess how students perceived their problem solving and critical thinking ability with 1 meaning very weak and 5 meaning very strong.

For the closing survey, the students were asked six questions. Of the six questions, two were repeats from the initial survey, asking the students to define critical thinking and problem solving as well as ranking themselves on each skill on a scale of 1 to 5. The other questions asked the students about what they obtained from the inquiry activities, if the skills they learned are transferable, and to explain why they ranked themselves the way they did in the Likert-scale section. This survey focused on what was ascertained, the applicability of the skills, and self-reflective ratings that could be used to compare initial and final survey results.

Initial Survey Results and Analysis

The environmental science classes included in this study include 20 total students. Of the 20 students, 18 students completed the survey. The other two students were not present for the day of the survey and did not make it up. After completing the initial survey, I examined the questions for trends and completed statistical analysis on the Likert scale results. For the qualitative results, when looking at life goals the students showed a mixed variety of life goals, with a small handful hoping to go into science fields like engineering or computer science. Given the variety of life goals, the skills that students listed as being needed to reach their goals varied but in multiple cases the students listed more knowledge-based requirements rather than true skills. Of those who listed skills, the most common skills to show up were time management, listening and communication, motivation/focus, and organization. A small number of students also mentioned the need for problem solving skills. The next major trend extrapolated was the high level of agreement, with all 18 students agreeing, that problem solving and critical thinking skills are transferrable and necessary for life.

Initial Likert Scale Response Frequencies for Problem Solving

Likert Scale Value	1-Very Weak	2-Weak	3-Medium	4-Strong	5-Very Strong	Average
Frequency of Response	0	0	4	11	3	3.94

Looking to the Likert scale results, when asked to rate their ability to use problem solving skills, the average result was 3.94. On the scale created, 3 equated to medium skill level and 4 equated to strong skill level. Looking to the individual results, four students ranked themselves at a level 3 (medium), 11 students ranked themselves at a level 4(strong), and three students ranked themselves at a level 5 (very strong). Each survey was done anonymously so individuals cannot be tracked via survey to see how the Likert scale rankings will change over the course of the surveys but from the onset, the students ranked themselves very highly on problem solving.

Initial Likert Scale Response Frequencies for Critical Thinking

Likert Scale Value	1-Very Weak	2-Weak	3-Medium	4-Strong	5-Very Strong	Average
Frequency of Response	0	0	6	11	1	3.72

Looking at the critical thinking ratings, the class average was only slightly lower at 3.72. For this skill, six students ranked themselves at a level 3, 11 students ranked themselves at a level 4, and only one student ranked themself at a level 5. This shows that while most students still had high confidence in their critical thinking skills, there were more students to rank themselves in the medium range and less who ranked themselves in the very strong rank. Overall, these numbers show that the students had high confidence in their skill set but when asked to define the terms of problem solving and critical thinking, they expressed verbal struggle with coming up with a definition or provided very vague definitions. While the expectation is not for students to provide a perfect dictionary definition, the lack of ability to clearly define the skills while still highly ranking themselves shows some discontinuity. This could show early signs of higher ranking than true skill set ability or the possibility of students not fully grasping the true nature of each of the two skills that are being focused on. Future surveys and exploration of the student's inquiry-based work will provide more information in this area.

Closing Survey Results and Analysis

By the end of the study period for this project, the total number of students was 21, with one female student switching into the class later than the other students. Of the 21 students, only 16 students completed surveys. The five students who did not complete surveys were out of class for various reasons, two were absent for a school related trip and the others were out of the school for the day for unknown reasons, possibly illness. Examining the results, the first question asked the students if they gained skill, knowledge, or both from the inquiry work. The bulk of the responses had both as their answer. They shared that they felt growth in many ways and that they were able to get better as more labs went on. A small number of students shared that they felt they grew in knowledge and had better conceptual understanding due to the activities that were done. The next question asked what skills the students developed through their work. The most common skills shared included: collaboration/teamwork, problem solving, application of knowledge, and organization of ideas and evidence. Teamwork and collaboration were the most often listed skill. While this was not the focus of the project, the ability to work together and collaborate is very important and can allow for greater problem-solving and critical thinking in the long term. The third question asked about the application of their skills learned to life and other classes. 14 of the 16 students agreed that the skills learned can be translated to school and life. Of the two who did not say yes, one gave no response and one said maybe. For the student who said maybe, they shared that it depended on the circumstances as to whether or not they could apply the skills. Overall, this question shows that students see the value and transferability of the skill being developed. The question with the biggest struggle was number four. Just as I asked the students to define problem solving and critical thinking before we began this work, I asked them again to define the terms in hope of seeing how their definitions may now differ or have expanded. Seven of the 16 students said the skills were good or well and gave vague answers that did not define the words. A few of these seven tried to connect their answer back to the work that was completed. Overall, of these seven students, their answers did not fit with that was being asked. One student did not answer question four. The remaining students, eight of the 16, gave detailed answers. These answers included the critical thinking is using knowledge to apply it to a solution and to think deeply. For critical thinking, they defined that it was a connection between knowledge and applying it. For problem-solving, the definitions were still a bit basic. The most common answer was that problem-solving is a solution or answer to a problem or situation. A few students shared that they noticed a connection between problem-solving and critical thinking. While some students were able to give more detailed information on the final survey when compared to the initial survey, the results were still a bit lacking in this area.

