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Preservice Teachers Learn: How Coal Keeps the Lights on

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Abstract

At the end of 2022, there were 2439 coal-fired power plants operating around the world, and over 7000 active coal mines (Global Energy Monitor, 2022). Coal burning was the largest source of greenhouse gases that impact climate change, and coal mining caused extensive environmental damage (US Energy and Information Administration, 2022). Decisions about the use of coal in energy production are made by world leaders, but everyday citizens vote for and appoint those leaders. Do everyday citizens understand the most basic science about coal? Do the teachers who are supposed to educate them in their youth? Energy literacy is so important; it leads to informed decisions about energy use at home, wise consumer choices, and to national and international energy policies (DeWaters & Powers, 2011). In this study, 56 pre-service elementary teachers were asked if they understood how coal was used to produce electricity. They were then taught using a constructivist teaching methodology including manipulatives, diagrams, videos, and group discussions (Schnittka, 2017). After the lesson, they were asked again, "How does coal keep the lights on?" Pre-test scores were very low, but gains were strong from pre to post-test. In a delayed post-test, the participants who retained the concepts the best over time had discussed it with a friend or relative. For long-term retention and the ability to potentially apply a concept to everyday life, teachers must realize that learning gains can be ethereal, and that they need to build in tools to aid in long-term retention of concepts. More importantly, teachers need to understand the science and engineering behind the technologies that impact our world so severely, so that they can pass on lessons to youth and advocate for a sustainable future.

Keywords: energy literacy, concept retention, sustainability education, power plant, coal

Introduction

An informed, literate society requires informed, literate teachers. Teachers are a vital force for social change (Iliško, 2007) and sustainable development (UNESCO, 2022) and this is especially important when it comes to concepts that impact our survival as a species and the environmental health of the planet. For example, burning coal is the largest source of greenhouse gases that impacts climate change (US Energy and Information Administration, 2022). There are 2439 coal-fired power plants operating around

the world, and over 7000 active coal mines. Nearly half of all power plants and coal mines are in China, and there are hundreds of coal-fired power plants in the United States and India, and hundreds of active coal mines in Australia, India, Indonesia, Russia, South Africa, and the United States (Global Energy Monitor, 2022). Despite initiatives to shut down coal fired power plants, coal power production is at an all-time high (World Economic Forum, 2021). Do today's youth understand this? Do their teachers? Decisions about the use of coal in energy production are made by world leaders, but everyday citizens vote for and appoint those leaders, and these everyday citizens are educated by schoolteachers. One of the 17 sustainable development goals outlined by the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2022) is to ensure all learners "acquire knowledge and skills needed to promote sustainable development." Another goal is to ensure access to "affordable, reliable, sustainable and modern energy for all." This study investigates how well preservice teachers understand how coal is used to produce electricity, a key component of sustainability literacy which targets two of the UNESCO goals, and describes an intervention used to help them understand coal science and engineering.

At the most basic level, misconceptions about energy begin at a young age and can easily persist into adulthood. Even the term, "energy", is used non-scientifically in everyday language such that the scientific meaning is often obscured. In addition to the many non-scientific uses of the word, children often form their own scientific theories about energy. They think that energy is a fluid or ingredient which flows from one place to another to make things work. They think energy can be used up, and that it is required for motion (Watts, 1983). Middle school students lack knowledge about energy resources, including where fossil fuels come from (Bodzin, 2012) and secondary students have low energy literacy overall (Akitsu & Ishihara, 2018; Barrow & Morrisey, 2010; DeWaters & Powers, 2011). Misconceptions about energy resources persist into adulthood, even for teachers (Rule, 2005). Without a basic understanding of energy, a more complex understanding of energy transformations is impossible, and an understanding of sustainable energy is out of reach. Explicit interventions are needed to target these conceptions (Watts, 1983).

Karlijn van den Broek (2019) reviewed the literature worldwide on four types of energy literacy: device, action, financial, and multifaceted, and found that energy literacy is quite low overall. While environmental education interventions have had positive impacts on cognitive knowledge about energy, there is not definitive evidence that current energy education interventions result in changed behaviors related to conservation and energy saving. Martins, Madaleno, and Dias (2020) conducted a literature review on the knowledge, affective, and behavioral dimensions of energy literacy. They found moderate levels of energy literacy in Taiwan (Lee et al., 2015), Denmark (Sovacool & Blyth, 2015), and New Zealand (Aguirre-Bielschowdky et al., 2017), but low levels in the US, Portugal, Switzerland, and Finland. None of the studies that were reviewed mentioned the coal → electricity system. DeWaters and Powers (2007, 2008, 2012) established an energy literacy questionnaire which covered the cognitive, affective, and behavior dimensions of energy literacy. The cognitive dimension included concepts such as the 1st and 2nd laws of thermodynamics, the relationship between energy and power, and energy sources. The questionnaire did not cover the coal → electricity pathway.

