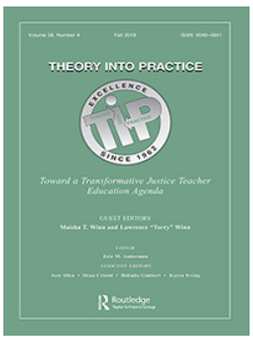

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Teaching to Transform: (W)holistic Science Pedagogy

As the scientific and technological divide widens, access to quality science instruction has become a civil rights issue: those equipped with the knowledge and skill will remain caretakers of status and power. This inequality is especially salient for students in marginalized communities and schools where stereotypes fuel low expectations for academic achievement and success. For many students the classroom represents their earliest formal experience with both the content and process of science, placing science teachers in a unique and precarious position: getting students excited and engaged about science while simultaneously preparing the next generation of STEM professionals. We offer the (W)holistic Science Pedagogy (WSP), a student-centered approach of instruction to disrupt patterns and hierarchies. The WSP approach requires 5 commitments from the teacher: A commitment (1) to an ever-developing self-awareness, (2) to science and its practices, (3) to science as a transformative agent, (4) to their students' social emotional wellness, and (5) to restorative practices. In this article, we define the 5 commitments and present an example lesson that reflects the commitments.

A scientific and technological divide along the lines of race, class, and gender can be seen in the data about who studies science in college and who chooses to pursue careers in science. According to US Census Bureau data, Black and Latino/Hispanic people are underrepresented in the science, technology, engineering, and math (STEM) workforce, while Whites and specific groups of Asians are often overrepresented (Landivar, 2013). Data on the enthoracial makeup of those awarded STEM degrees and certifications show similar patterns. Indeed, the recipients of 667,919 STEM degrees and certifications awarded in 2015 were 63.6% White, 8.6% Black, 12.1% Hispanic, 11.6% Asian, and 3.3% multi-racial (US Department of Education, Institute of Education Sciences, National Center for Education Statistics, 2017). These pernicious gaps in engagement begin as

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early as elementary school and are often reflected in students' interests (Osborne & Collins, 2000), desire to identify with STEM fields (Carlone, Haun-Frank, & Webb, 2011), and academic performance (US Department of Education, Institute of Education Sciences, National Center for Education Statistics, 2015).

The classroom represents many students' first formal experience with the content and process of science, placing science teachers with the precarious task of getting students excited about and engaged with science and preparing the next generation of STEM professionals. However, previous efforts to boost achievement in science have not significantly lessened the persistent outcome gaps between ethno-racial groups (Gray, 2014). This may be because efforts to level the playing field have paid little attention to the enduring macro-structures and systems at play in science, schooling, and society, focusing instead on individual student participation.

It is important to analyze the role of classroom instruction in perpetuating these outcome gaps, as well as how classroom instruction might become a tool to disrupt these harmful patterns. We argue that science instruction grounded in transformative justice education has significant potential as an appropriate departure from mainstream science teaching and learning practices. To put this into context, we describe what (W)holistic Science Pedagogy might prioritize and require, illustrating what this approach might look like in practice with an example middle school science lesson.

What is Transformative Justice Education?

A transformative approach to teaching and learning necessitates a change in students' thinking that leads them to action in their world (Brown, 2004). Transformative learning is a process where learners use discourse and critical reflection to make sense of and challenge their current experiences, assumptions, and frames for understanding those experiences and assumptions in new contexts (Mezirow, 1997). Mezirow argued that transformative learning requires effective discourse where students have

> full information; are free from coercion; have equal opportunity to assume the various roles of discourse (to advance beliefs, challenge, defend, explain, assess evidence, and judge arguments); become critically reflective of assumptions; are empathic and open to other perspectives; are willing to listen and to search for common ground or a synthesis of different points of view; and can make a tentative best judgment to guide action. (p. 10)

Winn (2018) situates transformative justice-oriented teacher education as a model that "views teaching as a justice-seeking endeavor and learning as both a civil and human right for all students" (p. 145), urging teachers to "engage in the deep work they must do to unlearn racist ideas that manifest in punishing their Black and Latinx students more than their White and Asian peers," while maintaining "high expectations for the life trajectories of all their students and resist acting as gatekeepers with students who do not fit easily into comfortable or familiar schemata" (p. 146). Winn encourages educators to become and remain concerned about all students and their families and provide learning environments that are empathetic, compassionate, and restorative in nature.