Final Likert Scale Response Frequencies for Problem Solving

Likert Scale Value	1-Very Weak	2-Weak	3-Medium	4-Strong	5-Very Strong	Average
Frequency of Response	0	0	6	7	3	3.81

Final Likert Scale Response Frequencies for Critical Thinking

Likert Scale Value	1-Very Weak	2-Weak	3-Medium	4-Strong	5-Very Strong	Average
Frequency of Response	0	1	5	6	4	3.81

The final area was the Likert-scale results. For problem-solving, the average score was a 3.81. Looking that the frequency of the answers, six students defined themselves at a 3, seven students at a 4, and three students at a 5. For critical thinking, the average ranking was also a 3.81. In terms of frequency, one student reported a 2, five reported at a 3, six reported at a 4, and four students reported at a 5. The average scores for each skill show similar values to the original survey results. Between the initial and closing survey ranking, there was a decrease in the problem-solving ranking average from 3.94 to 3.81 and the critical thinking shows an increase from initial to closing rankings from 3.72 to 3.81. Overall, this shows that the students ranked themselves about the same. Frequency wise, the second survey led to a self-ranking of a 2 on the Likert-scale for critical thinking by one student and a decrease in the number of students who reported themselves to be at a level 4 for both skills. These data points show little growth and some decline, but I think that the students may have overestimated themselves in some cases in the beginning and in their explanations of how they ranked themselves some even said that they saw improvement, but they have more room to grow and develop. Additionally, after exposure to the skills and working with them, some students may be over critical and underestimate their ability to use these skills. With anonymous surveying, more specific comparisons of ranking cannot be complete on a student-by-student basis. Overall, the surveys show growth among students in their qualitative answers.

Inquiry-Based Activities and Labs

1. Ecological Footprints Activity -completed both individually and with small groups to analyze the impact of themselves and how their impact compares to others-included

examination of one owns actions and behaviors as well as consideration for possible changes that could be made.

2. Tragedy of the Commons Lab- group based activity that is a simulated experience of how the actions of the few affect the community; this activity especially requires problem solving to determine the best approach to take, especially in the sense of whether the group will consult with each other or if they will so their own individual plans
3. EPA Law Presentations- this is project-based learning oriented and requires the analysis of real examples and laws such that students can make an informative document/flyer/pamphlet that they could use to convince others that their law is important and necessary- this highlights critical thinking and research oriented skills that connect class content to real life examples and experiences The students explored specific environmental laws from the modern environmental laws (late 1900s; 1970s and on) as well as their history. The last component was to explore the impact of their specific law. This required more application of knowledge and critical thinking.
4. Choose an Approach Inquiry Activity-Students are given a situation and must complete a brief/short version of cost benefit analysis. After this they then explore the costs and benefits of different policy approaches that could be used to implement environmental programs such as tax breaks, tax penalties, subsidies, and local incentives. This gets to the heart of critical thinking as they are applying their knowledge to a specific scenario.
5. pH Lab-The start of chapter 3 is a partial review of key chemistry and biology topics, with more of a focus on chemistry. A pH lab was developed for students to measure pH with pH paper. After completing the pH testing of some household-based products, the students then completed analysis and connections questions where they made connections

between the environment and how harsh acids and bases can impact different ecosystems and organisms. They closed with a thinking-based question that asked them to share if they though acids or bases caused more damage. While there was not one correct answer, the goal of this question was pushing the students to think critically and use all the information from the lab to explain and support their thought process.

