

Using the Project-based Approach to Teach Scientific Reasoning

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Abstract: It is important to teach subject matter reasoning in the science classroom. Science is a process of making sense of the natural world. Unfortunately, science is often taught as a list of discoveries to be memorized. Inquiry is essential to teach scientific reasoning. Inquiry is core component of the National Science Education Standards, and is required by many state science standards. Project-based learning is an approach to teaching inquiry. Students are taught subject matter reasoning through using skills necessary to be successful in a project-based learning (PBL) classroom. PBL takes a great deal of planning and investment on the teachers' part, but the benefits to the students' knowledge and reasoning skills are more than worth the time and effort.

Introduction

Imagine a classroom with 24 students sitting at desks in rows where the teacher is standing in front of the room. The teacher has been lecturing for 20 minutes about ecology and ecosystems. While looking around the room, most students are doodling, looking out the window or are sneaking to use their cellphones. Obviously, these students are disengaged from what the teacher is lecturing about. The students are being taught to memorize and regurgitate information rather than participate in the active process of science.

Now imagine a classroom with the same 24 students and teacher. The students are all over the classroom working in small groups while the teacher circulates among them. The students are talking with one another. Some students are using computers, while others are drawing on poster boards and looking through the textbook. All the students are engaged and working on something. The students are actively using the skills they have been taught to produce a product that models their understanding. What you are seeing is a project-based learning environment, which enables students to use subject matter reasoning.

Building a classroom environment that is able to support this approach to teaching science take time and effort on the part of the teacher. Students must be willing to learn a new way to learn. Despite the effort needed to accomplish this approach to teaching, all the effort is well worth it. Students who learn science using this approach have a deeper knowledge of the process of science. Students can reason with problems presented to them both in the classroom and in the real world. The students well rounded understanding of scientific concepts and reasoning are shown by increased standardized test scores.

Subject Matter Reasoning

Subject matter reasoning is the ability to reason and make sense within the context of one's subject matter (Next Generation Science Standards, 2013). Reasoning

is used cross all content areas, to argue and evaluate claims in a subject using supporting arguments and evidence. The Next Generation Science standards state that students should be able to do the following to be able to reason in science:

- ask questions,
- develop and use models,
- plan and carry out investigations,
- analyze and interpret data,
- use mathematics and computational thinking,
- construct explanations (for science) and design solutions (for engineering),
- engage in argument for evidence, and
- obtain, evaluate, and communicate information. (NGSS, 2013).

Many students struggle with science in an academic setting. These are students who completely understand the concepts in science if they are explained using common language. This same set of students struggle to answer questions if they are worded differently than the practice problems performed in class. They have trouble making connections in science class and applying their knowledge to new situations. By teaching subject matter reasoning, students will learn how to find patterns and apply what they are learning to new circumstances.

Whitehead (1929) stated “In training a child to activity of thought, above all things we must beware of ‘inert ideas’---that is to say, ideas that are merely received into the mind without being utilized, or tested, or thrown into fresh combinations”. With a large emphasis on data driven content strategies and government oversight looking for a way to hold teachers accountable, many educators are searching for ways to push their students to have higher ordered thinking skills. Subject matter reasoning is one-way educators can teach their students to think critically and make connections between content areas.

Inquiry Education

Today research leans heavily on the constructivist view of education. There is a big push in education to teach using student centered techniques and inquiry. National Science Education Standards states “inquiry into authentic questions generated from student experiences is the central strategy for teaching science (National Research Council, 1996).” Inquiry involves designing a learning environment that allow students to explore and make sense of natural phenomena. Hawkins (1974) states “messing about evolves with the child, it becomes a way of working that is no longer childish, the kind of self-disciplined probing and exploring that is the essence of creativity.”

Inquiry is a way of teaching that support students in using subject matter reasoning. In inquiry learning, students need to be able to communicate with one another as well as the teacher. The National Academy of Science states that students

need to be proficient in four areas to be considered proficient in science. Through inquiry students should be able to:

- generate and evaluate scientific evidence and explanation,
- know, use and interpret scientific explanations of the natural world,
- understand the nature and development of scientific knowledge, and
- participate productively in scientific practices and discourse. (NRC, 2000)

Project Based Learning

Project-based learning is a student-centered method of inquiry instruction in which students gain deeper knowledge by actively exploring and investigating an authentic, engaging, and complex question, problem or challenge (Buck Institute for Education, 2017). Project based learning or PBL encompasses all areas of subject matter reasoning. In PBL students must communicate, collaborate, ask questions, argue their point as well as use technology and make connections. Hugerat (2016) states that PBL must be central to the curriculum, not peripheral to the curriculum. PBL must also focus on projects or problems that are realistic and allow students to encounter central concepts and principles of their discipline. Projects should involve student's investigation and be student driven to a significant degree. Above all projects should be real world and not school like, student should be answering a real work question.

