Spring 2023

Exploring Approaches to Anti-Racist STEM Education

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Abstract: STEM educators have long been left out of discussions around anti-racist education, education that teaches about social justice issues and organizing to solve them. There are little resources or research that specifically address anti-racist STEM education, making it difficult for STEM educators to discuss social justice issues in the classroom. This project asks how to incorporate lessons on anti-racism into a general physics curriculum for high school students. I answer this question through a review of literature studying anti-racist pedagogy, methods for building scientific literacy and techniques for STEM education to draw conclusions about what the best methods for creating anti-racist STEM education are. The literature review uncovers that anti-racist STEM education will support students' understanding of social justice issues, and teach them how to use the sciences to combat those issues. Constructivism and project based learning are two techniques for curriculum development discussed as being complementary to this goal. In this project, I also develop a sample "proof of concept" lesson plan about electric circuits, resistance through a wire, and equitable access to electricity for high school students, to demonstrate what anti-racist STEM education can look like using the tools uncovered in the literature review. Ultimately, this project will be useful for STEM educators hoping to connect the sciences with anti-racist principles.

Suggested Citation: Malhotra, Saket. (2023). *"Exploring Approaches to Anti-Racist STEM Education."* (Unpublished Education Studies capstone). Yale University, New Haven, CT.

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Acknowledgements

This project would not have been completed without the constant support of my advisors, Talya Zemach-Bersin, Daniel HoSang, and Melissa Scheve. Their advice through each part of this process was invaluable in helping me create something beneficial for STEM teachers everywhere.

I also want to give thanks to Dr. Erica Watson. She is a former 9th grade science teacher from Groton, Connecticut, who my friend Dora Guo and I worked with in our sophomore year to try and help her integrate anti-racist curriculum into her classroom. Erica's passion for her students to get an education they need and deserve to make a positive impact on our world has inspired my interest in anti-racist science education, and this capstone project. I am so blessed and honored to have Erica as a lifelong friend.

Introduction

Discovering the Need for an Intervention in STEM Education

For the class “Anti-racist Curriculum and Pedagogy,” students are matched with teachers and tasked with helping them incorporate anti-racism into their curriculum. When I took this class, my partner Dora and I worked with a now-former high school general science teacher, Erica Watson. Much of what we found for Erica revolved around discussions about contributions of scientists from marginalized backgrounds. This topic allowed students to discuss the kind of challenges these scientists must have faced in getting their discoveries recognized and earning respect in their fields. We felt, however, that this wasn’t very well integrated into the curriculum, and that it could easily be skipped over in most classrooms, especially ones with standardized state or AP exams at the end. Additionally, we realized that our unit about prominent scientists of color was motivated by a misconception that students of color may not want to pursue STEM. In actuality, there are structural barriers that explain why students of color don't become scientists, and showing scientists of color as an exception like this could push students away. Dora and I wanted to find how the material already built into science classes could be used to advocate for policies that combat systemic racism. We found very little on the subject.

In this project, I will research ways to fill that gap for high school physics classrooms by studying literature on incorporating anti-racism into science classes, and subsequently creating an example unit using that research demonstrating how it can be done in physics classes. The need for anti-racist STEM education becomes evident from the kinds of global issues humanity has and will continue to face. Modern issues would benefit from people being able to use science as a tool to decide their voting behavior, day-to-day activities, and interaction with the community. This kind of decision making requires the ability to question and argue topics related to science, but current science education is absent of that. By compiling literature on how to craft science curriculum that achieves these anti-racist goals and developing sample curriculum that teachers can use, I hope to make more teachers aware of the potential science classes have in making students organizers against systemic injustice and make the process of developing anti-racist science curricula easier for teachers.

Scope of Research

This project seeks to answer the question "how can students be taught to use science to achieve anti-racist goals" through a literature review and the development of a lesson plan. The literature review will look at past work discussing how to teach anti-racism in high school classes generally, how scholars link the sciences with systemic racism, and methods for teaching the sciences to come out with a set of methodology that teaches anti-racist sciences. This research will not be engaging with the debates that already exist around if anti-racism should be taught in schools, or the attacks on race-conscious education schools around the US are currently facing. This research will also focus entirely on curriculum, the lessons, activities, and projects students work on during the school year, and will not discuss teachers' behavior towards students, school climate, disciplinary measures in school, or any part of the students' learning experience outside of the curriculum.

This research also has a very specific definition of anti-racist science education: education that teaches students how to use science to achieve anti-racist goals (this definition is defended in the literature review). This may differ from other understandings of anti-racist science, such as ones that point out how racism on the part of researchers has led to testing on POC communities, or ones that focus on the exploitative origins of certain scientific fields like geology, which was developed to learn how to best extract oil and other resources from the ground. While it is important to learn about these aspects of science in the classroom, that is not what this intervention aims to do. I fear that such a focus can push students of marginalized backgrounds away from science as it characterizes the subject as something harmful to their communities. This research aims to make anti-racist science education action oriented, with the belief that seeing how science can improve their communities will encourage more students to go into science and use it for positive change.

Background Research

History of Science Education

Science education standards have gone through many sets of reforms in the US. Standards tend to change based on the needs of the cultures at that time (Yager, 2000, p.51). Science education standards didn't exist before the 1890s (Belcher, 2017, p.14). What was taught differed largely from school to school. In the 1890s, due to an influx of high school students and an increase in science due to technological advancements that impacted daily life, science standards were developed by major universities (Belcher, 2017, p.14). The first set of standards focused on laboratory physics, and outlined what sorts of physics labs the Harvard physics department recommended students partake in before college (Belcher, 2017, p.14). Between 1900 and World War 2, standards shifted to be more cost effective and efficient, leading to science standards that prioritized rote memorization rather than learning from experience (Belcher, 2017, p.15).

The Cold War spurred the establishment of the National Science Foundation in the 1950s, which was dedicated to updating science education standards to compete with Soviet powers (Belcher, 2018, p.16). The focus on science curriculum at this time was changed from memorization to developing skills scientists use to understand the world (Yager, 2000, p.51).

Classrooms shifted to teach inquiry through laboratory experiments (Yager, 2000, p.51). Interestingly, they also attempted to separate science and technology, and removed any curriculum related to the technology people interact with on a day to day basis, like telephones (Yager, 2000, p,51). One of the reasons for this was to make the experimentation done in the classroom fascinating and irregular to motivate exploration; the National Science Foundation believed that the science of the everyday would bore students and push them away from wanting to learn science (Belcher, 2017, p.22).

In the 1980s, policymakers decided to prioritize funding projects to experiment with and better understand how people learn and use that research to improve curriculum standards (Yager, 2000, p.52). One of the places that conducted these studies was the National Commission on Excellence in Education under the Reagan administration (Sahin, 2015, p.5). In 1985, Project 2061 began with the mission of improving science literacy (Sahin, 2015, p.4). They put out the Science for All Americans report (SFAA), which had a broad definition of science literacy that included: familiarity with the natural world and respect in its utility, awareness of now science, math, and technology depend on each other, and knowing how to use scientific knowledge for personal and social gain (Project 2061). This definition focuses on the uses of science, rather than knowing science just for the sake of exploration, like previous standards valued.

SFAA's recommendations on material to improve science literacy were based on the contents' utility, intrinsic value, philosophical value, childhood enrichment, and social responsibility (Project 2061). Social responsibility was defined by asking, "Is the proposed content likely to help citizens participate intelligently in making social and political decisions on matters involving science and technology?" (Project 2061). SFAA recommendations are widely cited in literature about improving science education today, and its goals align largely with the goals of this project, to show students how to use science to combat systemic injustice, however the material SFAA puts out and the implementation of these standards have not achieved these goals (Sahin, 2015, p.8). Students cannot learn how to apply science to the real world without understanding how the real world works, and the many facets of inequity that still exist. SFAA standards are positive in how they advocate for students to apply science to political decisions, but doing so in a colorblind way runs the risk of students not having examples and work from class that can mimic the real world, which is not colorblind. As discussed in the literature review, at its very core, science is not a neutral subject, and the way science is studied and performed has already deepened inequity globally.

State of Anti-Racist Education

Anti-racist curriculum is not something that appears in every classroom, and for many teachers it may seem like a new concept that is developing, but it has significant history back in the Black Panther Party's Liberation Schools in 1969. Black panthers opened schools, such as the Oakland Community School, to teach Black youth an honest history of themselves, a counternarrative to the whitewashed history being put out in other schools (Drummond, 2016). These classes taught students to be proud of their heritage and how to participate in movements for Black liberation as they got older (Drummond, 2016). These schools were commended for far above average standardized testing rates and putting out students who became community leaders and activists despite coming from families that faced hardship (Petrella, 2017). The Oakland Community School shows us the kind of impact an environment wholly dedicated to anti-racist practice can have on youth of color, and the future of a community.