6. Tectonic Plates Lab-food based items to explore movement of tectonic plates; students determine ways to model all the different plate movements and the effects of such movements; think critically about the best way to exhibit each movement and solve problems that may come up when differing ideas arise. The graham cracker plate tectonics was the first open inquiry opportunity for the students, where they took more control. I modeled the expectation with the first plate tectonic relationship and wrote out a procedure that was to be followed and then the students wrote down their observations. For the other three boundaries the students were required to observe but also write the procedures that were the best steps to follow to observe each plate motion and event. This required problem-solving and critical thinking.
7. Pangea activity-This is the least lab-oriented activity. However, it is central on problem solving. In this activity, the students cut out the continents and are tasked with putting them together as they looked 225 million years ago. This is not just a guess and hope you are correct situation. Each continent is labeled and has clues on them, such as animal records, fossil records, and environmental features that are shared. These icons give clues as to where connections may have once existed between continents.

Results from the Inquiry-based activities and labs

1. **Quantitative Results of the Inquiry-based activities**

Each of the labs and activities were analyzed to determine the mean, the high score, the low score, and the number of students who did not submit the assignment. For the students who did not submit their work, a 0 is put into the grade book. The grades of zero were not included in the determination of the mean score or the low score. The 0's were omitted to give a more accurate value of how much learning and skill growth was attained by those who turned in the assignment. An additional note to include is that the two classes were combined to determine one average for all students involved as the two classes are on the smaller side and together only account for 21 students. Below is a chart of the numerical data for each assignment.

	Ecological Footprints Activity	Tragedy of the Commons Lab	EPA Law Presentation	Choose an Approach Inquiry Activity	pH Lab	Tectonic Plates Lab	Pangea Activity
Mean grade (%)	76.39	94.90	84.33	91.07	83.36	77.87	92.78
High grade (%)	97.14	100	100	100	98	100	100
Low grade (%)	50	78.95	75	75	58	53.70	75

Missing submissions	1	4	0	7	7	0	3

Looking at the mean scores, from the initial lab to the last activity, there was an overall increase in scores. While the increase was not perfectly upward and had some dips on later labs, the general trend shows that the students were finding greater success overtime through greater exposure to inquiry work. For the plate tectonics lab, this was the first and most open inquiry activity the students had done to date. Most of the other labs were guided inquiry with more structure built in and heavier inquiry-based skill work required in the analysis portion.

Looking to the high and low scores, the high scores were very steady and consistent overtime with scores ranging from 97 to 100. The lows hovered around 75 for many assignments, with three assignments having scores in the 50's. The first activity had a low score of 50 and highlights the struggle some students experienced with the first activity. Another low score to note is the tectonic plates lab. This open inquiry also presented challenges and saw a large dip in the low score.

The last area to examine in the missing work. Within the two classes that participated in the study, there have been some struggles with turning in work all year. This impacts the students grades and over the span of inquiry activities the missing work got worse, rather than better. The fourth and fifth activities saw the worst lack of submission. Just like all other activities, the students completed the labs in class and would have to take the labs home for homework if they did not finish in class. After these two labs, submissions did improve but overall, lack of submissions was an issue within this study.

2. **Qualitative results of the Ecological Footprints Activity-9/25/23**

Looking at student responses and teacher observational data, this was the students first inquiry activity of the year. The assignment was completed in class over two days. Any work that was unfinished after day two was assigned as homework. The students experienced some difficulties, but these difficulties were very surface level and questioning what they were supposed to be doing. In many cases, I lead them to reread the directions and that clear up some confusion but in cases where it did not, I provided support if clarification was still needed. This activity incorporated the use of an online website tool and the use of google sheets to make a graph. The students had some troubles with the making graphs on google sheets so greater support was needed. In terms of the answers to the analysis questions, the students gave very simple answers and when asked to elaborate gave few details. Some portions were also left blank or skipped which reduced overall grades. Overall, this first lab highlighted areas of weakness in the students and when considering the self-scoring they completed on their surveys, the first assignment showed some students with weaker skill sets than they may have originally expected of themselves.

3. **Qualitative results of the Tragedy of the Commons Lab-9/27/23**

Based on teacher observation, it is clear the students enjoyed the lab. It required teamwork and collaboration while “fishing” for “fish” (candy). The driving force of this motivation could be correlated to the candy as they were excited to eat some of it after the lab was over. In the lab itself, most teams were able to successfully fish without pushing their fish into extinction. Two groups put their pond into extinction early into the trials and therefore had to report zero fish for the remaining trial years. One group pushed half of their fish into extinction. The other groups who made it through all their years used the last year to collect as many fish as possible as they had rationed in the early years. Looking to the post lab questions, the students made some connections from the lab back to the concept of the tragedy of the commons, but again they were more surface level. A few were able to dive deeper into their insights and make connections, but this was only a select few students. Even with these select few students, critical thinking was starting to expand. Given that multiple students pushed fish into extinction, one question asked if they were successful. In this answer, some gave vague answers, such as not fishing as quickly, on how they could have done better but one or two gave detailed examples of improvement, such as setting up a more detailed plan within the group and divide the fish up in a way that was beneficial for long term success for the fish, themselves, and the whole group. This highlights initial growth in problem solving skills.