In a three-year study conducted by Han, Capraro, & Capraro (2015) researchers found that struggling students have increased achievement scores on state tests when taught STEM skills using PBL. Students were taught core concepts in STEM using PBL every six weeks for three years. This longitudinal study showed that low performing students of all demographic backgrounds scored significantly higher on achievement tests in mathematics. The results show that implementing PBL in the stem classroom has a positive influence on student test scores and helps in closing the achievement gap.

In a study out of Turkey, researchers found that teaching physics through games under a PBL model was effective in long-term retention of concepts. For example, some physics topics can be taught through everyday games such as billiards and darts. Through PBL students were engaged in asking questions and developing explanations with real-world situations. Presenting physics through games illustrates to students that physics is not limited to the laboratories and theory but is present in everyday life (Baraan, Maskan, & Yasar, 2018).

PBL pitfalls to avoid

While studying student achievement scores Kizkapan & Bektas (2016) found that teaching using PBL shows no significant difference over students taught using traditional methods. However, the researchers found their methods were lacking. The students in the study failed to take the projects seriously, they believed the projects

were just another grade like homework that they did not have to complete 100% of the time.

The researchers found that they did not allow enough time for the students to complete the projects and the students needed more guidance regarding time. There were three large factors that played into the study finding no significant difference: students lacked social skills needed to work in a group and deal with conflict, the students were unfamiliar with a student-centered approach to learning, making the jump from being lectured to, to having to perform and produce a product difficult for the students in the study and fear of failure and disinterest (Kizkapan & Bektas, 2016). The researchers found that the students did not want to look stupid in front of their peers.

The students also had trouble getting excited about the topic. Since the topic did not interest the students, they failed to put in the effort necessary to complete the project. Kizkapan & Bektas (2016) suggests that educators introducing the concept of PBL with their students should slowly introduce the ideas with small activities throughout the semester. The teachers should also setup a time schedule to ensure that students are working efficiently and are on track with their learning. The study by Kizkapan & Bektas (2016) shows that implementing PBL in the classroom can be difficult for educators, but it is not impossible.

Although there are struggles with PBL, this approach has proven to be effective in teaching students subject matter reasoning. Students who are unfamiliar with PBL need immense amounts of guidance. PBL is a learned teaching strategy for both the educator and the students. It takes time and lots of energy to design and use PBL in the classroom. An article by Quigley, Marshall, Deaton, Cook, & Padilla (2019) includes many questions posed by educators about PBL and ways to meet the challenges of teaching PBL (2019). McBride, Bhatti, Hannan, & Feinberg, (2004) also address challenges to PBL and inquiry-based science teaching methods. They identified a lack of training and time as factors for why science teachers chose not to teach using inquiry and recommend that be specifically designed to help train science teachers how to teach using inquiry.

Communication is key

To be able to inquire about their learning, students must be able to communicate with each other and their teachers. “Social independence theory suggests that social skills play an important role in enhancing collaboration and solving conflicts” (Lee, Huh, & Reigeluth, 2015). Collaboration is a process in which group members exchange ideas, opinions as well as emotions. Whenever people are working together there is room for conflict to enter. Being able to deal with conflict and communicate effectively to complete an assignment is crucial to students learning through inquiry (Lee, Huh, & Reigeluth, 2015). No one learns in a bubble; the students around them as well as the classroom environment impact students. By building a classroom environment of respect and openness, educators allow students to explore their learning freely.

Yun & Kim (2015) observed 44 8th grade Korean students and taught them argumentation techniques through small group hands on activities. After teaching the students how to support their ideas with evidence and allowing students to ex-

plore freely, Yun and Kim found that students were better able to listen to each other's ideas and more freely share their own thoughts. The key to this study was the teacher reminding students that there is no correct answer and asking the students metacognitive questions. By asking questions and valuing participation, the teachers enabled the students to take responsibility for their own learning. "To create a permissive atmosphere for participation, schools should enable students to learn how to argue and build scientific argumentation norms" (Yun & Kim, 2015).

How to implement PBL in secondary science

Quigley, et al, 2011 discuss four challenges to teaching using inquiry. The four challenges are:

Challenge 1: How can we measure the quality of inquiry as implemented in the classroom?