While the Black Panther Liberation Schools no longer exist, many organizations have started putting out curriculum that follows similar goals: to teach students an honest history that centers injustice towards people of color and train them to be future activists. The organizations Teaching for Change and Rethinking Schools have taken strides to make this kind of curriculum more accessible to teachers through the Zinn Education Project, where teachers can find lesson plans, worksheets, and advice from other teachers that support them in building an anti-racist classroom (Zinn Ed Project). Looking at these past examples of anti-racist education reveals, however, that almost all of the curricula out there can be used only in history, English, and social science classrooms. The science curricula available on the Zinn Education Project is either inadequate in its impacts by only providing a multicultural education highlighting the work of scientists of color, or it disconnects the political implications of science from the actual content students need to learn (Zinn Ed Project). Most the science curricula available has a focus on environmental justice, which can be a very useful avenue for connecting a topic in science with a conversion on the effects of systemic racism, but these curricula mostly forgo the physical science of climate change and environmental issues students should know to pursue research and organizing in these topics (Zinn Ed Project). This project begins the work filling in the gap left in the Zinn Education Project of anti-racist curriculum that covers science topics.

Methodology

This project produces a literature review of past research to show how a teacher can define and implement anti-racist curriculum into their science classroom. It also produces a sample "proof of concept" lesson plan developed from the literature review teaching about electric circuits and resistance through a wire, and seeing how those concepts can help us understand issues and solutions regarding equitable access to electricity. The literature review has two sections: “What is Anti-Racist STEM Education", and “Building Anti-Racist STEM Curriculum.” The first section studies what past scholars have said about scientific literacy and the purposes of STEM education in order to make conclusions about what anti-racist STEM education should look like. It also compares anti-racist STEM education to multicultural STEM education and highlights their different outcomes. The second section studies different approaches to building science education, specifically constructivism and project based learning, and highlights their benefits in constructing anti-racist STEM education. The second section also explores how mathematics educators have viewed teaching math for social justice and brings out successes and failures in their curricula. This project also produces a lesson plan to show readers what lessons that teach anti-racist STEM could look like. The lesson’s learning goals come from the AP Physics C: Electricity and Magnetism Course and Exam Description, focusing on Big Idea 3: Fields (topics FIE-3A to FIE-3C) (2020 College Board, 2019, p.67). The sample lesson was created using takeaways from the literature review and includes a reflection detailing how each idea from the literature review was used.

Literature Review

What is Anti-Racist STEM education?

My definition of anti-racist STEM education is a pedagogical practice that builds up the knowledge of STEM subjects so that it can be used as a tool to combat systemic injustices against marginalized populations. Systemic injustice here is defined as the methods through which access to resources is denied to groups of people because of race, gender, ability, class, and other facets of identity. Some examples of systemic injustice we see today include the underfunding of schools that primarily serve students of color, the building of environmentally hazardous buildings around communities of color, or the lack of accessible access to buildings for people who use mobility aids. Anti-racism specifically seeks to create equitable outcomes on racial lines, though all of the aforementioned facets of identity are fundamentally linked, so combating racial inequity means also combating all other forms of inequity.

My understanding of anti-racist STEM education, and the definition that will be used for this project, is inspired by understanding science as a subject impacted by dominant oppressive ideologies, and by education for scientific literacy. The following sections will uncover debates around these subjects.

Science as a Non-Neutral Subject

It is a common belief around STEM subjects such as math, physics, and biology, that what is learned in those courses is a hard truth. Social constructions like race and class are seen as to not interfere with how STEM is thought about or taught. Many feminist epistemologists have pushed back against this belief, and while proving that STEM is not a neutral subject is not an aim of this literature review, it is still useful to review some of the arguments of feminist epistemologists as it can shed more light on why emergent views of scientific literacy discussed in later sections are more beneficial to developing students' worldviews in an equity-aligned manner.

Brickhouse writes about how like all knowledge, scientific knowledge will reflect the dominant ideologies of the societies it is developed and practiced in (2000, p.283). Scientific development during the Enlightenment era created gendered dualisms that continue to impact humans' relationships with the natural world and knowledge today (Brickhouse, 2000, p.283). Enlightenment era thinkers created definitions of what is wild or domestic, culture or nature, objective or subjective, and many more dualisms that were mapped onto definitions of what is masculine and feminine, with the side of nature and knowledge that is masculine holding more value in society (Brickhouse, 2000, p.283). These concepts and divisions scientists observe in the natural world are also socially constructed rather than proven with any sort of fact or truth (Brickhouse, 2000, p.283). Social inequities on many facts of identity are both mapped onto these divisions and deepened as a result of those divisions being supported and enforced (Brickhouse, 2000, p.284).

One key example of this idea is the way science was conducted when the US military was doing nuclear tests on the Bikini Atoll during the Cold War. Bikinians, the original inhabitants of the Bikini Atoll were asked to vacate their ancestral home in 1946 so that the US military could conduct many nuclear bomb tests in the area after it came under US control after World War 2 (Teaiwa, 1994, p.89). That atoll and many surrounding islands became uninhabitable due to severe radiation, and the islands the indigenous populations were relocated to were not able to sustain their ways of life, so these tests led to significant loss of life and culture for these people (Teaiwa, 1994, p.91). This story makes clear the kind of value the US military gave to Bikinian lives, and how enlightenment dualities that are a part of science are mapped onto the racial hierarchy. Bikini Atoll was chosen in part because it was classified as remote and wild, an area hundreds of miles from any sort of metropolis or majorly populated center (Teaiwa, 1994, p,89). The area was, of course, populated by the people of the Marshall Islands, but a majority of Marshallese people and land did not fall under western conceptions of what civilization looked like or what domesticated land was, assigning it to be of lower value, making it acceptable to conduct nuclear tests in this area (Twaiwa, 1994, p.90). A similar project was done at the Nevada Test Site, located 65 miles from Las Vegas and in operation from 1951 to 1992, which resulted in many people, especially indigenous populations, becoming sick and having their land become dangerous all through radiation exposure (Atomic Heritage Foundation, 2022). The US military was conducting science in both of these sites as they sought to understand how nuclear bombs worked and could become most effective, but the subject was separated from human life, or did not value all human life, so science was conducted in a way that caused immense harm to so many communities. These stories demonstrate a political investment in physics; discovery and deeper understanding in its topics was done to further western imperialism and military control. A "neutral" approach to science which only prioritized discovery without heed for how those discoveries affect human life is also to blame for these catastrophes. The example shows how science as a subject cannot be neutral or separated from society, and how if one tries to practice it neutrally, it only ends up upholding existing structures of domination that do not care for all life.

This paper specifically looks at physics because of how it can be less intuitively connected to racism and systemic oppression. The aforementioned example shows one way that physics is not a neutral subject. Barad describes the Newtonian worldview dominant in physics which assumes that the truth can be distilled from studies of the natural world that obscure any reference to the scientist or any human, who would bring subjectivity into the field (1995, p.46). Barad shows how feminist sensibilities can be brought into scientific study and application to make alternative ways of understanding the world more promising, and can point directly to how to use science for positive ends (1995, p.68). The questions still remain, however, of what anti-racist science taught in schools should look like, and more specifically, what kind of anti-racist science all students, no matter their future career path, need to know. These questions help us defend the definition of anti-racist science curriculum brought up in this section, and understanding different views of scientific literacy is a valuable way to answer these questions.

Scientific Literacy: How Should Students Understand Science

Scientific literacy does not have a widely accepted or standard definition amongst academics, though as mentioned previously SFAA has a definition that informs national standards. Norris and Phillips found eleven definitions of scientific literacy from literature on the subject, showing the diversity of ways people understand the subject (Norris & Phillips, 2003, p.225).

Norris and Phillips make a distinction between fundamental and derived definitions of scientific literacy, arguing that most definitions we have available are derived from other forms of literacy, mainly reading and writing, and applied to the sciences (2003, p.226). Norris and Phillips ask us to accept this gap, and instead argue that reading and writing are what is fundamental to scientific literacy (2003, p.231). Any scientific theory requires the use of text to convey information it is putting out, so the goal of learning scientific literacy is to read and interpret scientific text (Norris & Phillips, 2003, p.231). Interpretation of scientific texts is not fixed, and is always the result of discourse, so people with scientific literacy should be able to create their own conclusions from reading and observing scientific information, using the texts as bounds for interpretation (Norris & Phillips, 2003, p.232). This way of viewing scientific literacy is notably different from the SFAA definition described in the background section. This definition doesn't really include an understanding of the natural world or knowledge of scientific facts, rather focusing on the ability of someone to read, understand, and make conclusions from scientific texts, which is more similar to how basic literacy is described. This interpretation of science literacy shows us how interlinked different school subjects are, and how science classrooms should not only focus on teaching facts about science, rather they should build on skills taught in other classes high school students take, like English and history, and apply them to scientific contexts.

