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An overview of inquiry-based learning in science education

by

Brittan Erin Aldrich

An Honors Capstone

submitted in partial fulfillment of the requirements

for the Honors Diploma

to

The Honors College

of

The University of Alabama in Huntsville

May 13th, 2020

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Abstract

Students in the United States are underperforming in K- 2 science. One potential way to solve this problem may involve the way science instruction is delivered. Inquiry based learning is widely considered to be the most effective approach to teaching science to students. This literature review attempts to help teachers and teacher educators understand the current consensus regarding inquiry based education in science. This paper will explain what inquiry based education is, the different types of inquiry education, why inquiry is preferred over traditional direct instruction in the science classroom, how inquiry can be implemented successfully, and the challenges associated with implementing inquiry education in a classroom and on a large scale.

An overview of inquiry-based learning in science education

Students in the United States are not scoring well on tests that assess their knowledge and understanding of science. According to the Organization for Economic Cooperation and Development (OECD), students in the United States ranked 5th in the world in science competency based on the Programme for International Student Assessment (OECD, 20 8). One of the methods used to track students' proficiency in science is called the National Assessment of Educational Progress (NAEP) test (National Center for Education Statistics, 20 8). The science portion of this assessment is designed to assess students' "knowledge and abilities in the areas of Earth and space science, physical science, and life science" (National Center for Education Statistics, 20 8, para.). According to NAEP, over half of the nation's 8th and 2th grade students in the United States (66% and 78% respectively) scored below proficient in science in 20 5. While this may be an improvement from the last NAEP test in 2008, it is important to note that only a quarter of high school seniors are proficient in science when they graduate (20 8). One strategy that may help students score higher on these kinds of assessments is implementing inquiry-based learning in science classrooms.

There are two main methods to teaching science, teacher-centered teaching also known as direct instruction, or traditional teaching, and student centered teaching. The first approach, direct instruction, is teacher centered; the teacher is in control of the delivery of information and is responsible for conveying concepts to students who are then provided with the opportunity to apply the concepts (Wenno, 20 4). The second approach, student centered teaching, includes inquiry-based learning; the primary goal for this approach is for students to learn about science content by doing science (Peters, 2006).

Inquiry-based learning uses inquiry as a mechanism for teaching students scientific processes and content knowledge (Sotiriou, Bybee, & Bogner, 20 7) and requires students to actively engage in experiments, data collection, data analysis, and critical thinking in order to devise evidence based explanations. This is consistent with a constructivist approach to teaching which focuses around the idea that knowledge is actively constructed by students rather than passively passed from student to teacher (Zion & Mendelovici, 20 2). In contrast to direct instruction, a constructivist approach to teaching is student centered and encourages students to learn by doing, discussing, and thinking critically (Shah, 20 9). Inquiry-based learning, as it is described above, is consistent with the constructivist approach to teaching because it requires students to engage in doing science rather than remembering facts or concepts.

The inquiry approach focuses not only on teaching students content but on teaching students how to "act like a scientist". Teaching students to "act like a scientist includes teaching them scientific processes like hypothesizing, collecting data, making observations, creating evidence based explanations, and planning and carrying out investigations among others (Ellwood & Abrams, 20 7). This approach is based on the idea that science is not a collection of facts and principles that can be memorized but rather a way of thinking and a process for solving problems and answering questions (Sotiriou, Bybee, & Bogner 20 7). Inquiry-based education, ideally, provides students with opportunities to engage in scientific practices, use forms of scientific discourse, and perform within scientific contexts (Sotiriou et al., 20 7).

This paper will discuss inquiry-based learning as a method of teaching science, why inquiry is the best method for science instruction, the levels of inquiry that exist, how to implement inquiry-based learning in the classroom, and the challenges associated with

inquiry-based learning. Implementing inquiry effectively in a classroom can be extremely difficult for teachers especially when they do not have the necessary support available to them (Kececi, 20 7). Teachers may encounter many different challenges when they attempt to implement inquiry. This paper will also address three of these major challenges along with how to implement inquiry in the most impactful way.

Why is inquiry better?