The National Research Council [NRC] (2012) describes energy as a disciplinary core idea that spans all the grades and cautions elementary teachers to be very careful

about using the word "energy" inappropriately in elementary school due to the ease with which it can be used incorrectly and plant the seeds of misconceptions. Energy is also a crosscutting concept which spans topics in the life and physical sciences. The NRC advises that by the end of grade 5, students should understand that energy can be transferred from place to place by electric currents, which can then be used locally to produce motion, sound, heat, or light (NRC, 2012, p. 125). Grade 5 teachers should be able to understand and teach how motion created by burning coal can generate electricity. Teacher education programs have been given the charge to integrate lessons on sustainability into their programs (UNESCO, 2009), and some have (Merritt, Archambault, & Hale, 2018), but there is little research on teachers' understandings of how coal is transformed into electricity. The power plants that dot our landscape are mysterious black boxes to so many. Something like coal or water or uranium or natural gas goes in, and magically, electricity comes out. Fusion power research is now in the news with major advances being made (Tollefson & Gibney, 2022). How many world citizens understand that this too will be used to boil water, make steam, and turn magnets? Black boxes can be dangerous items in science and technology if the privilege that comes with understanding the workings inside the box is held by only a few, namely world leaders. If not taught in schools, how should citizens learn about energy issues and sustainability from a scientific perspective?

Theoretical Framework

The theoretical framework used in this study to teach the participants and interpret the results can be described as social constructivism (Vygotsky, 1978). Pre-conceived ideas were elicited, and then participants were provided with opportunities to build on their mental models as they engaged in hands-on experiences and interpretive discussions with each other and the teacher (Schnittka, 2017; Palinscar, 1998; Tobin & Tippins, 1993; Von Glaserfeld, 1989). The collaborative and social nature of the lesson meant that participants could learn more together than they could alone. Negotiating new ideas with the instructor, who acted as a "more knowledgeable other" (Vygotsky, 1978) provided scaffolding as participants constructed models to help them understand the role of coal in power generation. Since we did not actually visit and tour a coal-fired power plant, building mental models and visualizing them was necessary. Mental models are internal models of reality which people build, and they are useful for understanding something that is abstract or theoretical and are built upon when new knowledge is added (Johnson-Laird, 1983). As we represented the system of power generation with a drawn version of our mental model and discussed it, we were using tools. Vygotsky theorized that when tools are used, particularly speech, people can function at a higher level. Our construction of a model acted as an "object to think with" by making an abstract concept more concrete and tangible (Papert, 1980).

The Purpose of the Study

The purpose of this study was to explore pre-service elementary science teachers' conceptual understandings of how coal is transformed into electricity prior to and after instruction. Specifically, the study addressed the following questions:

1. What are pre-service elementary science teachers' conceptions of the transformation of coal to electricity?
2. What is the effect (near-term and far) of an energy lesson on pre-service elementary science teachers' understanding of how coal is used to generate electricity?

Research Methods and Participants

Over the course of three years, 56 pre-service teachers participated in this study, which was approved by the Institutional Review Board of the university they were attending. These pre-service teachers were undergraduates in their senior year of college enrolled in a 3-credit elementary science methods course at a state university in a midwestern US state. The course featured weekly activities that modeled the 5E Learning Cycle (Bybee et al., 2006) and was based on inquiry in a social constructivist framework of instruction. Alternative conceptions were assessed on a regular basis, both before and after instruction. Energy, as a theme, ran through the semester, with lessons on thermal energy, sound energy, energy flow in ecosystems, and electrical circuits. All participants had previously completed the required number of college courses in physics, geology, biology, and chemistry. Four of the participants were male, while 52 were female. Four were African American, one had Asian ethnicity, one had Hispanic ethnicity, and the rest had European ethnicity. Most participants were in their early 20s.

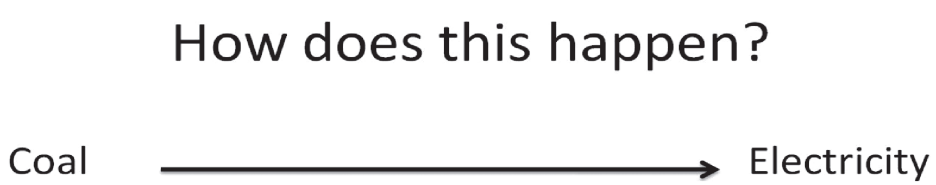
This research, while qualitative in nature, was an interrupted time-series design, a quasi-experimental design where one group is administered a treatment, and posttest scores are compared with pretest scores, with delayed posttests administered later (Ferron & Rendina-Gobioff, 2005).