4. **Qualitative results of the EPA Law Presentations-10/6/23**

Observationally, the students had to report about the law, how it has changed and been updated over the years, and how it has impacted the environment. This third component was to bring in critical thinking. The first two areas can be found directly on the EPA website, a link that I provided to the students. With the final portion a bit of research had to be done and then analysis of the finding needed to be done to fully share the impacts. Some groups showed great analysis and insights on the impact of their law, even providing specific details or examples to strengthen their point. Other groups were very vague and gave generalized conclusions. Vague conclusions included that it helped the environment and provided no expansion on the specific ways it helped. At this point, the ability to critically think was looking like a skill that was growing within the students to some degree. While some only had minor growth, others were appearing to have strong growth.

5. Qualitative results of the Choose an Approach Inquiry Activity-10/13/23

Observationally, the students had many ideas on the pros and cons of the policy that they were tasked with analyzing. Some students gave a lot of ideas that were on the simpler side while others gave few ideas but incorporated a lot of thought and details. When comparing the ways that the policy could be applied (tax breaks, incentives, subsidies) the students gave more literal, surface level answers. Even with some surface level answers, all students were engaged in some level of discussion and collaboration with some going into deep discussion to consider all aspects. One group took it a step further and even did calculations in their cost benefit analysis. In the closing questions, the students were asked which way would be the best and worst way to implement the new policy. Tax breaks and tax penalties came up the most, some thought tax breaks were worst while others thought tax breaks were best. This was interesting to see. The students had to support their ideas for these two questions and the answers were interesting to observe. In this area explanations varied but all used a moderate level of details. In the final question, where students could suggest a different policy or modify the presented policy, the students showed good critical thinking with modifications to the plan to improve how it could be used and a few even suggested new plans. The new plans that were suggested included slightly less detail than those who modified the present plan but showed problem-solving and critical thinking based on coming up with new ideas overall.

6. Qualitative results of the pH Lab-10/26/23

Looking to the quality of their work, there was some issue with the pH paper readings. This caused some results to be off by a pH degree of one or two. This required me to look back to the procedure and make changes for future use. Points were not deducted in pH paper reading errors. After the pH readings, students had to apply their learning to situations using provided excerpts that looked at how acids impact waters and bases impact soils. In some cases, the students gave highly detailed responses, but most students were still a bit simple or vague in their responses. In their explanation of how a lake turning more acidic would harm the aquatic area, some simply stated it would harm the fish. This is very basic and lacks depth. A few went into greater detailing what would happen to fish at various life cycle stages and talking about specific pH values where fish and even their prey would experience grave harm. The vague answers could be linked to the weaker performance on the prelab questions, which students could use their notes to answer but many did not. The last question was the most critical thinking oriented as I asked them to pick whether they though acids or basses were more harmful to the overall environment. This had a mix of answers between acids, bases, and a few who said both. I expected the mixed answers, although I did not anticipate both as an answer. In all cases, the support for their answer was mixed in detail. Just as I saw with the other conclusion questions, the explanations were vague or highly detailed. This shows that a disconnect is happening. While some students made connections back to waters and soils being impacted by acids and bases, respectively, others simply shared that their selection was more dangerous and would negatively harm the environment but did not go into specific examples. Some students are seeing great growth in critical thinking and applying their knowledge, but others were still on very low growth levels.

7. Qualitative results of the Tectonic Plates Lab-10/27/23

Examining the qualitative results for the sixth inquiry activity, it is important to note that this was the first open inquiry activity that the students took more control in. A model was provided for the first section to guide them, but after this they oversaw writing a procedure, carrying it out, and making observations. The procedure writing section proved to be of challenge. Some groups wrote detailed multi-step procedures that could be easily followed and replicated by others. This included procedures with 5 or 6 steps to model the movement of each type of plate boundary. Other, however, did not give steps. They were very brief and vague in their work. Some students gave one step with no details. This would be very hard for other to model or replicate. Others gave two steps but were again missing information that allows for replication. Another area of weakness was that lack of connection students made between the types of natural disasters and landforms that different plate boundaries create or cause. Overall, while some students did very well, working collaboratively to write procedures and collect observations, there was a greater number of students who had trouble with procedure writing and this will require more work in this area as the year continues. This lab was the most challenging for the students to date and those who successfully completed the lab were more collaborative than those who struggled.