Although inquiry-based learning may take longer to perform in the classroom, it has been shown to lead to a deeper understanding of content knowledge and science processes such as, hypothesizing, planning and conducting investigations, inferring, etc. (Sotiriou et al., 20 7). Multiple studies have shown that implementing inquiry-based learning in the classroom is more effective at teaching students science than direct instruction. Yanto, Subali, and Suyanto (20 9) claim that the implementation of inquiry is more effective at improving student scientific reasoning competency than direct instruction. Similarly, Heindl (20 9) found that inquiry-based learning improved learning better than traditional instruction. Furthermore, a study done by Wilson, Taylor, Kowalski, Carlson, and Society for Research on Educational Effectiveness (2009) found that students who experienced inquiry-based instruction achieved higher scores in areas such as knowledge, scientific reasoning, and argumentation than students who experienced traditional instruction. These studies demonstrate how inquiry-based learning is more effective at teaching students scientific processes and content knowledge.

Inquiry-based learning not only improves students' abilities and competencies in science, it also affects how they perceive science. Research has shown that there is a connection between students' achievement in science classes and how much they enjoy science (Filippi & Agarwal,

20 7). How much students enjoy science has a direct effect on their level of success in the science classroom (Filippi & Agarwal, 20 7). Self-efficacy, the belief in one's own abilities, has also been shown to affect a student's success in science class (Filippi & Agarwal, 20 7). Inquiry activities have the ability to increase how much students enjoy science and their self efficacy in the subject and therefore improve students' science reasoning and performance in science classes (Filippi & Agarwal, 20 7). Ellwood and Abrams (20 7) echo this sentiment by stating that students succeed in science when they enjoy science and that implementing inquiry-based learning into the classroom increases how much students enjoy science. Therefore, inquiry-based learning by increasing enjoyment also increases success for students.

Another argument that can be made as to why inquiry is a better method of teaching science stems from the structure of the Next Generation Science Standards (NGSS; Lead States, 20 3). The NGSS are science content standards for grades K- 2 that were developed by states to improve science education for all students. Each standard integrates three dimensions of science learning including science and engineering practices, disciplinary core ideas, and crosscutting concepts (NGSS Lead States, 20 3). The science and engineering practices refer to skills that students need to engage in science. These practices include asking questions and defining problems, developing and using models, and planning and carrying out investigations among others. Inquiry-based learning also allows students to engage in and develop these practices while investigating scientific phenomenon (NGSS Lead States, 20 3). This method of instruction allows students to engage with all parts of the NGS standards at once.

What are the levels of inquiry?

Inquiry is the best approach to teaching students science as a discipline, but not all inquiries are created equally. Depending on the source, there are three or four different levels of inquiry, with differing names. According to Yanto et al., the levels of inquiry include structured, guided, and free inquiry (20 9). Structured inquiry is the most controlled and least student orientated form of inquiry. Guided inquiry is more student centered, but there are still components of the inquiry that are controlled or restricted by the teacher. Free inquiry is completely student centered. During this kind of inquiry, students are responsible for choosing and designing all components of the inquiry (Zion & Mendelovici, 20 2). A discussion of each level will be provided in the subsequent paragraphs.

Structured inquiries are the most restrictive to students of the three levels of inquiry. A structured inquiry is characterized by the teacher presenting students with a research question, and a procedure designed to investigate the given question. Students use the given procedure and guidance to complete the investigation that will end with a predetermined result (Zion & Mendelovici, 20 2). So many aspects of the investigation are given to students by the teacher that it restricts students to a predetermined narrow scope. This level of inquiry is teacher centered rather than student centered meaning that students are not as actively involved in creating or evaluating the questions, procedures, or processes involved in the activity. Students are following a procedure rather than designing an investigation. During a structured inquiry, students do not come up with their own questions and do not attempt to find an original way to answer the question. Structured inquiry does not require students to use scientific processes such as creating a question and planning and carrying out an investigation to answer a question.

However, structured inquiry activities do help students develop basic inquiry skills, like, recording data, making hypotheses, making and recording observations, and drawing conclusions (Zion & Mendelovici, 20 2).

The nature of a structured inquiry makes it very effective at teaching students the basic inquiry skills listed above, but it is not useful for giving students a meaningful experience with more complex scientific processes and critical thinking. Research shows that structured inquiry is ineffective at helping students develop critical thinking skills, their ability to use scientific processes, and positive attitudes towards science (Zion & Mendelovici, 20 2). Structured inquiry is ideal for students who have little to no experience with learning through inquiry. Learning through inquiry can be jarring for students who have never done it before, and a structured inquiry is a great way to scaffold students to begin developing inquiry skills. The goal is to use structured inquiries to build basic inquiry skills that students can then develop using guided and free or open inquiries.