Assessment

An open response question prompt was used for the pre- assessment, the post-assessment, and the delayed post-assessment. This assessment was chosen because it closely targets the goals of the lesson, and is therefore instructionally sensitive (Ruiz-Primo et al., 2012). The question, "How does this happen?" was accompanied by two photographs connected by an arrow. The first photo was of coal, and the second was of an electric power pole. See Figure 1.

Figure 1

Assessment



Responses to the prompt were scored using the following rubric for a possible total of 10 points. This rubric was based on the main components of the process taught in the lesson. One point was given if the participant mentioned that…

coal was burned	1 point
water is involved	1 point
water is boiled	1 point
steam is produced	1 point
something is turned or moved	1 point
a turbine is involved	1 point
magnets are involved	1 point
coils of wire are involved	1 point
a generator is involved	1 point
energy is involved	1 point

To assess the validity of this assessment, it was also administered to 36 mechanical engineering undergraduate students in the final semester of their senior year, with the assumption that these mechanical engineering students should perform the better than the preservice teachers prior to instruction, and that the pre-service elementary teachers would score the same or better than the engineering students after instruction. Cronbach's alpha was computed for the administration to the engineering students to be $\alpha = .669$. An independent sample *t*-test indicated that the engineering students did indeed score higher than the pre-service teachers before their lesson on energy with the teacher mean of 1.68 points out of 10, and the engineering student mean of 4.58 points out of 10. An independent samples *t*-test demonstrated that these means are significantly different ($p < .001$). After instruction, the pre-service teachers' post test scores were the same as the engineering student scores ($p = 0.86$) with a post test mean of 4.71 out of 10 possible points.

In order to assess inter-rater reliability for this assessment, a second rater was trained and given a subset of 32 of the pre-service teacher tests. Scores from the two raters were compared after several trials and many discussions, and the rubric interpretation was clarified. The inter-rater reliability was determined to be 98.4 %.

Instruction

Instruction took place during one 90 minute class period toward the end of the semester. During the semester, participants had experienced many physical science energy lessons in the science methods class about magnetism, sound, electricity, heat, and motion. They had enough knowledge from the semester to make sense of an elaboration of these basic concepts. The goals of the instruction were to assess prior knowledge, provide concrete sense making activities that addressed prior conceptions, and finish up with an interpretive discussion of what was learned. To do this, stations were set up around the room, and participants moved in groups from one station to the other until all were completed. At each station, participants were asked to do a task and discuss the energy transformations taking place. The instructor asked probing questions as she walked around the room from group to group, and tried to elicit ideas and provide connections from prior knowledge to new ideas. The stations are described below.

Sound tubes

Sound tubes are long cylindrical tubes with ridges. Three lengths were provided. Participants were asked to spin each of the three tubes above their heads and listen for differences. They were asked to use their prior knowledge about sound to discuss what

created the sound energy, and determine what kind of energy was transformed into sound energy. This activity helped participants create mental models about motion and energy.

Hand-held generator with bell

A hand-held generator was connected to a doorbell that worked because of an electromagnet and a metal hammer clanging on the bell. Participants were asked to crank the generator forwards and backwards and observe the action at the bell. They were asked to use their prior knowledge about electric circuits and sound to discuss how they thought energy was transformed from the cranking hand to the electricity entering the bell, to the sound made by the bell. They had to make close observations to notice the electromagnet and make inferences based on their knowledge of electricity and magnetism. This activity was their first exposure to the concept of electromagnetism.

Hand-crank flashlight and hand-crank generator

A flashlight that operated when a crank was turned and an antique table-top generator with a large light bulb were present at this station. Participants were asked to make both lights come on and carefully observe the similarities between both systems. They were to use their prior knowledge of electric circuits and light bulbs to make inferences about how the energy was transformed.

Radiometer with light, hair dryer and turkey baster

The blades of a radiometer spin when heated. This is due to small forces created as the gas next to the dark side of the blades gains more kinetic energy. Participants were asked to try and make the radiometer blades spin with a turkey baster, a hair dryer, and a shop light. Using knowledge about heat transfer gained in previous lessons, participants were asked to make inferences about which type of energy was making the blades spin. This activity introduced the idea that heat can cause motion.

Solar cricket with shop light

A solar cricket jumps around when light is shined on it. The cricket has a small solar cell on top and a very small electric motor that spins. The motor wobbles, which makes the cricket move around on its thin spindly legs. Participants had previous experiences with solar cells and with motors, and they were asked to observe the system and describe the energy transformations taking place.

Dissected motor

At this station, participants were presented with a dissected electric motor. The magnetic pieces were colored red and blue, and the magnet wire coils were very easy to see. The participants were asked to use their prior experiences with magnets and motors to draw, examine, and determine how an electric motor uses electrical energy to produce kinetic energy. They were asked to compare this motor to the hand-crank generators they had experienced and make a comparison between motors and generators.