Within the field of science education, the notion of transformative learning is not new. Advocates highlight the need for instructional approaches that are connected to students' lives, enable critique of science and the world in and outside school, and are action-oriented toward social justice (Barton, 2002; Moore, 2008; Mutegi, 2011; Winn, 2018). Moore (2008) encourages teachers to use a multicultural framework to "empower and transform curriculum and themselves while simultaneously connecting science content to the lives, interests, and experiences of urban elementary learners" (p. 606), highlighting critical reflection, journaling, and reading as methods that can be aligned with a social justice orientation. Similarly, Barton (2002) underscores the value of urban science education programs that aim to engage teachers and students in "critiques that will help to transform their understandings of

place and practice of science in creating a more just world" (p. 18).

Winn (2018) proposes that science curricula address historical harm inflicted on communities of color in the name of science and consider how science classes can become "part of a long arc of justice" (p. 155). Situating schools as "vehicles for social change," Mutegi (2011) encourages teachers of African American students to provide socially transformative curricula that "emphasize-[s] political and social change" (p. 13). Mutegi makes the case for liberatory curricula that help African American students realize their colonized status, understand how those power dynamics have been and continue to be maintained, and consider how they might wrest that power from their colonizers.

While these authors focus on urban contexts and students of African descent, we argue that transformative justice-oriented science curricula are appropriate for all students, irrespective of geographic location, ethnic and racial identity, and socioeconomic status. Building from existing ideas about transformative science education, we outline (W)holistic Science Pedagogy (WSP) as one approach to science teaching that avoids communicating science as static facts and instead promotes science as a personally relevant and useful tool to understand various phenomena. Our framework expands the existing literature by emphasizing the need for teachers to develop the practices of deep self-analysis, attention to students' wellness, and a restorative stance that permeates their approach to teaching. The following sections outline (1) commitments a (w)holistic science teacher must make to teach science that promotes equity, engagement, and transformative justice-oriented learning for all students; and (2) an example of the type of lesson a WSP-guided teacher might create.

(W)holistic Science Pedagogy

(W)holistic Science Pedagogy is a teacher- and student-centered approach to instruction that disrupts marginalizing patterns and hierarchies. The WSP approach requires that the teacher commit to: (1) ever-developing self-awareness, (2) science and its practices, (3) science as a transformative agent, (4) students' social-emotional wellness, and (5) restorative practices. Interaction between (w)holistic science teachers and their students leads to the creation of a learning space and set of classroom science experiences that engage and reflect students' whole selves and interests.

The WSP approach promotes strategies and tools that ground students' emerging content knowledge in critical awareness about the structures and institutions that have created and maintained society's racial, gendered, and economic hierarchies (Powell, 2010). (W)holistic science teachers recognize connections between students' lived experiences and their degree of science learning participation – and subsequent learning outcomes. These teachers also attend to the social, emotional, and academic needs of all students – and recognize that this approach benefits the greater community. As classroom and school leaders, (w)holistic science teachers recognize the necessity of emotionally, socially, and intellectually safe learning spaces for all students.

Ever-Developing Self-Awareness

(W)holistic science teachers must be actively self-aware to change and improve their pedagogy. This is a process of ongoing critical reflection (Brookfield, 1995) and critical consciousness: recognizing and reflecting on their own privilege and position of comparative power in society while being mindful of how the socio-political constructs of gender, race, ethnicity, and class inform the culture of schools and systems of education. Because values and ideologies influence instruction, teachers must constantly question the foundations of their personal belief systems. (W)holistic science teachers interrogate their beliefs and values and – upon finding any values connected to oppression, superiority, White supremacy, etc. – do the work of deconstructing these harmful mindsets. Ultimately, this framework encourages science teachers

themselves to reflect a more socially just and inclusive system and practice of science for everyone.

Science And Its Practices

Experts from a broad array of science fields agree students should learn about the core features, practices, and processes of scientists to (1) develop a greater sense of how science shapes their world and (2) gain a more sophisticated way of thinking as they move through their lives (McComas, Clough, & Almazroa, 1998). McComas et al. affirm that "the *nature* of science is a fundamental domain for guiding science educators in accurately portraying science to students" (emphasis added, p. 5). That is, teachers committed to science and its practices consistently engage students in ways that reflect scientific habits of mind. Such teaching guides students through hands-on, inquiry- and problem-based science experiences that establish multiple points of entry for students using a more expansive array of teaching styles.

Science as a Transformative Agent

(W)holistic science teaching is a paradigm for inclusion, rather than tolerance. Inherently transformative, WSP calls on classroom teachers to responsibly and objectively examine old and new records and documents that have reified an unjust conceptualization of "scientific literacy." To become a catalyst for transformation, science teachers must provide diverse conceptions of the content, process, purpose, and practitioners of science (Mutegi, 2011). Effective and transformational science pedagogy includes the innovations, scholarship, and other contributions of people outside the dominant majority, and may involve engaging students in discourse around the historical impact of science in shaping public opinion and ideology on issues of identity, race, class, and gender. WSP seeks to engage students with meaningful and critical content and initiate conversations that empower students to use science as a tool to reshape their environment and disrupt injustice.

