

Feminist Pedagogy

Volume 4
Issue 2 *Feminist Pedagogy in STEM: The
Intersection of STEM Pedagogy and Feminist
Theory*

Article 3

Creating Meaningful Connections with the Electron Transport Chain Beyond a Virtual Classroom

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Recommended Citation

Giddings, Lesley-Ann () "Creating Meaningful Connections with the Electron Transport Chain Beyond a Virtual Classroom," *Feminist Pedagogy*. Vol. 4: Iss. 2, Article 3.

Available at: <https://digitalcommons.calpoly.edu/feministpedagogy/vol4/iss2/3>

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Cover Page Footnote

Acknowledgments I would like to thank all of my metabolism students (2015–2021) who participated in these reenactment projects, especially Ahlenne Abreu, Sofia Baptista, Lillian Beaubien, Sophie Chertock, Naomi Falkenberg, and Matlhabeli Molaoli for sharing their work (Figure 1). I would also like to acknowledge Jill Mikucki and Erin Eggleston for their feedback on this work.

Creating Meaningful Connections with the Electron Transport Chain Beyond a Virtual Classroom

Introduction and Rationale

Pioneering feminist educator bell hooks (1994) asserted that education should be the practice of freedom, recognizing students as whole beings—a foundational principle in feminist pedagogy. Courses that center this pedagogy promote community and shared power, challenging the ideas of individualism and authority to create equitable and collaborative learning environments (Webb et al., 2002). However, the shift to remote instruction during the COVID-19 pandemic posed challenges to realizing these notions (Dhala & Johnson, 2021; Lederer et al., 2021). Universities adopted videoconferencing platforms, such as Zoom, Microsoft Teams, and Google Meet, to connect students and faculty worldwide, yet technological issues and the absence of community created barriers to fostering effective and empowering learning environments (Dhala & Johnson, 2021; Jones & Shelton, 2022; Peper et al., 2021). During remote instruction, students developed short attention spans as well as ‘Zoom fatigue’ or exhaustion due to the cognitive demands of virtual platforms of communication (Wiederhold, 2020) and added distractions due to being in new workspaces that were not all conducive to learning (Gillis & Krull, 2020). Furthermore, virtual attendance did not necessarily reflect engagement, as some students would log into class without contributing to class discussions (Hollister et al., 2022). While schools tried to replicate the in-person learning experience virtually, these experiences were not equivalent.

Remote instruction during the COVID-19 pandemic was particularly difficult for marginalized students (Kimble-Hill et al., 2020). For example, students with disabilities struggled in school because they had to do more independent learning without having a full range of academic and student support services (Meleo-Erwin et al., 2021). Economically disadvantaged students struggled to have their needs met, including financial stability, housing (Goldrick-Rab et al., 2020), quiet spaces to learn, or internet connectivity, hindering their full participation in class and widening disparities (Peper et al., 2021). There were also fewer opportunities for students in person to engage in active learning, an effective method for students, especially marginalized students (Nardo et al., 2022), to learn concepts through discussions and completing activities with their peers (Cohn et al., 1994; McGuire & McGuire, 2015). Active learning helps students foster meaningful connections with concepts, instructors, and peers, building community within the classroom. However, facilitating active learning in the virtual classroom was challenging, especially in large lecture courses where instructors could not easily identify students needing assistance, as students were not simultaneously visible on the computer screen (Peper et al., 2021).

In addition to the challenges posed by remote instruction, the pandemic also underscored the need for improved scientific communication with the public (Choo & Lewis, 2021). The spread of misinformation and skepticism exposed the public’s distrust in scientific advancements for personal and public health (de Figueiredo et al., 2020; Gillis & Krull, 2020). To build trust and educate the public, more scientists are recognizing the need for transparency and improved communication, as public engagement results in better-informed decision making (Tuttle et al., 2023). With the shift to remote learning, I saw an opportunity for students to teach their family and friends about the science they were learning.

Here, I present an assignment designed to promote a meaningful understanding of the electron transport chain and its role in oxidative phosphorylation, while building community, decentering authority, and broadening access to science education, upholding feminist pedagogical principles in a virtual biochemistry class.

This original teaching activity aimed to create community, engage students in active learning, and promote scientific literacy within and outside of a remote biochemistry of metabolism class of 20 students. To enroll in this course, students complete pre-requisites of general and organic chemistry, cell biology, and a biochemistry course on the structure and function of biomacromolecules. Metabolism courses cover numerous biochemical reactions, most of which are involved in multiple pathways and can be overwhelming to students (Schultz, 2005). One daunting pathway is the electron transport chain (Teplá & Klímová, 2015), which converts energy in the form of reduced electron carriers (e.g., reduced nicotinamide adenine dinucleotide, NADH; reduced flavin adenine dinucleotide, FADH₂) to create electrochemical gradients. The electron transport chain is a component of oxidative phosphorylation, a process that couples the free energy stored in the resulting electrochemical gradients to synthesize adenosine triphosphate (ATP), the energy currency of the cell (Berg et al., 2019). Students typically get an overview of this process in a biology course but do not learn its detailed chemical steps. Electron transport involves a number of protein complexes and changes in reduction potentials throughout various parts of these complexes, which can be hard to follow, especially for students with limited attention spans during remote learning in a global pandemic (Wiederhold, 2020).