Wind turbine model

A small wind turbine was wired to a Light Emitting Diode (LED). When a hair dryer was turned on and pointed at the blades of the turbine, the bulb glowed. Participants

were asked to use their prior knowledge about hand-cranked generators to determine how kinetic energy from wind was transformed into light energy. This activity was the ideal precursor to the lesson on coal which followed.

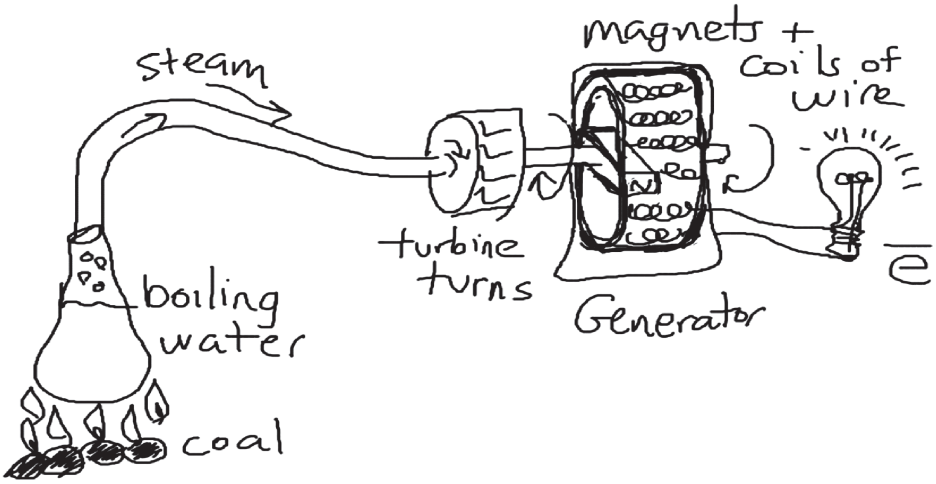
All materials for the stations were readily available, generally inexpensive, and easy to obtain. After participants worked through the stations, the instructor conducted a whole class discussion with participants about what was observed and inferred. This was followed by the instructor presenting the class with a large lump of coal and asking, "how does coal keep the lights on?" The following is a transcript of the discussion one semester:

> *Instructor: So here I have a large lump of coal. Now that you've seen many examples of how electricity is created and used in many energy transformations, what role to you think coal plays in the production of electricity that we use in this classroom?*
> *Student A: It's burned in a power plant.*
> *Instructor: Why is it burned? What happens when it burns?*
> *Student B: It gets hot.*
> *Instructor: Yes, but then what is done with that heat? Any ideas? I'll give you a hint, and then I bet you can figure out all the rest from the knowledge you have. The coal is burned in order to boil water.*
> *Student C: What? To boil water? Just to boil water? But why?*
> *(Instructor draws a fire with a pot of boiling water on the board.)*
> *Instructor: What do you get leaving this pot of boiling water?*
> *Students: Steam.*
> *Instructor: What can you do with steam, especially if you collect it and force it into a small pipe?*
> *Student D: Oh! It's like a hot humid wind! You can use it to turn something!*
> *(Instructor draws the steam in a pipe and the blades of a turbine.)*
> *Instructor: This is a turbine that spins. So, what would be connected to the turbine with the blades that spin?*
> *Student A: A generator like the one we used?*
> *Instructor: What do you think is inside a generator?*
> *Student E: A generator is like a motor, like the one inside the hand-held generator and the hand crank flashlight.*
> *Instructor: Tell me what you found inside the motor that was dissected?*
> *Student C: A motor contains coils of wires and magnets.*
> *(Instructor draws a generator with coils of wire and magnets connected to the spinning turbine blades.)*

A diagram similar to the one in Figure 2 was eventually drawn on the board by the instructor from student ideas. Every time this lesson was taught over the course of three years, participants asked why water had to be boiled to make the turbine turn. They asked why another source of moving fluid like wind or water was not typically used. Every semester, the discussion turned to nuclear power plants, and participants were always shocked to find out that nuclear fuel is simply used to boil water. The most basic of tasks, boiling water, was accomplished with the heat transferred from uranium fission.

Figure 2

Diagram on How Electricity is Created From a Burning Fuel



Immediately after the discussion about electricity production, during the last few minutes of class, the post assessment was administered after the board was erased. Participants were not allowed to use their notes during the post assessment. Six months later, the post-test was administered again to a subset of participants.

Delayed Post-Assessment

To determine how well the participants remembered the process, telephone interviews were conducted with a subset of participants many months after instruction took place. Sixteen months had passed since instruction for year 1 participants. Eleven months had passed for year 2 participants, and four months had passed for year 3 participants. An attempt was made to contact each of the 56 original study participants; however, two cohorts of participants had graduated from the university and could not be located. Two of the year 1 participants, four of the year 2 participants, and 11 of the year 3 participants agreed to be interviewed.