Students' Social-Emotional Wellness

(W)holistic science teachers tend to use curricula that are socially just and culturally relevant, highlighting systemic and/or local injustices and guiding students to confront inequities exacerbated or created by scientific phenomena or popular readings of science concepts, while also exploring how to leverage science to combat inequities (Patterson, Morrison, & Schindel, 2017). WSP seeks to provide students with powerful science learning experiences that are meaningful and motivating and allow/push them to grapple with issues of injustice that will sometimes be deeply personal. Because the intensity of this type of learning practice may trigger some students and make them vulnerable to sorrow, hopelessness, and frustration, teachers must also monitor, encourage, and support students' social-emotional wellbeing.

Restorative Practices

(W)holistic science teachers committed to restorative practice go beyond classroom management to create more engaged and rigorous learning. Because many students have experienced harm *because* of their demographic profile and due to dominant, harmful narratives that impact them, restorative practices in science require ongoing socio-cultural critique. (W)holistic science teachers provide students with oppositional voices and counter-narratives to encourage a dynamic and engaging dialogic process of awareness-raising, community-building, and healing. This process creates spaces for students who feel marginalized by their experiences in science to reflect on those negative experiences.

Example Lesson Design

Early in a middle school physical science chemistry unit on matter, this multiple-day interdisciplinary lesson introduces the topic of chemical reactions and touches on atomic structure, the periodic table, and the chemical and physical properties of elements. The activity gives

students an opportunity to consider contemporary issues related to chemistry the Flint, Michigan water.

The example lesson addresses the Next Generation Science Standards (NGSS) for knowledge and patterns of chemical reactions: Middle School Physical Science Standard MS-PS1-5 reads, *[Students will] develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved* (Council of State Science Supervisors, 2013). One of the NGSS goals around matter and its interactions is that students will determine whether a chemical reaction has occurred. Rather than focus directly on chemical reactions, the example lesson builds on students' knowledge of specific elements as part of chemical change. Subsequent lessons then draw on this information to explore the chemical reactions that occur when various elements and compounds interact.

The example lesson also addresses 2 key Common Core English Language Arts Standards: CCSS.ELA-Literacy.RST.6–8.1 reads *cite textual evidence to support analysis of science and technical texts*, and 6–8.2 reads *determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions* (Council of Chief State School Officers & National Governors Association, 2012). This lesson requires that students examine and synthesize information from various sources to create coherent explanations. Two objectives guided the lesson design: 1) students would come to understand that chemical reactions have major effects on the environment and humans, and 2) students would use evidence from multiple sources to support their understanding of the events that occurred in Flint.

Chemistry Around Us: The Example Lesson

Affirmation

The lesson begins with students reciting a daily affirmation:

> We are scientists! We are born asking questions about the world. Through rigorous experimentation and inquiry, we discover, find solutions, and ask more questions! We are scholars, we travel our paths learning, experimenting, communicating, and growing. We are warriors! With courage and compassion, we use our skills and talents to create change! We discipline ourselves so that no one else must! And, so it is!

This affirmation signals the beginning of class and leads up to the warm-up activity, which we call "Power-up."

Introduction/Power-Up

To introduce this lesson and activate prior knowledge, students are asked to provide a written response to the prompt "What do we know about recent events in Flint, Michigan?" This allows students to share what they already know, think, and feel. Students are given 3 minutes to write their response to share with the group. This is not an evaluative activity but an opportunity to get the whole class thinking about what might or might not have occurred in Flint.

The teacher then encourages the students to connect their personal knowledge and experiences with water to the discussion by asking if and why they believe water is important. The intention is that students begin developing an empathetic mindset to guide their review of the data and keep them mindful of how significant the tragedy in Flint has been, and why it is considered a crisis.

Investigative Journalism Activity

Next, students are introduced to their special assignment as investigative science journalists. They examine data from various sources and explain the story of what happened in Flint, working in small groups.

Card sort and report writing. The groups receive a set of cards containing various pieces of information related to the events in Flint, including pictures, narrative, and a time stamp.

As a team, they carefully examine and discuss each card before logically ordering them to tell the story of Flint. After 10 minutes, they write their account of Flint based on the sequence of their cards. Next, the same groups receive a second set of cards to study and incorporate into their previous card sequence. After another 10 minutes, students update and revise their initial story, writing a final report on poster paper.