Learning Objectives

The assignment involved creating a ten-minute video explaining the electron transport chain and its connection to oxidative phosphorylation to a nonscientist and assessing their understanding. The project aimed for students to achieve the following learning goals:

- 1) Understand the goals of oxidative phosphorylation and why they are critical for the survival of the cell. The main goals are as follows:
 - a) protein complexes work together to transfer electrons from reduced electron carriers to oxygen (i.e., electron transport)
 - b) oxidation-reduction reactions are coupled to proton gradients
 - c) ATP synthase uses proton gradients to synthesize ATP from adenosine diphosphate (ADP) and inorganic phosphate
- 2) Identify the steps involved in the electron transport chain
- 3) Develop analogies using layman's terms to teach the electron transport chain to nonscientists
- 4) Evaluate the effectiveness of analogies used to teach nonscientists

Explanation

This project offers a creative way for students to learn about the electron transport chain through actively engaging with this process and teaching their communities. The assignment was given in the first week and due in the last half of the course (e.g., week 8 out of 14 weeks) when the electron transport chain would be formally discussed in class.

Weekly scaffolded homework assignments were assigned to help students develop ideas about how they might represent this process. I provided feedback and guidance on homework to identify and fill gaps in knowledge, ensuring no student was left behind. The following tasks were assigned each week:

Week 1. Define the overall goals. Read the chapter on oxidative phosphorylation (Berg et al., 2019) and describe three main concepts about this process.

Week 2. Examine the detailed steps. Go deeper and provide five additional details about each main concept, one of which should include the electron transport chain. One should have a total of 15 details, five of which are about electron transport.

Week 3. Develop analogies. How might one visually convey five of these points?

Week 4. Understand how the details come together. How can you highlight the other ten details within the five visual representations described in week 3?

Week 5. Assess whether the analogies are effective teaching aids. How can one assess whether the nonscientist being taught understands the process in the video?

The scaffolded assignment utilized the full range of Bloom's taxonomy (Bloom et al., 1956; Krathwohl, 2002) and metacognitive learning strategies, including analogies, guided practice, and structured reflection (Ellis et al., 2014). Students read their textbooks to identify and understand key ideas, which were later deconstructed into layman's terms and applied to new visual representations. Then, students self-reflected as they developed methods of assessment to evaluate whether their representations were effective in teaching nonscientists. These methods included questions a nonscientist would answer after watching or participating in the reenactment. By integrating this assignment early into the semester, I could use the electron transport chain as a point of reference throughout the semester and continually connect it to other related processes learned, emphasizing the interconnectedness of metabolic pathways. By the time the electron transport chain was taught in class, students had previewed the process and could deeply engage with the topic.

Students spent five weeks designing these projects and two weeks recording reenactments of the electron transport chain (Figure 1) using FlipGrid (www.flipgrid.com), a free video discussion platform used to develop social learning. They recorded and uploaded videos onto FlipGrid (<https://flipgrid.com/+gei25muo>), where they engaged with their peers' videos as they might interact with friends on social media (i.e., using the 'like' button, emojis, and posting comments). FlipGrid fosters positive relationships and communication between students and instructors in remote education (Agan et al., 2020). Thus, FlipGrid was used for students to connect with each other remotely and learn the concepts of the electron transport chain on their own terms while encouraging creativity. While FlipGrid is another virtual communication platform, students made fun, short videos that they could listen to and engage with at their own pace, minimizing fatigue. FlipGrid also facilitated the exchange of class videos with their family and friends, building community beyond the virtual biochemistry class.