During the interview, participants were asked three questions:

1. How does coal turns into electricity?
2. Have you used that particular information in your daily life or teaching experiences since learning it in your methods class?
3. What do you remember about class the day you were taught about coal and electricity?

Results and Discussion

Pre-Assessment

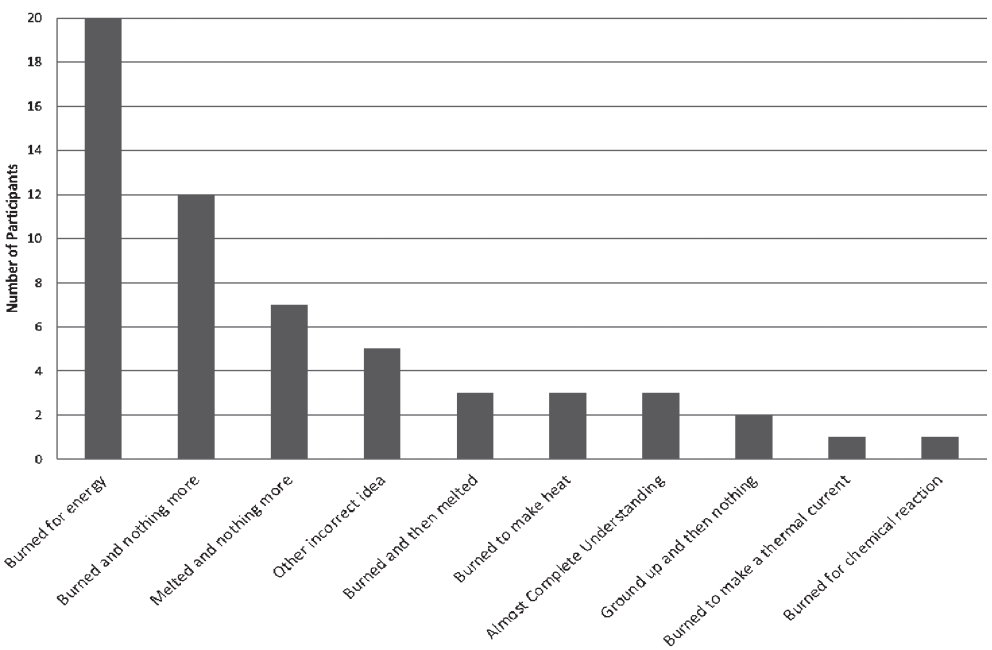
Prior to instruction, participants knew very little about how electricity is generated in a coal fired power plant. When asked the question, they were painfully shocked that they had never considered it before. They developed a thirst for understanding and

were generally frustrated that the instructor would not simply tell them how coal is used to create electricity. Through the process of inquiry and collaborative discussion, they were tasked with figuring out the answer for themselves.

Fifty-six participants completed the pre assessment. Two (3.5 %) had an almost complete understanding about how coal is burned to boil water into steam, which then moves a turbine connected to a generator that contains magnets and coils of wire. The remaining 54 participants had a variety of incomplete and incorrect understandings, primarily around burning, melting, or grinding of coal. Forty-one participants (73 %) stated that the coal is burned; seven (12.5 %) said that coal is melted, two said that coal is ground up, and six had no idea how the coal was used. Of those 41 participants who acknowledged that coal is burned, 20 related burning to energy. They said that the coal produces energy, creates energy, releases, generates, or collects energy, but had no further understanding. Only one student stated that the coal transforms energy, but that was the extent of the understanding. Of the 41 participants who said that coal is burned, 12 had no idea what happened next. One said that burning created a chemical reaction, one said that burning created a thermal current, three said that burning the coal makes heat but had nothing more to say, one said that the coal became magnetic after burning it, and three said that the coal was burned and then melted to produce electricity. Some responses were nonsensical. See Figure 3. Using the rubric created to analyze the responses, the average pre-test score for each of the three years was calculated. Year 1 participants scored 2.1 points out of 10, year 2 participants scored 1.7 points out of 10, and year 3 participants scored 1.4 points out of 10. Combined, the average pretest score was 1.68 points out of 10.