8. Qualitative results of the Pangae Activity-10/30/23

The Pangae Activity was a bit different than the other work that had been done so far. This work was puzzle-based. The students had to use the continents and the context clues of rock formations, animals, and fossils to determine where the plates were located 225 million years ago. This was a successful lab for many students who seemed to do well with the puzzle-like nature of the work. A few were a bit unsure and asked for feedback after initial attempts, with many seeing success after their first or second try. With the placements of the continents, many were spot on or almost spot on. Some students were just slightly off by one or two continents, with India, Antarctica, and Australia having the most mix ups or incorrect placements. There was also one student who placed the continents where they belong according to today's Earth. A second student almost did this same error but reached out to ask questions which cleared up this issue. A note to consider with this activity was that it was started in class where students could not use their laptops to simply google Pangea to see what it looked like, as the goal was to use the clues on each continent to construct the work. However, some students did not finish in class and had to bring it home. This means that they could have used other resources rather than just the contest clues. Even with this consideration, the students performed well on this inquiry activity and were able to use problem solving and critical thinking to solve problem of where to put each continent.

Weaknesses in the capstone

A note that is important to share when considering the data collected in the capstone is that late submissions and lack of submissions did plague the classes. This dragged many averages down for individual students. While the missing submissions were not factored into the above quantitative analysis, they are important to recognize and account for as the missing submissions will impact the overall number of scores that are averaged and could lead to a greater sway of averages as some assignments have more submission than others. In an attempt to lower late submissions and lack of submissions, communication was completed in class as well as through email and online announcements to families and students with limited success. Continued communication and discussion are needed in this area both with the students and families as well as between the teacher and colleagues to see how this issue can be relieved or improved such that students have full support and can succeed.

Limitations and Further Steps

This project was successful as growth was seen within the students. However, an important area to note is the time frame of this work. Based on the literature review that was completed, there was a high expectation that the growth within the students would be seen to a larger degree. While there was growth, there was a let down when comparing expectations with the final result. It is important to note that the growth that was observed was only for the months of September and October, when the original mindset was geared towards work that would be carried out from September to December. While other studies in the literature were carried out over longer periods of time and allowed for more time for trends to be observed and higher growth levels. This facet must be considered by the teacher who carried out this work and all other teachers who will consider undertaking this type of work going forward. Growth takes time to manifest within the classroom and cannot be rushed. With all this in mind, more work and longer study is needed. Inquiry work will continue to be a mainstay within the classroom that was studied in this capstone project. This will allow the teacher to continue to monitor growth and development within the students for the remainder of the school year. For future applications and consideration of this project, the timing framework for classroom-based research is critical to consider and factor into the planning process.

Conclusions

Overall, considering all aspects of this project, from the research portion to the implementation, the goal of this project was to determine how inquiry-based science work could impact secondary science students' skill sets. This specific study was a focus on critical thinking and problem-solving skills as these are tools that can be applied to future endeavors. These skills and others have been studied in the past through inquiry work and high level of positive outcomes were seem.

Looking to the work completed in this study, a combination of surveying, quantitative data, and qualitative observations were used to study the growth of problem-solving and critical thinking in two high school environmental science classes. From the start of the school year in September through the end of October, seven inquiry-based labs and activities were assigned and completed. Through the consideration of the student's perspective in surveys, as well as the numerical grade-based data, teacher observation of in class learning behaviors, and trends in student answers on each of the seven individual assignments, a great amount of data was collected and analyzed.

Through analysis of the final results, it was discovered that there was some level of growth among the students in critical thinking and problem-solving ability. This growth varied from student to student and was not as strong as originally expected or when compared to other research that has been completed by others. However, even with different degrees of skill growth, this work does show that inquiry positively benefits the students in their ability to grow in critical thinking and problem-solving skills. Not only did they grow in critical thinking and problem-solving, but through student self-reporting and teacher observation, it is clear they grew in collaboration skills as well. This was not a skill originally of focus, but it was a result that was observed by students and teachers.

Overall, this work saw moderate levels of success. Over the course of the first school marking period, the students were able to become stronger to some degree in both critical thinking and problem-solving. These skills have the opportunity for continual growth in the remainder of the school year. With continual growth, the students can call back to these skills in future courses and in life in general. The students will not only leave their course with new knowledge but skills that can be applied to a myriad of experiences. This is especially critical at the secondary school level, as the students may not use the knowledge, they learned daily, but they can use the skills they have learned for the rest of their lives. With this in mind, the results of this study should be further studied and investigated in other secondary classrooms, especially other science classrooms, to allow for an expansion of the results and the greater development of critical thinking and problem-solving within all students. With continual exposure and practice with these specific skills and others, students will only grow stronger in their abilities and can handle all the challenges they may face in their futures.

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