Gallery walk/video. Posters are displayed around the room for a gallery walk so all groups can see other groups' work. While reviewing the posters, each team looks for new understandings. After this, students watch a detailed video explaining the Flint crisis. Students then participate in a think-pair-share to synthesize and discuss any new insights gained from the gallery walk and informational video, adding any updates to their reports.

Critical reflection. For the final part of this lesson, students discuss the following questions in their small groups:

1. Who was harmed?
2. What harm was done?
3. What was the cause of the harm?
4. Who's responsible for the harm? How? Why?
5. What ideas do you have about what can/should be done to repair the harm?
6. What might justice look like for those who were harmed?
7. Can there be justice? Why? Why not?

After these conversations, students receive a sheet with additional information about the water crisis in Flint and space for written responses to the critical reflection questions.

Example Lesson Analysis

The example lesson demonstrates the key components of (W)holistic Science Pedagogy. This type of transformative education approach engages students across multiple domains, requiring a variety of skills and strategies that transcend subject matter and perceived academic disciplinary boundaries. Here we highlight the WSP commitment we feel is best reflected in each component of the lesson.

Affirmation Analysis

Teachers committed to WSP facilitate meaningful learning opportunities that validate students' personal experiences and support their self-esteem and identity development. Building on research suggesting that affirmation is an effective tool for various aspects of learning (Szente, 2007), this affirmation represents commitments to self-awareness and to students' social-emotional well-being. One injustice within formal STEM classrooms and workplaces has been the "chilly climate" (Blickenstaff, 2005) experienced by many people of color and women. Daily affirmation of science identity disrupts pervasive stereotypes of science as the domain of specific types of people, reminding all students that they are *already* scientists. And scholars. And warriors. Repeating this each day, students reframe themselves and their experiences as students, speaking a language of self-empowerment while implying they can transform themselves and their environment.

WSP teachers recognize that some students see themselves as outsiders within science classrooms and may doubt their ability to be successful. Critically reflective and self-aware science teachers understand stereotypes of "successful" students, and know how established hierarchies influence how students see themselves and others, as well as how their own positionality and privilege as a teacher can impact the classroom environment. The affirmation provides a daily opportunity for WSP teachers to leverage their power as construct-framers to assure students that science is part of their natural human identity.

Introduction/Power-Up Analysis

Representing the teacher's commitment to science and its practices, the power-up and

introduction draw on and legitimize students' pre-existing knowledge and experiences. While the lesson contains no formal experiment, the investigative inquiry activity demands that each student reflect on and develop a personal hypothesis about what life would be like without water. This introductory activity may bring forward misconceptions and misunderstandings about Flint and the causes of this water crisis, but it begins to mirror the process scientists tend to use. Scientists continually ask questions, draw on their base knowledge, develop hypotheses, do research, and collect data that may support or counter their previous ideas.

Investigative Journalism Activity Analysis

Card sort and report writing. The card sort activity reflects the students' commitment to science and its practices. Much like a team of scientists, the students work collaboratively toward collective meaning-making, assessing data, engaging in discussion and debate, and drawing conclusions. Science information is often communicated through charts, diagrams, graphs, and pictures, so the students examine various visual data sources to make decisions regarding the logical sequence of events in Flint. The card sort activity included multiple iterations; students modified and revised their initial explanations using new data and information, a process at the heart of scientific inquiry, discovery, and communication.

The card sort activity reflects a commitment to science as a transformative agent, as students explore how a current event was science-related *and* had justice implications. Here, students learn that lead, a metal, is a part of a chemical reaction that was a factor in the crisis. Applying their knowledge that chemical reactions can have grave impacts on society, students begin to wonder how science might play a role in the solution.

Poster and gallery walk. Here we see commitments to science and its practices. After sequencing the cards, discussing the story, and presenting their findings on a poster by writing or drawing their explanation of the events in Flint, the students observe their classmates' posters. As they share, confirm, and validate their knowledge, they build their identities as scientists and scholars. Opportunities to compare and contrast findings by looking at multiple interpretations and analyses of the same data demonstrate the additive nature of science, whereby understanding increases with additional input from other sources.

Video. The video segment of the lesson captures the commitment to science as a transformative agent by showing that both problems and solutions in Flint are tied to chemistry. Students learn how science can transform communities as environmentalists, doctors, and activists explain how lead adversely impacted water quality and the health of entire neighborhoods. This portion of the lesson allows students to use a science lens to understand a recent event, and to see non-scientists using science knowledge to make meaning about science-related issues important to them. Community members using science knowledge to expose politicians and demand accountability exemplify how people outside the formal domain of science leverage science as a tool for transformation and social justice in their own lives.