Figure 3

Responses on the Pre-Assessment About How Coal Turns Into Electricity



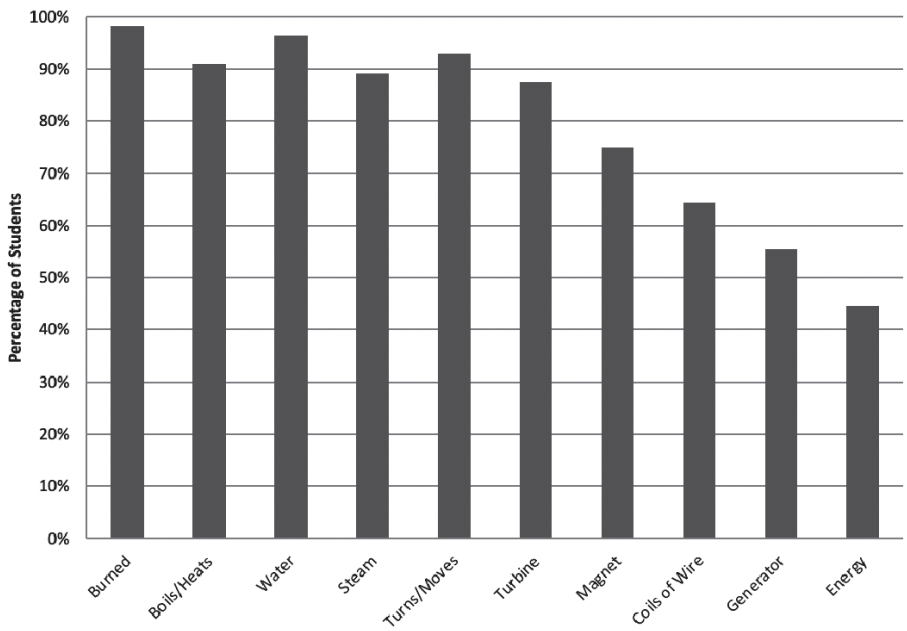
Post-Assessment

Participants invariably expressed great relief after instruction that they finally understood how coal is used to generate electricity. They expressed shame that they did not know this process after attending nearly four years of college. They wondered aloud how many of their friends or family members in would be able to answer the simple question, "How does coal keep the lights on?" They were relieved to have learned this information, and expressed confidence that it would help them make more informed decisions about coal mining, electricity production, and alternative energy sources.

All 56 participants completed the post assessment. They were asked the same, very simple question, "How does coal turn into electricity?" Over 90 % of participants could identify that water is boiled or heated. Over 80 % identified steam as a product the moves into a turbine. Most participants stated that the turbine turns, and that magnets and coils of wire are involved. However, only 55 % of participants mentioned that a generator is involved and only 45 % mentioned energy in their description of the process. See Figure 4 for the frequency of rubric items that were mentioned in the post-assessment given at the end of class.

Figure 4

Participants' Immediate Post-Conceptions About How Coal Keeps the Lights on



An exemplary example of the change in understanding from pre to post is depicted by Janelle's responses (Janelle, pre and post-tests).

Pre-test response: Melt it down by burning it then it is transformed into electricity through the traveling electrons.

Post-test response: The chemical energy of coal being burned turns to thermal energy from the heat of the fire. The fire then boils water which creates steam (wind energy) that then turns a turbine. The turbine travels through a generator (which contains a magnet and coils). This magnetic energy powers through a wire and creates electrical energy by lighting bulbs.

A poor example of change in understanding is depicted by Laura's responses (Laura, pre and post-tests).

Pre-test response: They burn it.

Post-test response: Coal is burned down to dust and then is boiled (thermal energy). Then it travels through a generator with a magnet, which then causes the light to shine.

Responses to the prompt were scored using the same rubric as before, for a possible total of 10 points. If describing 7 of the 10 important elements in the generation of electrical energy from coal (a passing score on most assessments) is considered a successful learning outcome, then 46 of 56 participants (82 %) were successful on the post-test.

Lingering Misconceptions

A detailed analysis of exact word choices and phrasing reveals some lingering misconceptions after instruction. The following list contains these phrases:

Turbine moves air… (Jeremy, post-test).
Magnets and coils react, making magnetism, which turns into electricity (Emmy, post-test).
The chemicals and steam go through a tube… (Rachel, post-test).
Coal… combusts, turns into smoke that makes turbines… (Sakura, post-test).
Coal is burned down to dust and then is boiled (Laura, post-test).
Coal is burned which then turns to boiling water (Amy, post-test).
Coal is burned, then the fuels boil (Cherry, post-test).
Steam is used to generate a turbine (Glenda, post-test).
Magnets + coils of water (Kendra, post-test).