Valladares compiled texts about scientific literacy and came out with three distinct visions for scientific literacy that build upon each other (2021). These visions expand on Norris and Phillips' view of scientific literacy and connect the topic to anti-racist ends. Vision one focuses on making sure students know scientific facts, preparing students to become scientists, while vision two acknowledges that most students will not become scientists, and rather contextualizes science in students' lives and cultures, as well as the historical dimensions of science (Valladares, 2021, p.564). Vision two has students use science to solve societal problems (Valladares, 2021, p.565). The third vision incorporates elements of visions one and two and attempts to make a science for transformation, where science is taught to be used for liberatory ends (Valladares, 2021, p.565). Valladares describes vision three as moving students from science advocates to honest brokers, who take ethical consequences and historic injustices into account as they make scientific solutions to societal problems (2021, p.565). Roth and Barton and Hodson all put out visions for scientific literacy that best match vision three but apply it more effectively to what it looks like in day to day practice, and what education with that goal in mind could look like.

Roth and Barton view science as one of many resources people can use to influence decision making (other resources could be personal morals, legal understanding, and cultural relevance) (Roth & Barton, 2004, p.22). One example of scientific literacy in action that they provide is many people interrogating environmental consultants insisting that water contamination is not present in their city at a town hall looking for community input on this topic. Scientific literacy shows up from everyone bringing up their personal experiences with the water, questioning the methods the consultants used in testing water, and using their background knowledge of how the water systems in the area works to come to a decision that they should not trust the consultants' assessments (Roth & Barton, 2004, p.48). They saw this as an example of scientific literacy in action because many people used science on top of other methods of reasoning in order to come to a collective decision. Like how Phillips and Norris see scientific literacy, this view incorporates skills of argumentation and history that people may develop in non-science classes but applies them to scientific issues.

Roth and Barton's arguments in *Rethinking Scientific Literacy* focus on what the goal of STEM education should be but leave unanswered the question of how this skill can be taught in a classroom setting. Hodson provides more clarity by describing what science education for sociopolitical action means and what its implications would be (1999). Hodson describes anti-racist curriculum as "a curriculum that educates, enlightens, and changes both attitudes and behavior, and sows the seeds for the reshaping of contemporary society and its underlying values" (1999, p.777). It not only teaches students what the state of the world is and the kinds of injustices that exist, but also provides lessons on how to use certain tools to dismantle systemic injustice. Hodson recommends that teachers bring students to town hall meetings, volunteer events, and organize workshops to directly provide opportunities for students to get involved with their communities (1999). Roth and Barton claim that currently, science literacy is defined as being able to question nature without questioning science and scientists (2004, p.3). Being unable to question authority and conduct counter research in this way is detrimental to students' future abilities to make their own informed decisions and leaves them susceptible to repeating the status quo (Hodson, 1999, p.791).

Putting ideas from the four studies discussed together, we can conclude that an anti-racist science classroom will teach students to put together many different skills, not all developed in the science classroom, and use those skills to address science-related inequities. I argue that the teacher's role in building scientific literacy amongst students is to show students how to use reading, writing, and argumentation skills to defend and oppose scientific stances, specifically ones that relate to social justice issues. The section "Building Anti-Racist STEM Curricula" goes into the specific practices teachers can use for this goal.

Building Anti-Racist STEM Curricula

In this section of the literature review, I compile information about theories of science education in order to develop a framework of what teaching methods I think would be most conducive to anti-racist science teaching. Many of the sources discussed in the last section are useful in describing what anti-racist science education should achieve, but there remains a gap on what pedagogical tools and teaching methods are needed to reach that goal.

Dewey's 1910 address "Science as Method" provides the most useful starting place for this literature review (Rudolph, 2014). Like Roth and Barton and Hodson, Dewey believed there was too much focus on the subject matter of science, and believed educators should make sure students understand the methods of doing science (Rudolph, 2014, p.1060). This means that students should be able to identify gaps in scientific knowledge and have the skills to know how to conduct inquiry to close these gaps (Rudolph, 2014, p.1062). Dewey's arguments corroborate views on what building scientific literacy means that were discussed in previous sections. Viewing education through a constructivist lens and having a focus on project based learning are two avenues to help teachers develop anti-racist science curriculum, and develop students' reading, writing, and argumentation skills as they apply to sciences. The following sections will define and defend these positions.

Constructivism

Constructivism has taken off as an ideology that influences many parts of teacher training programs in the last few decades (Hausfather, 2001, p.15). Constructivism refers to education pedagogies that acknowledge how students actively construct knowledge for themselves rather than simply receive it from educators (Hausfather, 2001, p.15). This theory of education prioritizes students' background knowledge as a starting place, requiring teachers to understand where each student is at, and new content is built upon that knowledge through students' active engagement (Hausfather, 2001, p.18). Constructivism utilizes multiple forms of knowledge, builds on prior knowledge of students, and recognizes the social nature of knowledge production in order to ensure deep understanding of concepts (Hausfather, 2001, p.16). This theory of education is primarily student-led, although Hausfather mentions how even lecturing and teacher-led demonstrations can be effective constructivist education techniques, as long as they begin with a students' prior knowledge (2001, p.18). As will be discussed further in the next section, constructivism prioritizes students developing an understanding of subject matter on their own, and this means doing their own investigation, and going through an argumentative process with teachers and classmates to come to conclusions about scientific claims.

Constructivism in Practice

It can be difficult to conceptualize what a constructivist pedagogy looks like in practice, especially for very factual subjects like the sciences. Tytler's compilation of literature on constructivist teaching approaches show a few models science teachers can use to build out lesson plans with this pedagogy in mind, putting theories of constructivism into practice (2002, p.31). The first one he describes is a generative learning model which follows the following four phases (Tytler, 2002, p.31). This model has shown success in European schools.

1. Preliminary: Teachers begin by having surveys and activities for students to identify how students already think about certain concepts while the teacher would study students' views and find evidence which challenges those views.
2. Focus: The class then works on clarifying their own views on a topic by asking questions related to the concept and answering open ended questions from teachers, and finally presenting their view on a topic.
3. Challenge: The teacher would then bring out the scientists' view, which may be different from the students' as an additional but equally valid way of seeing the topic, and begins presenting evidence that the students can challenge and discuss.
4. Application: This lesson finishes by students answering a number of problems of increasing complexity that apply the scientists' view of the concept to different situations, while the teacher facilitates debates and provides support in more advanced problems. Students can try out these problems from both their premeditated view and the scientists'

view and evaluate which approaches make the most sense, while determining gaps that still exist in their understanding.

An interactive approach which modifies the generative learning model has seen success in Australia (Tytler, 2002, p.32). This approach begins similarly, with the teacher determining how students understand the content initially and having the students clarify their views, but rather than practice problems to cement and build on previous knowledge, the class conducts an investigation based on a question they decide will help them understand the content (Tytler, 2002, p.32). The question can be something they all do not have an answer to or all disagree on what the answer is, and the investigation could be an experiment or consulting experts and doing research (Tytler, 2002, p.32).

The final method Tytler brings up has been used in Japanese science classrooms and is somewhat of a mix of the prior two (2002, p.33). Here, the teacher will still begin with understanding students' interests and opinions on the topic, but students can now pursue individual research questions related to the concept, and share findings with the whole class (Tytler, 2002, p.33). This allows multiple angles to be explored, and classes gain a more holistic view of the material. The teacher would help students find patterns, similarities and differences, and potential errors across the class's research, and also encourage students to compare findings with their previously held notions of the concept so they can build on what they previously knew (Tytler, 2002, p.33). This lesson ends by students noting what they want to investigate in the next lesson, to draw cohesion between units (Tytler, 2002, p.33).

These approaches have many differences, but some of the main throughlines between them is that they do not require teachers to be the information experts. Even in the generative learning model, where the teacher shares the scientists' view, the teacher defers authority to the scientist. This removes an expectation that the teacher should know everything about a subject and brings them down to the students' level, which helps facilitate a discussion and argument based class. Constructivist learning becomes more effective with the teacher and students discussing concepts as if they are all investigators engaging the learning process together (Tytler, 2002, p.33). This also ensures students are actively discussing and creating knowledge with each other rather than just consuming knowledge from a teacher (Tytler, 2002, p.34). These methods all do not include correcting students if they have the wrong idea about any subject. Tytler argues that to help students build on preexisting knowledge, they should not be told that assumptions based on preexisting knowledge are wrong, as that will still lead them to a more factual result (2002, p.30). Individual and class level investigations, as they appear in Australian and Japanese science classrooms, can be highly productive in teaching students how abstract concepts are applied in the real world, specifically contexts related to social inequity. Teachers can utilize both to foster teamwork and community understanding as well as encourage the development of individual identities with projects important to students' own experiences.