Critical reflection. The critical reflection component of the example lesson reflects commitments to restorative practices. Responding to critical questions about Flint, students become problem solvers working through issues of justice, equity, and fairness, considering whether it is possible to undo harm. Students also consider the role science in the creation of – and potential solutions to – the Flint crisis. Opportunities to discuss inequities and injustices emerge as students contemplate how the constructs of race and class thread through this crisis. As students engage in rigorous discourse around the idea of "repairing harm" at the levels of the individual, community, and wider society, the teacher fosters a restorative impulse by guiding them to consider

how the pursuit of justice might restore relationships and wellbeing.

Conclusion

(W)holistic Science Pedagogy is a vehicle to transformative science learning. While this lesson and framework provide teachers with a blueprint for action-oriented science learning, a pedagogical approach to engage students in relevant ways is insufficient. Teachers must choose to do the work of self-transformation outlined by Mezirow (1991), Winn (2018), and Moore (2008) before they can facilitate transformative learning environments for their students.

Moore (2008) highlights why this work must begin in teacher education programs. Beyond methods for teaching science, science teacher education courses should include opportunities for pre-service teachers to reflect on their personal identity, consider ways for understanding how their identity pertains to their students, cultivate ways to understand their students' backgrounds and geographical context, and develop tools for critical reflection. Teachers who develop a strong sense of self-awareness must also be taught how to develop curricula (or modify a prescribed curriculum) that is relevant to students and encourages them to use science as a tool to think critically about their lives and the world around them. Teachers must be equipped to create lessons like the one we described in this paper, so it is incumbent upon teacher educators to provide readings, models, and opportunities to practice preparing for and cultivating transformative learning experiences.

Because most teachers feel discomfort discussing and addressing issues of race and oppression (Sheth, 2019), they need opportunities to practice navigating spaces where personal biases, microaggressions, and other challenging forms of oppression may occur. Teaching in socially transformative ways requires a willingness and ability to address racism and other forms of oppression that may be inherent in the community or curriculum, arise in discussion, or shape participation in class interactions. We acknowledge that confronting injustice is particularly challenging and intimidating for those new to acknowledging and discussing these issues. The glaring implication here is that teachers need spaces to cultivate their practices of – and identities as agents of – social change and transformation (Moore, 2008). Beyond examples and models of transformative science instruction, they need opportunities to practice and reflect on their instruction.

We believe our instructional model supports and is likely to help increase diversity, inclusion, and the cultivation of more equitable and just science learning experiences for all students. Students are whole beings socialized through multiple experiences, interactions, and identities. As such, educators must move toward less overly-scripted, more socially and culturally relevant curricula if we are to create meaningful, real-world learning opportunities for critical thinking. The approach must be holistic, responding to students' mental, physical, and emotional needs. WSP is an example of a science education framework that situates science, scientific thinking, and science teaching and learning as tools of liberation, healing, and transformation.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Additional Resources

1. Gorski, P. C. (2013). Reaching and teaching students in poverty: Strategies for erasing the opportunity gap. New York, NY: Teachers College Press.

This book considers the multi-faceted impact of poverty and other social injustices have on students learning. Teachers are encouraged to recognize, respond to, and redress bias, discrimination, and inequity in their personal belief systems and in their classroom. Gorski introduces readers to his Equity Literacy framework and provides strategies and other resources to help teachers develop their self-awareness and curriculum that centers equitable and just learning for all students.

2. Koenig, D. (2013). Just Science. *Teaching Tolerance, 44*. Retrieved from https://www.tolerance.org/magazine/summer-2013/just-science

This article explores how teachers can bring social justice issues into the science classroom. In addition to the article there are resources including a toolkit that offer additional support and information about how science teachers can create classrooms where science is an agent of transformation. The toolkit can be accessed here: https://www.tolerance.org/magazine/summer-2013/toolkit-for-just-science

3. Lindahl, A. (2012). Facing Cancer: Social justice in biology class. *Rethinking Schools, 26*, 14-18. Retrieved from https://www.rethinkingschools.org/articles/facing-cancer-social-justice-in-biology-class

This article provides an example of one teacher's approach to teaching science as a transformative agent. Ms. Lindahl, a high school science teacher, shares with statistics from national and intercultural cancer databases with her students. Her goal: to help students see how corporate and government policies, pollution, and racism play a role in the disparities of incidences of cancer and mortality rates across low-income communities and communities of color. This article is important because it also highlights the need for teachers to attend to and address the harm teaching about social injustices can cause students.