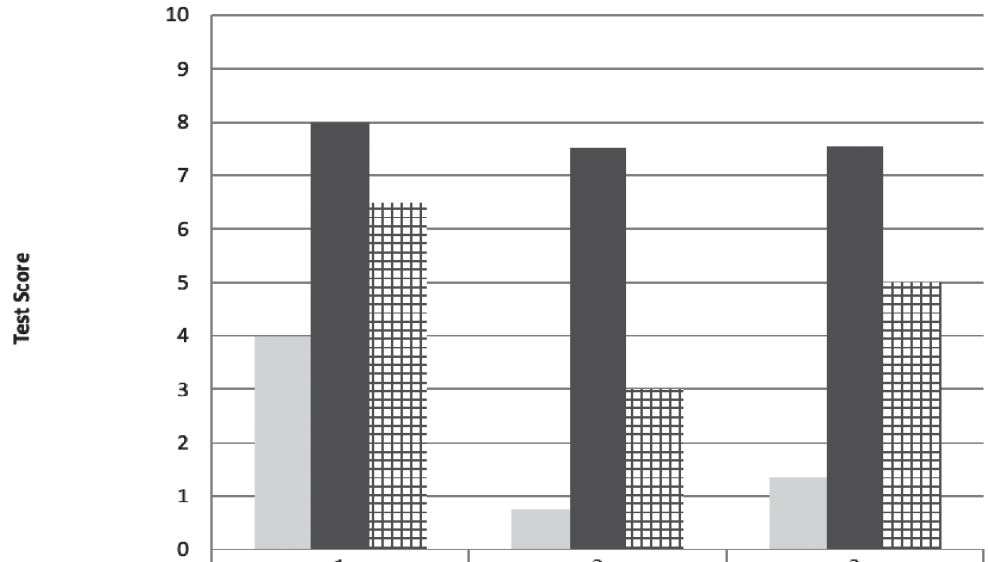
Individual follow up interviews would be necessary to determine whether some of these were the result of hasty writing, or of true lack of understanding.

Delayed Post-Assessment

The telephone interviews conducted many months after instruction were audio taped and transcribed for analysis. Responses to the first question were scored using the same 10-point rubric that was used during the previous administrations of the test. See Figure 5. Responses to the second question were used to try and draw conclusions about why some people did not remember the process while others did. Responses to question 3 were used to try and determine whether the hands-on activities, the discussion, the assessment, or the graphic images helped form the longest lasting memories.

Figure 5

Pre, Post, and Delayed Test Results on How Coal Turns Into Electricity for Three Cohorts



	1	2	3
Pre-Test	4.00	0.75	1.36
Post-Test	8.00	7.50	7.55
+ Delayed Post-Test	6.50	3.00	5.00

Question 1: How does coal turns into electricity?

Table 1 contains scores from the pre-test, post-test, and delayed post-test scores for each interview participant, plus the change value – the number of points lost on the delayed post-test from the score on the initial post-test. A negative value indicates memory loss.

While all participants conveyed more understanding on the delayed post-test than they did on the pre-test, memory loss (calculated by subtracting post-test score from delayed post-test score) did exist in most cases between the time of the post-test and the delayed post-test. The memory loss was mild for cohort 1 and severe for cohort 2. Cohort 3 had a mixture of mild and severe memory loss. See Figure 5. A memory loss of -1 means that one concept was forgotten. Seven of the 17 participants had good retention of the concepts (no more than two concepts lost from post-test to delayed post-test). Ten of the participants had significant trouble with concept retention, forgetting from 3 to 7 concepts. Only 47 % of participants mentioned that water is boiled, and only 18 % mentioned that magnets are involved.

Table 1

Test Results: How Does Coal Turns Into Electricity?

	Pre-test	Post-test	Delayed post-test	Memory loss
Year 1 (16 mo. post)				
Abby	2	10	7	-3
Charles	6	6	6	0
Year 2 (11 mo. post)				
Katrina	1	7	2	-5
Tiarra	1	9	4	-5
Glenda	1	9	4	-5
Amy	0	5	2	-3
Year 3 (4 mo. post)				
Janelle	1	10	3	-7
Rachel	1	8	2	-6
Sabrina	1	8	3	-5
Andrea	2	8	5	-6
Shinetta	2	9	8	-1
Bill	2	8	8	0
Jessica	1	8	6	-2
Laura	1	4	1	-3
Molly	2	8	7	-1
Monica	2	8	7	-1
Sakura	0	4	5	1

Question 2: Have you used that particular information in your daily life or teaching experiences since learning it in your methods class?

When asked if participants had used the knowledge of how coal turns into electricity in their daily lives or teaching experiences since learning the material in their methods class, most participants said that they had not mentioned, discussed, or even thought about the energy transformation. However, seven participants answered that they did indeed use the information in their daily lives. Those who did not discuss the lesson forgot much of it. The group who did not discuss the concepts with a friend or relative after instruction forgot an average of 3.9 concepts. The group who did discuss the concepts after instruction forgot on average 1.4 concepts.

> Abby (year 1, memory loss = -3) had discussed it with her younger brother and her husband.
> Glenda (year 2, memory loss = -5) thinks she may have discussed it with her parents.
> Bill (year 3, memory loss = 0) had discussed it with his wife.
> Shinetta (year 3, memory loss = -1) had talked with her dad about it after class.
> Molly (year 3, memory loss = -1) had talked about it with her friend's mom and discussed why coal was used instead of wood to boil the water.

Sakura (year 3, memory gain = +1) had discussed it with her boyfriend who is an engineer.
Monica (year 3, memory loss = -1) talked with her dad about it because he works for an electric company, and she had talked with her husband who is studying science education.

The participants who retained the lesson the best had, for the most part, discussed it with a friend or relative. Without further research it is not certain that the act of discussing caused better memory retention, but there is a positive correlation between discussing how "Coal Keeps the Lights On" and articulating it in an interview several months later.