It is clear from Tytler's analysis that constructivist education can be effective in building scientific argumentation skills and showing students to question and argue against scientists, but Tien points out that this model will not always work when applied to an anti-racist discussion (2022). Tien investigates how to go about having critical discussions that lead to critical conclusions in a constructivist teaching approach (2022). In studying Community High School, one of the Berkeley Experimental Schools that operated in the 1970s, Tien found that having a very open, individualized, and flexible approach to learning actually led to a reproduction of preexisting racial hierarchies in school culture and the content students were learning (2022, p. 12). This school had teachers work with students so they could develop understanding in different subjects like English, drama, and science through avenues they were already interested in (Tien, 2022, p.11). This was a constructivist approach because of how it developed students' skills through individual interests and inquiry (Tien, 2022, p.11). Students who were already interested in activism and social justice were able to act on those interests with support from teachers, but they were a minority (Tien, 2022, p.12). Because of how students share interests and do work with each other, white student needs and interests ended up dominating school culture, pushing Black students out (Tien, 2022, p.12). Tien states that Community High School prioritized student autonomy over racial integration and the development of anti-racist ideals (2022, p.13). Constructivist pedagogy went too far in this school and ended up being counterproductive to anti-racist goals.

Tien compares Community High School with Black House, a school founded in response to the failings of Community High, that prioritized teaching for Black power and Black liberation (2022, p.14). All classes were centered around subjects as they related to Black peoples' culture, and teachers would often lecture in order to make sure students were engaged with an honest history of Black people and learned survival skills that would benefit the Black community (Tien, 2022, p.15). Black House also used constructivist pedagogy (Tien, 2022, p.16). Former students discussed how Black House teachers would ask students to relay their experiences with Blackness and use that as a starting point when discussing social issues impacting their community (Tien, 2022, p.16). Students' own experiences were a valued part of knowledge production in Black House, which developed their own racial consciousness (Tien, 2022, p.17). Curriculum would include student directed projects that benefited the community, allowing students to develop problem solving skills and understand what liberatory work means and looks like (Tien, 2022, p.16). Tien notes that constructivism worked in Black House and not

Community High because Black House tied constructivist practices to a critique of the present social order (2022, p.17).

Applying Tien's intervention on constructivism to science education as Tytler does, we can conclude that in order for a constructivist, anti-racist science pedagogy to be successful it must be rooted in anti-racist critiques and encourage students to explore relationships between science and inequity. For this to function in practice, teachers can choose a social issue for students to explore alongside a scientific topic, and ask students to discuss, explore, and research where that scientific topic appears in how people are currently addressing that social issue. Students' understanding of the topic would be built through real world application, specifically application to combating inequity, fulfilling the goals of anti-racist education.

Project Based Learning

Project Based Learning (PBL) has potential as a method for teaching science that can center anti-racist learning. This is a teaching method that asks students to derive projects that address real world problems and apply learning to things that impact their lives. Such a learning method has been shown to develop students' understanding of scientific topics and aligns with constructivism's self-directed style of teaching.

Some of the education models that came out of research done in the 1980s include modeling education and project based learning. Researchers in Arizona State University began emphasizing modeling education for physics, meaning teaching students how to create and learn from models that describe physics phenomena (Belcher, 2017, p.24). These models could be used to complement real experiments students can conduct. Being able to construct mental models to recreate a real experiment on paper proves to be a useful skill in solving physics problems (Belcher, 2017, p.33).

There is convincing evidence that students undergoing PBL have a better grasp of core science and math topics. A framework for science education published by the National Research Council Division of Behavioral and Social Sciences and Education: A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas provides a useful outline of what project-based learning looks like (National Research Council et al. 2012). We mainly see PBL in the framework for Scientific and Engineering Practices, which encourages students to use experiments and personal investigation to understand scientific concepts (National Research Council et al. 2012, p.11). It teaches the student the concept while also building research and experimentation skills. PBL was not introduced to schools through SFFA, though it would make sense that the recommendations in SFFA were influenced by findings and theory around PBL because they include many interactive activities for students in their model curriculum (Sahin, 2015, p.6). Histories described by organizations pushing for PBL seem to indicate that it was first conceived by people like John Dewey and Maria Montessori, who founded their own schools with alternative pedagogical practices, around the late 1800s and early 1900s (Doles, 2012; Edutopia, 2001, LiFT Learning, 2021). Later, the initiative of individual teachers in K-12 schools in the late 1900s brought about a push for academic studies comparing PBL with rote memorization which gave the concept further legitimacy (Doles, 2012; Edutopia, 2001, LiFT Learning, 2021).

Researchers have tested the effectiveness of PBL on understanding common core science standards through randomized control trials (Harris, 2015, p.16). They found that students who underwent PBL outperformed in tests administered by the researchers than those who did not (Harris, 2015, p.16). This study specifically used the National Research Council Division of Behavioral and Social Sciences and Education framework as its model for project based learning

(Harris, 2015, p.16). The study also found that there was only a significant impact when PBL was supported by district administrators, and the teacher did not have to acquire all resources and training for this style of teaching independently (Harris, 2015, p.17). Another study looking at how well students in Israel engage in discussions about socioscientific issues found that if the discussion learning format differs dramatically from how science is taught in a classroom (as in if it is taught in a rote memorization style), students are much less receptive to the discussion (Tal & Kedmi, 2007, p.26). The same unit that went over socioscientific issues related to the Mediterranean (such as who has ownership and access to what ecosystem resource the sea provides) was taught to multiple classrooms. The lesson encouraged open dialogue between communities that the researchers believe set the stage for future involvement in environmental issues, and helped students understand the daily applications of science (Tal & Kedmi, 2007, p.26). Tal and Kedmi's study is significant as it shows how it is not enough to teach the facts of science through memorization, and the anti-racist applications through discussion, rather they need to be taught congruously to be effective. It is clear from these studies that PBL helps students understand both science and socioscientific topics better.

Learning from Mathematics Curricula for Social Justice

Few examples exist of curricula that follow the definition of anti-racist science education posed in this paper, but those that do largely fall into the field of mathematics and are strongly influenced by Gutstein's work: *Reading and Writing the World with Mathematics: Toward a Pedagogy for Social Justice* (2005). Gutstein lists three social justice pedagogical goals and three mathematics pedagogical goals in helping teachers craft curricula for a mathematics for social justice (2005, p.24). Gutstein's social justice pedagogical goals teach students more about their social position, societal inequities, and ways to combat injustice, while mathematics pedagogical goals focus on the skills learned from math (2005, p.24). Gutstein claims that both sets of goals build each other up to strengthen student engagement and understanding of how to use math to deal with social problems (2005, p.24).

Social Justice Pedagogical Goals:

1. “Reading the world with mathematics,” or to use math to understand power and resource inequities (Gutstein, 2005; p.24). One example Gutstein provides is a project asking students to think about alternative ways military budgets can be used to service their community, which ended with students determining that one B-2 bomber could fund college scholarships for their schools’ graduating class for almost 80 years (2005; p. 26). This lesson made an abstract $2.1 billion number (the cost of a B-2 bomber) mean something in terms of their livelihoods and community, allowing them to read the world using mathematics (Gutstein, 2005, p.26).
2. “Writing the world with mathematics,” which means showing students how they can use math to change their social and material conditions (Gutstein, 2005, p.27). This idea of Gutstein closely mirrors the definition of scientific literacy posed by Roth and Barton, and the definition of anti-racist science education used for this paper (2004). An example given of a curriculum that achieves this goal is a study conducted by a high school statistics class of the disproportionate number of liquor stores in their predominantly Black neighborhood that was presented to their city council (Gutstein, 2005, p.27). Gutstein acknowledges that while this level of engagement with the city may not be feasible for every unit and every school, demonstrating to students how their math skills can make a positive impact on their community can have important ramifications to students’ understanding and engagement with the material (2005, p.27)

3. "Developing positive cultural and social identities," which means to help students engage with and develop their individual identities through mathematics curriculum (Gutstein, 2005, p.29). Gutstein doesn't provide a concrete example of what this can look like, but identity can be expressed through encouraging students to explore science-related questions that engage cultural elements they see in their household (like Barton & Osborne (1995) suggest in regard to multicultural chemistry classes for Mexican American students). Students can also express their individual identities by relaying their findings through creative means, like painting, rapping, or dancing. Caswell, et al. shares an example of students learning to compare large numbers by determining how much money in Ontario's budget was used for different services (2011, p.84). By sharing results creatively, students were more engaged with the content (Caswell, et al. 2011, p.84).

Mathematics Pedagogical Goals:

1. "Reading the mathematical word," which means building mathematical power amongst students, making sure they know how to do math so they can use those skills for broader goals (Gutstein, 2005, p.29).
2. "Succeeding academically in the traditional sense," which refers to doing well on standardized curriculum imposed on schools (Gutstein, 2005, p.30). Gutstein acknowledges that standardized testing models do not work for many students and that the system itself puts many students at a disadvantage, but also recognizes the socioeconomic uplift that comes from doing well on standardized tests so one can graduate high school and attend college (2005, p.30)

3. "Changing one's orientation to mathematics," refers to changing the perception that math is irrelevant to students' lives (Gutstein, 2005, p.30). Gutstein proposes to link math to real world injustice, in contrast with teaching through rote memorization and repetition, or with connecting math with everyday activities like shopping and traveling, which may not show any need for change (2005, p.31).