A guided inquiry is characterized by the teacher presenting students with research questions and procedures, but allowing the students to collaboratively come up with a process that investigates the question, and an expected result. Unlike a structured inquiry, the exact results are unknown to the teacher and students before the guided inquiry begins, but they are limited to the questions and procedures supplied by the teacher (Zion & Mendelovici, 20 2). Guided inquiry can be considered a middle ground between a structured inquiry and a free or open inquiry. This approach to inquiry can be useful for scaffolding students toward using complex scientific processes. Students who are severely lacking in scientific competence may struggle with the lack of teacher support in this type of inquiry. On the other hand, students who

have mastered basic inquiry skills may find this form of inquiry more challenging and engaging while continuing to develop more complex inquiry skills (Zion & Mendelovici, 20 2).

A free or open inquiry is the most student centered type of inquiry-based learning. During this form of inquiry, the teacher sets the realm for the inquiry, the broad topic which students can investigate, and the students develop a wide range of questions and processes designed to answer the questions (Zion & Mendelovici, 20 2). This is the least restrictive form of inquiry which causes students to take more control over their own learning. Free or open inquiry simulates the processes, decision making, and problem-solving that scientists use more realistically than structured and guided inquiry. An open inquiry activity provides students with a more authentic science experience and it allows students to learn scientific content in the way that scientists learn about real world phenomena. While this form of inquiry is aimed at being student centered, the teacher may still provide students with scaffolding during the process to help them develop the complex inquiry skills required to engage in an open inquiry (Zion & Mendelovici, 20 2).

The three different levels of inquiry have different benefits and shortcomings. Yanto et al. (20 9) claim that different levels of inquiry have different effects on students' science reasoning competency. The authors found that free inquiry was the most effective at increasing scientific reasoning in students followed by guided inquiry, structured inquiry, and direct instruction, in that order. Guided inquiry is effective at helping students who have already mastered the basic inquiry skills that can be developed using a structured inquiry. A guided inquiry challenges these students to develop more complex inquiry skills while still providing them with teacher support. Free or open inquiry is best utilized by students who have mastered structured and guided inquiries. Free or open inquiry offers these students a more challenging

and engaging experience while also offering students the most authentic scientific experience possible. Students who have not mastered basic inquiry skills may feel lost or confused during a free or open inquiry.

How can inquiry be implemented?

Implementing inquiry can be a daunting task for many science teachers for a variety of reasons. When inquiry is implemented correctly it can be an enriching experience for students (Ellwood & Abrams, 20 7). One of the most important things to keep in mind when implementing inquiry is incorporating aspects of the nature of science (Peters, 2006). The nature of science is a collection of the underlying concepts that lead to the development of new knowledge in science (i.e. evidence is needed to support science, cultural and historical contexts influence science, etc.; Peters, 2006). A deep understanding of the nature of science helps students realize that choices and scientific process skills, when combined correctly, will produce scientific knowledge (Peters, 2006).

The nature of science includes the underlying concepts that help guide students through the inquiry process to the end goal of developing content knowledge. For example, one construct of the nature of science is that science demands evidence (Peters, 2006). Scientists can often control conditions to obtain this evidence. By varying just one variable at a time, scientists can identify exclusive effects that are uncomplicated by other factors. A student who understands this, will have better knowledge of how to set up an experiment during an open-inquiry laboratory; these students are thinking like scientists. Students who do not have a deep understanding of the nature of science may just be going through the motions of the process

skills, unable to fully grasp the experimental design (Peters, 2006). Therefore, teachers can help students develop their inquiry skills by incorporating the nature of science into their lessons.

Another thing to keep in mind when implementing inquiry is creating scientific discourse between students in the classroom. Discourse in a scientific context is a part of the scientific process in which scientists communicate their research, argue, and debate with other scientists (Ellwood & Abrams, 20 7). This can include publishing, presenting, debating, and or collaborating with other scientists. A students' inquiry experience can benefit from the implementation of scientific discourse in the classroom. Inquiry works best when students are able to discuss and use critical thinking skills to fully develop content knowledge and inquiry skills (Ellwood & Abrams, 20 7). Students not only need to actively engage in hands-on inquiry activities, they also need to actively engage in scientific discourse with other students in order to get the most authentic scientific experience possible. A study found that, "allowing time to engage in critical discourse fosters acting like a scientist" (Ellwood & Abrams, 20 7, p. 423). The discourse students engage in during and following an investigation, mimics how scientists publish or present their work to the scientific community through journals or presentations. Allowing students to engage in this kind of discourse gives them an inquiry experience that is more authentic to what a scientist experiences.

What are the challenges associated with inquiry?