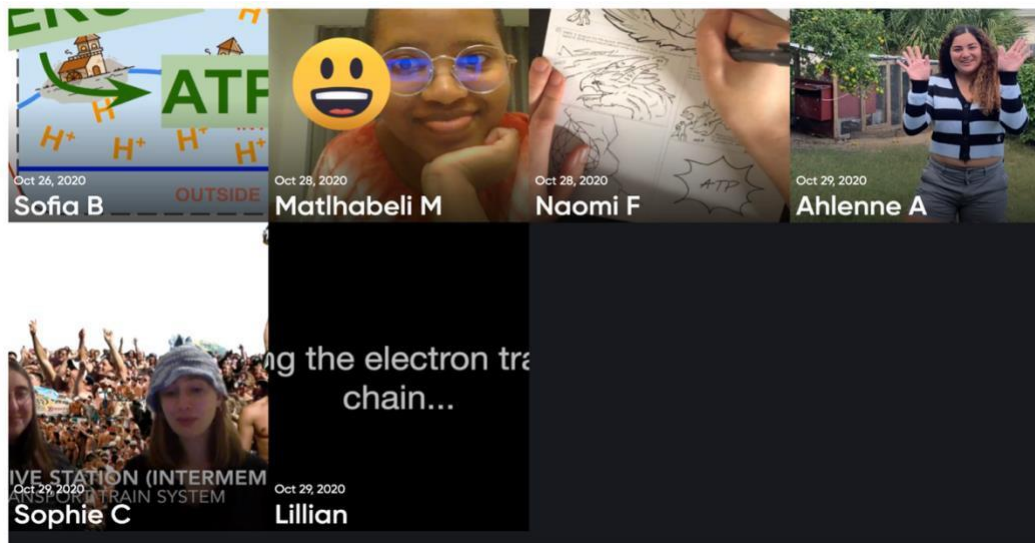


Figure 1. Snapshots of select FlipGrid videos made by students during the fall of 2020, which can be viewed at <https://flipgrid.com/+gei25muo>.

Debriefing and Assessment

FlipGrid videos were evaluated based on completeness, accuracy in the portrayal of the electron transport chain, and creativity. The grading rubric included the following categories: 1) creativity, 2) accuracy in representing the main goals of the process, 3) added details of each step in the process, 4) effective evaluation of the nonscientist's understanding of the process, and 5) whether the student appeared to have fun performing the reenactment. The grading scale ranged from 80 to 100, with 100 representing the mastery of all categories and a score of 80 rewarding effort despite incorporating only two out of five categories.

Aside from utilizing a rubric to assess the effectiveness of the assignment, the engagement of students and their local communities was also assessed. Students played the videos on FlipGrid, some shared class videos with family and friends, and a video was played in class to summarize the process once we covered the electron transport chain. FlipGrid records data on engagement with uploaded videos. From the 20 ten-minute videos made, there were 363 views and 56.2 hours of engagement. While students did not work together, they were able to see their peers' local communities and homes, and feel connected to them in ways that transcended the virtual classroom.

The assessment of the nonscientist's learning was included in each video. Friends and family were either involved in the reenactment and later questioned or they answered questions after watching the reenactment. Real world analogies used to recall aspects of the electron transport chain helped nonscientists engage with the material. For example, using analogies, such as trains, water mills, and 'positive' parties, helped nonscientists understand how energy is harnessed from electron transport and proton gradients to make ATP. Students were thrilled when their families and friends could identify key aspects of this complex process, demonstrating their analogies were effective. By making the electron transport chain more accessible through art, comedy, animals, and other real-life situations, nonscientists could engage with the science, extending the biochemistry course into local communities and empowering community members to be co-learners.

The assignment empowered students to take risks and think outside of the box to design engaging and relatable reenactments for their family and friends. For example, one student used a chicken coop in their backyard as a unique analogy, where the live chickens represented enzyme cofactors producing ‘egg’lectrons that were then passed along to reduce other protein complexes (e.g., pets and relatives). The assignment humanized the virtual student, enabled everyone to be a co-learner, and made biochemistry more accessible to others outside of the classroom. By demonstrating and explaining these processes in layman's terms, students felt a stronger connection not only to their communities but also to the electron transport chain itself, as they had to develop a deeper understanding of the process to be able to design effective analogies and visuals. Artistic students really appreciated this project because it gave them a rare opportunity to be rewarded for their creativity in a STEM course. Students gave the following positive feedback in their self-reflections of the assignment, demonstrating that they learned a lot through teaching others:

“I loved that assignment”

“The project allowed me to combine all my interests in biochemistry, storytelling and art. Not only that, but it required me to think more of the specific details and components of the electron transport chain.”

“I think in order to effectively explain something to someone else, you have to really know the material you’re discussing. This quiz really ensured I knew the material and recording the video with some friends was fun and something I’ve never done before for a class.”

“After many times learning it, I have never completely gotten all of the details, but this semester I feel very good about my understanding.”

The resulting videos can be used as a teaching tool in online and in-person biochemistry courses. FlipGrid videos can be linked to and embedded in other open-source educational platforms, such as Moodle and Canvas. I continue to play these videos in my in-person classes to help students visualize the electron transport chain and its connections to oxidative phosphorylation.

This virtual assignment offers new pedagogical possibilities, as it can be modified for in-person instruction and different audiences. Students can work in groups to create visual art installations of the electron transport chain or other biochemical pathways to educate their non-biochemistry majors on campus. In my post-pandemic biochemistry class, students made videos in which non-biochemists, including members of athletic teams, reenacted electron transfer by exchanging cookies or through the process of baking. On the due date, we invite non-biochemists to our in-person class and use visual art to teach them about the electron transport chain. At the end of these reenactments, non-biochemists provide feedback about what they learned by answering questions, demonstrating that the modified assignment can be used to engage and educate the greater college community about science. Importantly, students always remember this assignment and the fun they had exploring a biochemical process through a creative lens.

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