The mathematics-focused framework Gutstein provides follows much of the theory already developed in this paper about practices for anti-racist science education, but it is useful to review Gutstein's work because of how influential it is on this part of anti-racist STEM. Many teachers have written about their experiences teaching curriculum inspired by this set of goals. The Center for Urban Schooling based out of the University of Toronto provides multiple math lesson plans that claim to incorporate Gutstein's view of what math for social justice should look like for grades 3-8 (Center for Urban Schooling). Caswell et al. conducted a study on student and teacher responses to these lessons and found that teachers felt more confident in their teaching and traditionally unengaged students were more participative in the classroom as a result of these lessons (2011, p.81). The next two paragraphs focus on two of those lessons, *Importance of Water* and *Fair Trade*, and discuss successes, failures, and lessons learned from those units.

Importance of Water intends for 8th grade students to learn about volume and capacity conversions, while also demonstrating hardships that come from water scarcity. The lesson follows this structure:

1. Students collect rain in a rain catcher over one weekend and bring it to school.
2. Students discuss how effective their method of catching rain was, and what could have been improved to keep more water in the jugs.

3. Students are told facts about water scarcity around the world, and are told how lack of access to clean water hurts peoples' health. Students also contribute by discussing how their lives would change if they did not have access to clean water.
4. Each student is asked to determine how much water they have collected using many different units, so they can practice converting between mL, cm^3, L, and m^3.
5. Students are asked to estimate their family's water consumption on a weekly basis, attempting to put numbers to actions like handwashing, showering, or gardening. Students are asked how this compares to how much rainwater they could collect, and what they would do if they did not have access to that much water.
6. For the final exercise, the teacher tells the students that people around the world have to travel 6 kilometers for clean water. The teacher marks 5 meter lengths around the room, and asks students to go back and forth on those lengths as many times as they can, and to report how much they could walk in terms of kilometers. Students are asked to compare this with the 6 kilometers people have to travel to get water, and this exercise serves as a demonstration of the reality people with water scarcity have to face.

Importance of Water effectively teaches students a mathematical skill (unit conversions), and teaches students about a scarcity issue, however it does not encourage social change. Merely telling students about an issue does not automatically demonstrate it as being an equity issue. The lesson could be improved with a demonstration of how water scarcity is manufactured for a lot of Global South communities. Coca-Cola has been accused of extracting water from communities in Central America and India, in ways that do not leave enough for local people (JBArev, 2016). This topic opens the way for a rate-flow problem, where students are asked to determine how much water is remaining given how a certain amount flows into a reservoir from rain on a weekly basis, how much is taken out from a Coca-Cola plant on a weekly basis, and how much is left over for locals to use. This discussion can move into a lesson on consumer choice, where students learn about how their consumer decisions impact company profits and can improve the conditions of people affected by those companies.

Fair Trade intends for 8th grade students to learn about fair trade and the global clothing market, and assesses their ability to use graphs and percentages to analyze and present data. The lesson follows this structure:

1. Students look at each of their clothes and determine where each article of clothing was made.
2. They write their findings down on post-it notes, and stick them onto a world map on a wall indicating which countries their clothing came from. Most clothes will likely come from Global South countries.
3. Students are asked why they think this is, and to see if the brands they are wearing are American or if they are based in the countries of production. The teacher brings up the concept of fair trade, giving students the chance to define it, and describes how producers in other countries are often taken advantage of by being underpaid.
4. Students are then asked to map the frequency data taken from the class survey in a graph of their choosing, in what they think is the most effective way to represent the data, and they present these graphs to the rest of their class. They are also asked to present proposals to make the clothing industry more fair to workers abroad.

This lesson effectively teaches students about sampling and graphical analysis, while also explaining a concept important to equity discussions they may be having amongst themselves or with families. It does not necessarily push students towards any action, but the language of free trade and other economic terms is important for students to know to be able to make claims and arguments about global equity. It could be improved by a discussion of what activism for free trade has looked like in the past. Looking at boycotts and strikes of clothing companies in the past and quantifying losses incurred by the companies because of those measures can illustrate how much power community has for improving conditions of workers in other countries.

Takeaways to Build Anti-Racist STEM Curricula

Constructivist approaches to science teaching involves viewing how students understand certain science concepts, having a discussion about their understanding and other ways of viewing the natural world (from scientists) to come to a new understanding (Hausfather, 2001, p.16). Allowing students the opportunity to question science and scientists helps build the confidence to question authority, and becomes a natural lead in to questioning how other parts of society operate. Project based learning offers a way for students to engage deeply in their community through impactful and creative projects that apply what they learn about how a STEM concept is connected to a social justice issue. Rather than providing any specific method for curriculum design, Gustein provides very specific pedagogical goals anti-racist STEM curricula should follow to best meet students' needs (2005, p.24). It could be helpful for educators to see if their curricula fit these goals to test if the curricula accomplish anti-racist goals for students. The goals of "reading the world with mathematics" and "writing the world with mathematics" are essential to connecting STEM concepts with real world problems (Gutstein 2005, p.24). Students should understand that STEM can be used to describe and solve issues of systemic injustice. Integrating these three ideas will be beneficial for teachers hoping to implement anti-racist STEM education in their classes.

Electricity Access Lesson: A Proof of Concept for Anti-Racist STEM Curricula

About this Lesson

This is a lesson with a final project designed for students to learn about formulas for resistance, how their power grids work as a circuit, and how the current economic model of electric utilities fails people in rural areas. This lesson is designed around AP Physics C: Electricity and Magnetism and goes into Big Idea 3: Fields (topics FIE-3A to FIE-3C), taken from the AP Physics C: Electricity and Magnetism Course and Exam Description (2020 College Board, 2019, p.67). The required topics of AP Physics C: Electricity and Magnetism and structure were used out of convenience for the structure it provides, but this project requires no calculus, and only assumes some understanding of Ohm's law and Kirchoff's loop and junction rule, which are taught in many non-AP physics classes, and delves deep into the formula for resistance in a conductor. This project is suitable for any high school physics or science class which hopes to connect coursework on circuits with issues of equitable access to electricity.

In groups, students will conduct independent research on multiple avenues to learn how to solve issues related to making electricity more accessible. Students are encouraged to approach this from a physical route (determining what materials should be used for a power line, or what sources of energy would make most sense for a community), from an economic route (interrogating the profit incentives with which energy utilities operate, and explore alternative models for energy distribution), and any other paths students want to explore. Ultimately, they will become intimate with electric circuit diagrams, how power grids work, what public goods are, and how rural electrification issues are connected with issues of neglect of Indigenous communities on reservations.

How to Use this Resource

This lesson provides a minute-by-minute plan for teaching topics on electric circuits by connecting those topics to social justice issues, or teaching circuits in an anti-racist way. Teachers using this lesson are encouraged to adapt it to meet the needs of their classroom. This can mean only using some of the activities, changing the length of certain parts of the lesson, or taking the content and teaching it in ones' unique style. The overall project this lesson is part of is about anti-racist science curriculum and does not focus on classroom management practices, so the text below does not describe teaching strategies and rather focuses on tasks for teachers and students to express how to use science for anti-racist means. Teachers are encouraged to use classroom practices that encourage equity and belonging when teaching this content.

Lesson Details

1. **Content Area**: Physics, Electric Circuits
2. **Total Length**: 250 minutes teaching, 5 days to complete the final project.
3. **Enduring Understanding**: Students will understand how the physical properties of a wire impact how charge flows through the wire, learn about how electricity is distributed over a grid, and understand the causes and solutions for issues of electricity access.
4. **Essential Question**: By what processes does electricity become available in our homes?
5. **Summative Assessment for Unit**: Students will present a research report on ways to improve electricity access.
6. **Navigation:** This lesson is split into 6 activities. Each (except for Activity 0 which is a worksheet for students to fill before class) has a teacher agenda and a student agenda. On the teacher agenda, *italicized* text lists actions for the teacher to do, and italicized text lists things the teacher should say or ask students to do.

Activity 0: Understanding where students are at

Worksheet (two questions) to be completed and shared with the teacher before the first class period. *The teacher should read through the responses and make note of common threads among students' thinking.*

Answer the following questions based on your prior knowledge and the information in the below passage.

> For most Americans, their homes and businesses are connected to a power grid from which they are supplied with electricity. Electricity is produced at a power plant and distributed widely via transmission lines. Some electrical energy is lost during transmission, especially over long distances, so power plants produce much more energy than what a household uses, to account for what is lost during transmission. This system is often operated by a public utility company, a company that develops and maintains the infrastructure for the power grid. Utility companies make a profit by charging those connected to the power grid a little on top of the costs of maintaining the infrastructure (labor and materials costs). There is usually only one utility company allowed to operate within a certain service area as it can be redundant, costly, and harmful to city aesthetics to have many power lines, power plants, all operated by different companies, in one area. This means utility companies have a monopoly in their service area.