Challenge 2: How can teachers use discourse and discussion to encourage more effective inquiry-based learning?

Challenge 3: How can we get teachers to think of content and inquiry as not mutually exclusive, but rather aspects of the same goal?

Challenge 4: How can we help teachers learn to manage an effective inquiry classroom?

To address challenge one, the authors suggest using a program called EQUIP to measure the quality of teachers' lessons and their ability to teach using inquiry skills. EQUIP stands for Electronic Quality of Inquiry Protocol. One indicator used by this program to assess teacher inquiry quality is order of instruction. Teachers who allow students to explore a concept in some way before giving an explanation of the concept receive a higher inquiry quality score. Once teachers are able to rearrange the order of their lessons, they are on the path to include higher quality inquiry tasks within their teaching (Quigley, et al, 2011).

Another indicator used by the EQUIP program is complexity of questions. Teachers who ask their students to explain their reasoning and justify their claims score higher in inquiry quality than teachers who ask base level questions with one correct answer. By asking more why questions, teachers are challenging their students to think deeper and make connections between content presented.

The second challenge for educators teaching inquiry is discourse. Many students struggle with discourse and speaking kindly with one another. This was touched on the communication section earlier. One way to increase student discourse is to provide feedback to students about how well they are communicating with one another and how they can improve. Teachers can facilitate discourse within their classrooms by keeping discussions going and encouraging students to answer one another's questions, not just the questions from the teacher (Quigley, et al, 2011).

The second way is to provide follow up information to students while they are working on their projects. Many educators find it difficult to let go of the reins and allow students to be in charge of their own learning in inquiry settings such as project-based learning. By allowing students to question one another, educators

open many different lines of communication. When students do ask the teacher a question, the teachers should provide further knowledge of the concept or challenge students to justify their answers. Educators should ask follow up questions to provide information in the classroom, not just ask questions to evaluate student knowledge. By opening lines of communication and being supportive, science educators transform the atmosphere of their classroom into one of community learning and exploration.

Challenge 3 is all about changing the teacher's mindset on inquiry. Inquiry and questioning should not be a lesson on the scientific method at the beginning of the year and content the rest of the year. Teachers should switch their teaching to allow students to explore concepts and then have the concept explained. One way to do this is a three-step approach. First allow students to observe a scientific phenomenon, then students should make a claim explaining the phenomena. Second the students should question, analyze and research the phenomena to back up their claim. Thirdly the students should present their findings and make connections between the evidence they have collected (Quigley, et al, 2011).

Challenge 4 is the biggest challenge of all for educators. Almost all science educators have heard of inquiry and its importance in the science classroom, but how do you actually do inquiry? The first step is building a solid presence in your classroom as the teacher. The students need to know you are in charge and will keep all students learning. Along with this presence is building an atmosphere of learning and respect. This atmosphere is built by building relationships with each student and encouraging students to get to know one another. By setting an example of being able to make mistakes and learn from them, students see that it is okay to make mistakes in your room. Set forth general expectations of how students should communicate with one another and the teacher. There should be an expectation that students listen to one another, hear each other out and have appropriate ways to agree and disagree with one another (Quigley, et al, 2011).

The biggest component in a project-based learning classroom is having high expectations for your students and holding them accountable for learning. Expectations such as classroom rules and how discussions should unfold can be determined with the students. Students need to know that you as an educator are there to guide them and help them learn, but ultimately learning is up to each individual student.

Conclusion

Students need different skills today than they needed 20 years ago. The skills needed today include, creativity and initiative, the ability to communicate and collaborate with others, as well as the ability to problem solve and use technology. This group of skills are known as 21st century skills that all students will need in both in and out of school (Edmunds, Arshavsky, Glennie, Charles, & Rice, 2017).

There are many ways to teach science and science subject-based reasoning in the classroom. Much of the research points to inquiry science as being one of the best ways to teach subject matter reasoning. In the realm of inquiry, the most studied approach to inquiry learning, is project-based learning. PBL is a tall order for educators. Teaching using the PBL approach requires large amounts of time, plan-

ning and guidance of students. The more students participate in PBL, the easier it becomes for students to complete projects effectively.

Subject matter reasoning is needed in all subject areas. Teaching students how to reason in the science classroom will hopefully prompt students to use their reasoning skills in their other classes as well as in real life situations. Subject matter reasoning is needed to gain 21st century skills. By using the Project-based learning approach to teaching, we as educators are setting our students up for success in a changing world.

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