Question 3: What do you remember about class the day you were taught about coal and electricity?

When asked what they remembered from the lesson where they learned about coal and electricity, more than half the participants stated that the graphic which was drawn and displayed on the board was their most vivid memory (Figure 2). Less frequent memories were of activities, and few memories were about the pre-test, the PowerPoint, the YouTube video about power plants, or discussions in class.

Emotional Reaction

Several participants mentioned an emotional reaction they had either after the pre-test, or during the intervention. Since research indicates that emotions are often tied to memories and strengthen those memories (Hamann, 2001), this was an interesting find. Charles's story was remarkable. He said, "I'm pretty sure that the only reason I still remember is because I had a sense of pride that I knew how coal turned into electricity. I think that pride helped me to remember it since then (Charles, interview)." Molly, who only forgot one concept, said "I found it weird that the only purpose was to boil water. Why couldn't something else boil water, or something else spin the turbine? (Molly, interview)." Sam, who remembered one additional concept, said, "I've always wanted to know, hearing everyone talk about coal and why was so important, and how you get energy from something that looks like a rock (Sam, interview)." Living in a coal-producing state, they were conflicted that they did not know how that coal was used to produce electricity. "Coal Keeps the Lights On" is an advertisement on television, a slogan on license plates, and a popular song in this region of the US (Kurlinkus & Kurlinkus, 2018). Participants, most of whom grew up in the region, mentioned shock, intrigue, pride, and shame in not knowing how coal was used to produce electricity. It is a tense place to be between these two worlds, the place one grew up in, and the university classroom where sustainability issues are brought to the foreground. Bringing that tension to light is an important step to take (Holfelder, 2022).

Limitations and Future Work

This was a very small study with limitations of sample size and recruitment of participants to take the delayed post-test. Due to these limitations, this study cannot be

generalized to other pre-service elementary teachers. Future work could involve a larger sample with increased efforts to retain contact information for students who graduate from the university. Alternatively, the instruction could take place at the beginning of the semester so that the delayed post-test could take place at the end of the semester, increasing sample size and validity. Also, to test the hypotheses that memory is enhanced when participants talk about the concepts with another person after the lesson, an experiment can be set up whereby half of the students in the class are formally given the chance to discuss and teach a friend, and the other half are not.

Conclusions and Implications

This small research study with only one 90 minute intervention demonstrates a gross lack of understanding amongst pre-service elementary teachers as to how electricity is generated from coal in coal-fired power plants. That the participants were living in a major coal-producing region of the US makes this study even more contextually relevant (Häyrynen, Keinonen, & Kärkkäinen, 2021). Energy transformation is basic cognitive construct of scientific literacy included in the *Framework for K-12 Science Education* (NRC, 2012), and is embedded in UNESCO's goals for sustainable development (UNESCO, 2022). The participants completed almost four years of post-secondary education in preparation to become teachers in a coal-producing state, and still lacked even the most basic understanding about how electricity is generated. If these results are typical, it has severe implications for the energy literacy that citizens lack, which they need to make informed decisions on energy security and sustainability, and environmental protection. Education for Sustainable Development (ESD), with the aim of helping people find solutions for sustainability problems, begins with understanding basic scientific facts (Algurén, 2021; UNESCO, 2014).

Participants who rehearsed their new knowledge by discussing it with a friend or family member right after learning the material maintained it longer in their working memory. These participants had to make their mental model explicit to the person to whom they were communicating, and they must have had a high degree of original learning sufficient to teach it to another. However, participants with a high degree of original learning who did not discuss the concept after learning it lost the concept and could not articulate it well in the delayed posttest.

The instruction, which was aligned with a social constructivist framework, with hands-on explorations and interpretive discussions (Schnittka, 2017), was demonstrated to be successful in promoting learning. If we are to figure out how to stop environmental damage from anthropogenic climate change and come up with alternative ways to generate electricity, it needs to start with education about the impact that burning coal has on the land, the water, and all living creatures. To fully enact this goal, an energy literacy inventory needs to be created and distributed which includes the coal → electricity system in order to find out the degree to which the population comprehends the coal → electricity system. Then, curriculum needs to be developed and distributed with lessons that include the science of how coal "keeps the lights on." This knowledge also helps learners understand how hydroelectric and nuclear power plants function. The US Department of Energy has outlined the essential principles for energy literacy (USDOE, 2017), which includes principle 4.5, "Humans generate electricity in multiple ways," describing that electricity can be induced in a wire when a magnet moves relative to it, but nowhere in

the principles is a description of how coal is burned to heat water, produce steam, and use that steam to move the magnet near the wire. Future research involves creating an inventory for energy literacy need that includes the coal → electricity process, as well as creating and distributing curricula worldwide that embeds this essential concept.

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