1. What information do you think would be important for someone designing the process to supply your neighborhood with power? Think about characteristics of your city (population, area, etc.) and the design of the power grid distributing electricity.

(Example response) I live in a suburban city, so we do not have as many residents as a more metropolitan city, closer to 100,000 people who would use the grid. It is also more spread out, with more individual homes and less apartment buildings, so energy likely has to travel more before it reaches anyone's home. The area I live in has flat terrain, and does not have large storms often, so wires sending electricity can be above or below ground. I would want to know the shape of the city and where homes are concentrated. Having the power plant be close to the most residential areas means the least amount of energy would be lost via transmission, and the power plant would have to produce less energy.

2. It can be very difficult to transmit electricity over long distances. Why do you think that is? Provide at least 3 possible reasons.

(Example response) As distance increases, the materials cost of the wire needed to transmit electricity increases. Wires are naturally not always able to hold onto electricity, and over large distances that energy may be lost through diffusion processes with the air. As distance increases, the chances of the wire being cut from a storm or small animal chewing on the wire also increases because the wire is longer and will be exposed to more of the elements.

Activity 1 Mini-Review of Ohm's Law (40 min)

Learning Goal: Review Ohm's Law and series and parallel circuits.

<table>
<tr><td>Agenda (Teacher)</td><td>Agenda (Student)</td></tr>
<tr><td>Ohm's Law; 15 minutes

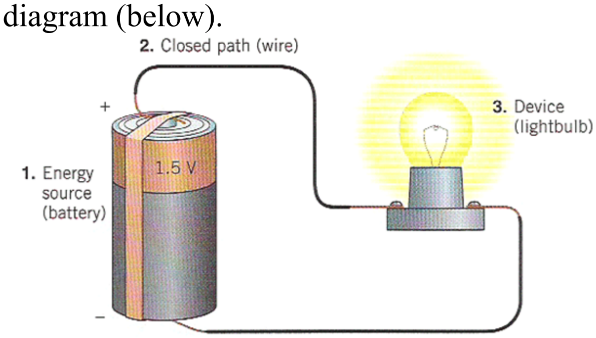
Briefly re-explain Ohm's Law and the formulas associated with it. Because this is review, to increase engagement the teacher can ask students to define terms and write out formulas on the board in this section.

Most students are likely familiar with Ohm's law, given by I=ΔV/R.

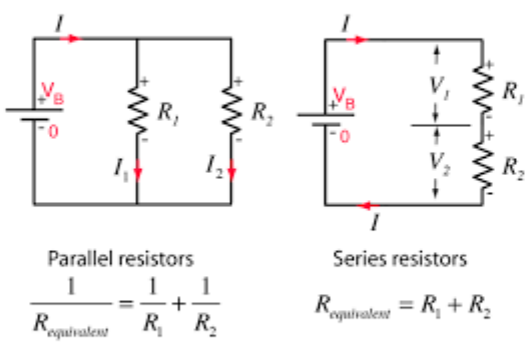
I represents current, given in units of Amperes, or Coulombs per Second, which is the flow of charges in a circuit.

ΔV represents Voltage or Potential Difference, given in units of Volts, or Joules per Coulomb, which is the energy supplied to a circuit.

R represents Resistance and is given in units of Ohms (Ω). Resistors are devices such as light bulbs or vacuums that use up energy supplied to the circuit.

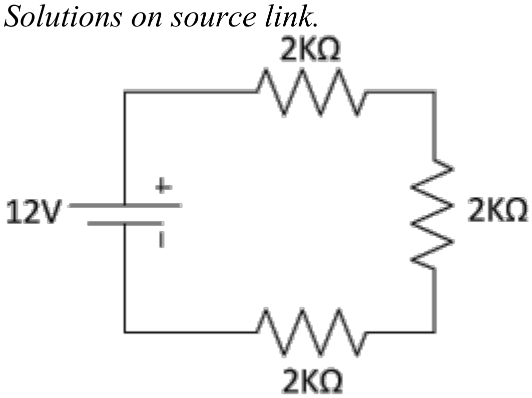
Students are also likely familiar with the basic circuit diagram (below).


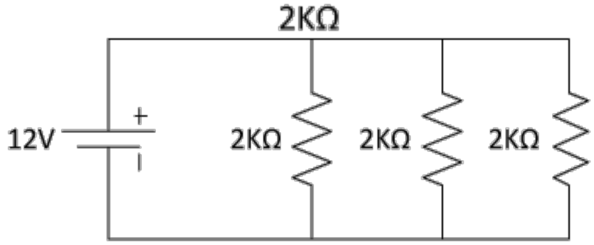
The battery supplies a potential difference and can start current flow (from Positive to Negative). As electrons flow across a device (lightbulb or any other resistor),</td><td>Listen to the teacher re-explain Ohm's law, engage in answering and asking questions about the topic.</td></tr>
</table>

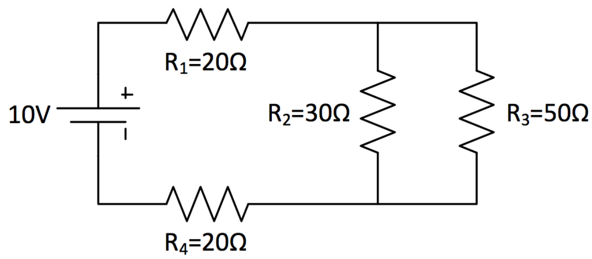
they create an electric field used to power that device. The power (energy per second) used by the device is given by the formula P=IΔV, where P is power with units Watts, or Joules per Second, I is current, and ΔV is potential difference across the resistor. Just as there is a positive potential difference (an increase in energy) across a battery which supplies energy, there is a negative potential difference across each resistor as they use energy. The sum of potential differences in a loop circuit must always add up to 0.	
Series and Parallel Circuits*; 15 minutes* *Also review: Explain the difference between Series and Parallel Circuits, and allow students to solve 3 practice problems to check understanding of Ohm's law before moving on to the Rural Electrification Project.*  (Image taken from here) (Nave) Total resistance formulas are dependent on how they are connected in a circuit. Significantly, how current and voltage behave at junctions is important to understanding how much power is used by resistors connected in parallel. The total voltage or electric potential difference along any loop must be equal to 0. In the first diagram, there are two loops, one across the battery and R1 and one across the battery and R2, so the voltage drops across R1 and R2 must equal 0. Current once meeting a junction (where the wire splits into parallel) must add up to the current in the wire before the junction, so I=I1+I2. *Question for students* There is a third loop that crosses R1 and R2 but not the	Listen to the teacher re-explain parallel and series circuits, engage in answering and asking questions about the topic, solve check for understanding problems provided by the teacher.

<table>
<tr>
<td>battery. Why is the total potential difference in this loop 0?
Answer
The current is positive when going from the positive end of a battery or power source to the negative end. In the R1R2 loop, the loop we draw is in the opposite direction of current for either R1 or R2, so the current we use to calculate potential difference becomes negative, and the potential difference becomes positive, and the total potential difference for that loop is 0.</td>
<td></td>
</tr>
<tr>
<td>Practice Problems; 10 minutes

Practice problems (taken from here) (APlusPhysics, 2017).

Draw/project each of the circuits below for students and have them work with a partner to find potential difference, current, and power dissipated across each resistor. Walk around and support students who may be struggling with these problems with their thinking. Solutions on source link.






</td>
<td>In groups of 2, find the potential difference, current, and power dissipated across each resistor for each of the 3 circuits drawn.</td>
</tr>
</table>

Activity 2 Understanding how Power is Distributed (100 minutes)

Learning Goal: Understand the mechanics of a city wide power grid.

<table>
<tr><td>Agenda (Teacher)</td><td>Agenda (Student)</td></tr>
<tr><td>

***Rotation learning about Power Grids**; 80 minutes*

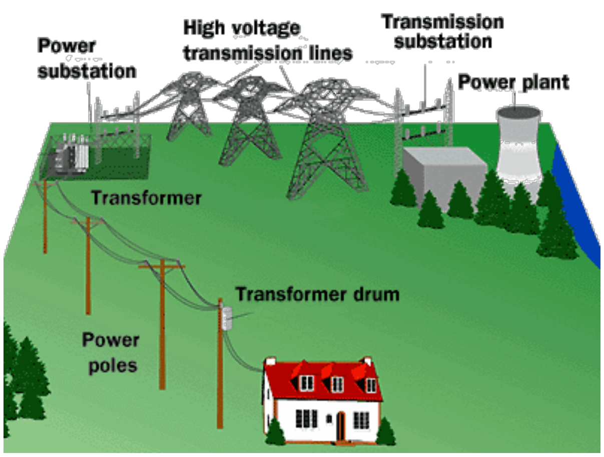
Paste 7 pieces of poster paper around the room, each accompanied by markers/something to write with. Label them as following:

1. Power Plant
2. Transmission Substation
3. High Voltage Transmission Lines
4. Power Substation
5. Transformer
6. Power Poles
7. Transformer Drum

Under each write, with enough space under each:

1. What is this used for?
2. What does this look like in my city?

Project the following image for students



(image taken from here) (Brain)

Assign students to 7 groups and have them each go to one poster with a laptop/some device they can conduct research with.