One of the first challenges teachers may face when attempting to implement inquiry in their classrooms is actually understanding what inquiry is. Inquiry has been a commonly misunderstood concept since its conception mainly due to the fact that it has been defined in various ways in literature. For example, Llewellyn claims that inquiry involves "pursuing a

question and figuring out the solutions to problems through a process of observation, development of explanations (theories), testing these through experimentation, discussing the outcomes, and adjusting theories based on the outcomes" (20 3, p. 8). As this definition demonstrates, inquiry encompasses many different skills and actions that require a lot of critical thinking from the person engaging in it. In contrast to Llewellyn (20 3), Feldman, Chapman, Vernaza-Hernandez, Ozalp, and Alshehri (20 2) believe that inquiry can mean a number of things, depending on the context. For example, when one uses the term "inquiry", they could mean the process that scientists use to study the natural world, a way to describe a learning process, or a pedagogical method. In different contexts "inquiry" can have any one of those meanings. The lack of clarity surrounding its definition adds to the confusion surrounding inquiry-based learning in education and more specifically in science education. This confusion can manifest in teachers not understanding the concept itself and are therefore hesitant to implement it in their classrooms.

One of the main challenges associated with implementing inquiry in science classrooms is lack of self-efficacy to implement inquiry-based learning (Kececi, 20 7). If teachers do not believe they can implement inquiry successfully, they may be less likely to try. A study by Kececi (20 7) suggests that one solution to this problem is to provide preservice teachers with opportunities to experience inquiry-based learning before they are expected to implement it in their own classrooms. In this study, preservice teachers participated in structured, guided, and open inquiry applications over the course of an academic year. Participants were given a self efficacy pre- and post-test. The study found that preservice teacher's self-efficacy regarding inquiry increased after completing the applications. This study concluded that preservice teachers

should participate in inquiry during their training because it helps them develop their own inquiry skills, it models for them how they should be teaching, and it increases their science self efficacy.

Inquiry-based learning can also be applied to current science teachers by providing them with professional development that allows them to experience inquiry-based learning activities in order to successfully implement inquiry into their own classroom. De Vries, Schouwenaars, and Stokhof (20 7) claim that one way in-service teachers can achieve this success is by adapting inquiry practices to fit their own needs. The authors continue to describe that inquiry-based learning is a flexible method of instruction and can be adapted to fit any classroom (De Veries et al., 20 7). Therefore, one way to help teachers implement inquiry into their classrooms may be to provide them with flexible inquiry-based learning professional development that allows them to experience inquiry and adapt it for their specific classrooms.

Another major challenge that comes with implementing inquiry into the science classroom is that not all teachers have access to the same amount or quality of supplies. Many inquiry-based learning activities are often hands-on activities which often require supplies that are not commonly found in a traditional school building. Some teachers receive instructional money or may use their department's money to purchase such supplies, but not all teachers have access to money for supplies beyond basic office supplies like pencils and paper. It is important that teachers are shown how they can do inquiry activities in a cost effective way. Giving teachers access to inquiry activities that students can do with little to no extra supplies could be really beneficial in this situation.

Conclusion

Despite inquiry-based learning being more effective at giving students a deeper understanding of science as a whole, many teachers are not comfortable with this method of instruction (Poon, Tan & Tan, 2009). Because inquiry-based learning involves more interactions with materials and other classmates, there is more to manage in regards to equipment, materials, and the social dynamics of students. This can be difficult for teachers without knowledge of preventative and interaction practices (Poon, et al., 2009). In addition to classroom management, confusion around what inquiry actually is, teachers lacking self-efficacy, and lack of supplies or materials are possible reasons why many teachers still do not incorporate inquiry-based learning into their classrooms on a regular basis.

It is important for the United States to find a solution to this problem because taxpayers continue to spend more and more money on education, but are falling behind other nations in scientific proficiency (NCES, 20 9). In 20 5, the United States spent 35% more per full-time student than the OECD average (NCES, 20 9). Our country falls in the middle of the pack when its students' scores on science proficiency assessments are compared to other countries' students. The research indicates that inquiry-based learning may be part of the solution to this problem due to its ability to not only increase students' self efficacy and how much they enjoy science (Filippi & Agarwal, 20 7) but to also increase students' scientific reasoning competency (Yanto et al., 20 9). School district administrators, school principals, and classroom teachers should promote inquiry-based learning in their science classrooms in order to produce more students who perform competitively when compared to other countries.

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Re: Capstone Approval

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I approve Brittan's Honors Capstone project.

On Thu, May 14, 2020 at 12:46 PM Brittan Aldrich <bea0005@uah.edu> wrote:

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