Explain that the projected image shows what the power grid of a typical city looks like, and that their task is to learn about how this process works as a class. Explain

</td><td>

Rotation: Do as much research as you can on the piece of the power grid you are assigned to in a certain time frame and write it down on the poster. Rotate and continue this for every poster. The first two groups can have 7 minutes, and every subsequent group can have 10 (as question 2 takes more time to answer). The first few groups at each poster can answer question 1, and once subsequent groups feel question 1 is sufficiently answered, they can move on to question 2. The 4th to 7th group at a station should only answer question 2.

Share out: Once everyone has been at each of the 7 stations (or when the teacher ends the exercise), go around and have each group share highlights, the answer to question 1 and what they find most interesting from question 2, on the poster they are currently at.

</td></tr>
</table>

the activity (Listed in the right column) and provide the following advice. Some helpful guiding questions for question 2 can be: - Where are power plants or power substations in my city? How many are there? - How does the power plant produce energy? - Are transmission lines and power lines underground or in the air? What materials are they made of? - How do transformers work? - How many people are served by each transformer drum? If information for one's specific city is not available, students can try searching for these answers for a city of a similar size, or for information on power grids generally. It could be helpful to look at their energy utility company's website for answers. *If at some point before the 7th rotation, the teacher feels students are struggling to find new information to put down, the teacher can end the activity and move into the share out portion.*	
20 minutes Discussion *Once students are back in their seats, lead a class discussion on how the power grid we see is similar to an electric circuit the class worked with in the last section, and ask if their answer to question 1 of the prework (What information do you think would be important for someone designing the process to supply your neighborhood with power?) has changed.* Some prompting ideas: - The power plant serves a similar role as a battery. - By what means did we find that transformers reduce the voltage provided to our homes to 240V? Powerful resistors in series can reduce further down a series circuit.	

Activity 3 Understanding the Rural Electrification Issue Part 1 (70 minutes)

Learning Goal: Students should understand physical reasons for why there are steep costs to electrifying rural areas, specifically communities in the Navajo nation.

Pre-work: Have half of the students read article 1 from POWER (Larson, 2020), and the other half read article 2 from Brookings (Tanana & Bowman, 2021).

Article 1: https://www.powermag.com/did-you-know-there-are-60000-u-s-citizens-who-lack-access-to-electricity/

Article 2: https://www.brookings.edu/blog/how-we-rise/2021/07/14/energizing-navajo-nation-how-electrification-can-secure-a-sustainable-future-for-indian-country/

Agenda (Teacher)	Agenda (Student)
Discussion of Articles*; 20 minutes* *Ask 2 students who read each article share something about them; something they learned, were surprised by, or felt from reading the article. After each student goes, encourage response from other students who also feel strongly about the idea shared, or any related ideas they want brought up.*	Discuss the 2 articles as a class.
Addressing Barriers to Electrification*; 10 minutes* *Read the following quotes (or refer to what a student said if the quotes were brought up in the previous discussion*) Article 1: "The Navajo Tribal Utility Authority's (NUTA) service territory is vast, and it only averages about four customers per mile. Furthermore, the per capita income in the region is only about $10,700, which is about one-fifth the U.S. average of $53,497, according to The World Bank." Article 2: "The average cost for NTUA to connect a home to an existing electric distribution line is $40,000." *Ask the class*: Given what we learned yesterday about how power grids work and this information, why do you think it costs so much for NTUA to electrify homes? I asked in the first worksheet for this class why it is difficult and costly to transmit electricity over long distances. Does anyone want to share a few ideas on	Answer questions posed by the teacher in class discussion.

why that is?	
Resistance Formulas; *25 minutes* Wires themselves actually have some amount of resistance. Even copper wires, which are very good conductors, are not perfect, and some amount of energy is lost as current moves through these wires. The formula for resistance through a wire is dependent on the length of the wire, its cross sectional area, and its resistivity, which depends on the material. Use the following simulation to determine the formula for resistance. Based just on cross sectional area and length of the wire. https://www.thephysicsaviary.com/Physics/Programs/Labs/ResistanceOfWireLab/ Each time you click on the wire, its length will change by a random amount, and each time you click on the cross section, its area will change by a random amount. (thephysicsaviary) (*Note: a simulation was used for accessibility to more classrooms. If a clamp meter to test amperage, a battery, and multiple lengths and cross sections of wire are available, that can be used to perform a similar test, with students using the clamp meter and battery voltage to find resistance of different wires)*	Students may already know that to find the resistance formula, they should plot resistance against each cross section or length and determine what the relation is. The teacher can assist students struggling to figure this out individually.
Application of Resistance Formulas; *15 minutes* We have found that resistance is directly proportional to length and inversely proportional to cross sectional area. Resistance is also directly proportional to resistivity, which measures how easy it is for charges to flow through a material. Colder metals have very low resistivity, and warmer objects and things like rubber and wood have high resistivity. What does this mean for homes that need to be connected to a power grid far away? How would you use this information to reduce barriers to electrification? *Write down ideas students have for later.*	Students should now be able to tell that the fact that resistance increases with length would add additional costs to the electrification of Navajo communities.

Activity 4 Understanding the Rural Electrification Issue Part 2 (40 minutes)

Learning Goal: Students should understand the failures of the current model of electric utilities in providing rural communities with electricity.

Agenda (Teacher)	Agenda (Student)
Introducing the For-Profit Model*; 20 minutes* Most electric utilities currently operate in a for-profit model, where they charge customers, everyone drawing power from the grid that they operate, an electric bill that constitutes the costs of maintaining the grid plus some extra for company profits. This model of electricity distribution can exacerbate problems of rural electrification and make electricity less reliable. Why do you think this is, based on prior knowledge and our discussion in previous classes? How would you design the economic system for electricity distribution that deals with issues of rural electrification? Discuss this with a partner for 5 minutes and have some theories and additional questions you would want answered to understand this question better ready. *Ask students to share the results of their discussion and take note of student responses on a whiteboard, marking theories worth exploring and questions to be answered separately.* *Ask students which questions posed can be combined (because they cover similar ideas), and have a final list of under 5 questions*	Answer questions posed by the teacher in class discussion.
Learning about Public Goods*; 20 minutes* *Have students take 7 minutes to read this article about failures of the current model of utility companies in Illinois (Kibbey, 2021):* https://www.nrdc.org/bio/jc-kibbey/utility-accountability-101-how-do-utilities-make-money *Ask students if anything we learn in this article answers any of the questions posed from the last part of this section, or if it brings up new questions to explore* What is the specific issue Kibbey is trying to address,	Read the article provided by the teacher, and answer questions posed in class discussion

and how does it relate to rural electrification? *Kibbey discusses how the for-profit utility model incentivizes companies to focus on forms of growth that keep prices high over making clean and reliable forms of energy accessible to all. Instead of expanding to rural areas who do not have reliable power, energy companies will stick to the same areas of operation as it leads to more profits.* Public power offers an alternative path to the for-profit models most utility companies have. Public power utilities are services run by local communities working to fill each other's needs. With the incentive being to meet community needs rather than making a profit, more reliable, sustainable, and accessible energy decisions can be made. For one example of what this has looked like: **Emerald People's Utility District, Oregon,** (20,800 customers) began its life as a public power utility in 1983, after separating from a private utility that offered poor customer service and poor reliability. The new utility created payment assistance programs to help its customers, conservation and energy savings programs, and community outreach programs including participating in local festivals and outreach to schools. The utility has won local, state and national awards for its outstanding customer service and has been featured in two best-selling management books for excellence in customer service. (Publicpower.org, https://www.publicpower.org/system/files/documents/municipalization-benefits_of_public_power.pdf) Public goods model a potential solution to the rural electrification issue by making electricity access a right that everyone must have, rather than a commodity that people can buy and sell. What other goods and services, beyond electricity, could benefit from removing a profit incentive? *The descriptions of public goods have less formal lecturing because it should draw largely from student questioning and inquiry. Some students will also become experts on this topic and present it to the class for the next activity.*	

Activity 5 Researching and Presenting Solutions to Electrification Access Issues

Learning Goal: Students should attempt to become experts in a specific topic related to electricity distribution and know how to present that topic to their classes.

The lesson culminates in the following final assignments.

Deliverable 1 (Due day 1): Project Proposal

- Form a group of up to 3 people (or decide to work alone)
- Choose a topic related to electricity access to delve into. Can be one of the topics above or a different topic entirely. The topic they choose should respond to a problem related to electrification access, and their research should relate in some way to one of the topics discussed in this lesson (Ohm's law, resistance formulas, power grid structures, economics of electricity distribution).
- Brainstorm questions you need to answer to effectively talk about and become experts on your topic. Make a plan about how you will research these questions.

Deliverable 2 (Due day 3): List of resources and final argument

- This deliverable serves as a paper outline.
- Students will have an argument their presentation will make, along with a sketch of what the rest of their presentation will look like, with some of the supporting facts for the main argument laid out with resources backing them up.

Deliverable 3 (Due day 5): Project Presentations

- Students will express what they learned over the week they spent working on this project to the rest of the class in a 7-20 minute presentation (length scaled by how many students are in the group). The presentation can take whatever forms students wish, including a play, a class demonstration, a short video or podcast, or a standard powerpoint presentation. Students are encouraged to share their expertise creatively.
- The class, when listening or watching the presentation, will ask questions and write notes on what they learned.
- The class will also provide feedback, two things they appreciated from the presentation and two things the presenter(s) could have done to make the conveyed information clearer written and handed back to the presenter.

Potential Topics for student inquiry:

1. How can a private utility model be transitioned to a public utility model
   a. Consider: What kind of action do residents need to take? What would the pushback be? Are there legal issues in your area that would make this more difficult?
2. Public vs Private vs other economic models for utility companies
   a. Consider: What models for distributing utilities exist beyond the public and private ones we have discussed in this lesson? Which model do you think would create the most equitable outcomes?

3. Going off-grid
    a. Consider: What does it mean for an entity to go off-grid in terms of its power consumption? What are the costs and benefits of disconnecting from the power grid? What investments are needed to pursue this style of living?
4. Renewable energy to solve rural electrification issues
    a. Consider: Can electrification be made more accessible if instead of coal-fired power plants cities used solar or wind farms, or other kinds of renewable energy?
5. New materials and methods
    a. Consider: Look at different types of wires, with different materials and cross sectional areas. Would switching to a different kind of wire, or changing the infrastructure of a power grid in a different way, make it easier to "plug in" households living far from the grid, such as the Navajo families we learned about in activity 3? Choose one thing to change, explain what the benefit would be from a physics and access standpoint, and discuss potential costs.

Students can delve into one of the above topics, or a different topic of their own choosing, as the final assessment for this lesson. The research project can start once Activity 4 is completed. This project consists of 3 different deliverables so that the teacher can provide feedback in turn, along with a completed rubric and grade at the end of the project. The final deliverable will be a presentation to teach the class what the group learned about their topic. Students are going to be assessed on how well they convey the material and are encouraged to convey it in fun and non-traditional manners (something other than a PowerPoint presentation), as to express themselves and make their lessons more engaging.

Sample Rubric *(to be shared with students)*
Students should self-evaluate their success in meeting each standard after their presentation, and the teacher can take their opinion into consideration when delivering a final grade.

	Exceeds Standard	**Meets Standard**	**Approaching Standard**	**Needs Support toward Standard**
Standard #1: *Students show a depth of understanding of their chosen topic.*	Students engage with a wide array of sources when presenting their topic, are able to respond to further inquiry by students and the teacher, and understand gaps in their own	Students engage with a wide array of sources when presenting their topic, and are able to respond to further inquiry by students and the teacher.	Students delve into key pieces of literature for their topic, but could look at a more diverse set of sources and ideas.	Students demonstrate that they have researched their topic, but could search for additional sources answering key questions related to their topic.

	knowledge and in current literature on the topic.			
Standard #2: *Students share information in a clear and concise way.*	Students are able to emphasize and make sure the audience understands key points. Students present their argument in a clear and concise way. The audience is not overwhelmed with a list of facts.	Students present their argument in a clear and concise way. The audience comes away with a solid picture of key points related to their topic.	Students show that they have a clear argument that the audience can understand, but there is room for the defense of this argument to be improved with a clearer structure.	Students show that they have an argument, but a litany of facts or lack of structure makes it hard for the audience to understand the argument fully.
Standard #3: *Students express their knowledge in an engaging and creative manner.*	Audience feels encouraged to actively listen to and engage with the students' presentation. There is active participation during and after the presentation. Audience questions and feedback indicate that they heard and learned from the students' presentation.	Audience feels encouraged to actively listen to and engage with the students' presentation. Audience feedback indicates that they learned from the presentation.	Audience enjoys and appreciates the lesson, and is clearly learning new material, but there are points where the presentation feels monotonous, which influences audience engagement.	The audience is clearly learning new material, but the delivery of the presentation may have made it difficult for the audience to internalize key points.

End of Lesson

Reflection on the Lesson: Applying Constructivism and Project Based Learning

This lesson employs discussion on constructivism for science education as described by Tytler (2002). As discussed in the literature review of this project, constructivist science teachers build on the preexisting knowledge and belief systems of the student to introduce new ways of looking at the natural world (Tytler, 2002, p.31). The lesson is also heavily influenced by Gustein's social justice and mathematics pedagogical goals, except adapted to a broader STEM context. Below list each pedagogical goal and the way this lesson meets that goal.

Social Justice Pedagogical Goals:

1. Reading the world with STEM: By looking at the issue of rural electrification in terms of resistance in wires, students understand some of the basic physics issues in play in this social justice issue and can begin to ask questions of why we have a system that will not serve certain communities just because of where they live.
2. Writing the world with STEM: Students' final research projects ask them to express and create solutions to electricity access by understanding them as physics issues and using either physics or alternative ways of viewing essential resources to create solutions.
3. Developing positive cultural and social identities: This lesson begins with students studying their own communities so that being a part of a larger community becomes a greater part of the students' cultural identity. Also, in presenting the final project creatively, students can discover passions in arts and performance that builds their identities.

STEM Pedagogical Goals:

1. Reading the STEM word: This lesson is for a physics class and does not stray far from the STEM topics in electric circuits and power grids they need to know for the class.

2. Succeeding academically in the traditional sense: As this lesson is designed from an advanced AP Physics C level, the kinds of understanding the social justice and STEM pedagogical goals promote can deepen understanding of physics topics they must know for that class and final AP exam. Gutstein writes that both mathematics and social justice pedagogical goals are needed to fulfill each other; that one cannot teach mathematics properly and in an engaging way without a social justice curriculum. Combining the two will help students succeed academically.
3. Changing one's orientation to STEM: Showing physics as something with real applications to their daily lives and being an integral part of how their community operates increases investment in learning about the subject.

This lesson begins with a worksheet to understand what students know about how they get electricity and how resistance works in wires. The teacher takes note of the students' preexisting knowledge and presents alternate ways of thinking in activities 2, 3, and 4, either directly or through having the students conduct their own research. The worksheet also primes them to start thinking like an engineer or city planner going into this lesson. The rotation exercise in activity 2 is meant to give students freedom to explore power grids as they relate to their own community. Students building an understanding of how systems in their community work helps them develop a sense of authority as someone with a say on how their power grids should be operated. The process of researching and sharing key ideas is also a skill they can build and use for organizing work and future research projects. Activity 3 begins to connect the topic of circuits to a real social justice issue, bringing those abstract concepts even closer to human experience. Activity 3 looks at the justice problem as a physics problem, to present one way of understanding issues of electricity access. By showing how physics can be used to explain limitations in electricity access, students build a positive political investment into learning physics, learning it for social good. Activity 4 employs constructivism by first gauging what students know about the economics of the electric grid currently and asking them to spot issues with it. Students build on that knowledge by learning about alternative ways of viewing this energy issue, through the lens of public goods, which can provide resources more reliably and in an equitable manner. Students can explore this topic, or other topics brought up in the lesson in Activity 5, where they become experts in topics like public goods and alternative designs for power grids and present arguments to the class. Tytler discusses the strategy of students identifying what they do not know about a subject and conducting and presenting research into that subject as a common constructivist technique that fosters personal investment into the material. Tai and Kedmi also research how the investigative approach, which is a kind of project based learning, can foster discussion of social issues regarding a project's study, as that is something bound to appear when students are conducting research. (2007, p.26). Overall, constructivism and project based learning offer useful templates for curriculum design for anti-racist science learning.

Conclusion

By compiling literature on anti-racist science education, I am providing an accessible resource for science educators who are open to anti-racist pedagogy but lack the time to navigate the field. The accompanying curriculum that I developed is a useful framework for what anti-racist curriculum can look like for subjects like physics, that often seem completely apolitical and neutral on face value. The literature review and accompanying lesson plan show how constructivism and project based learning offer useful templates for curriculum design for anti-racist STEM education. In future research, I would like to test these curricula that incorporate anti-racism into sciences and see if they support students' understanding of the materials better and if they succeed in fostering a greater understanding of systemic injustice. As educators increasingly experiment with incorporating anti-racism into the sciences, teaching pedagogies other than constructivism and project based learning can be compared alongside each other and further identify the diverse array of methods for teaching science from an anti-racist lens in different educational contexts.

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