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Culturally Relevant Science Teaching: A Literature Review

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Abstract

This educational research literature review paper aims to discuss the rationale, review eight empirical research studies, and identify knowledge gaps in culturally relevant pedagogy in science education. This paper focuses on synthesis, review, and comparison of the findings of the empirical studies, and categorizes them into thematic heads such as similarities and differences between studies under the broad categories of professional development (PD) programs and case studies. Following these reviews, the author summarizes her reflections and thoughts about the literature to understand the big picture of culturally relevant pedagogy in science education. The basis of this literature review are various philosophical foundations that undergird the research in this field, looking at the theoretical frameworks and standards in science education, such as Next Generation Science Standards. This paper hopes to identify knowledge gaps for future research and help educators address serious and pressing concerns regarding culturally relevant science teaching in an increasingly diverse world.

Keywords: Culturally relevant pedagogy, science education, professional development programs, equitable access to education, student science achievement

Introduction

Culture is the focal point of learning. Individual cultural experiences play an important role not only in receiving and communicating information, but also in molding the thinking process of individuals and groups of people. As a science teacher, I have always had a strong urge to adopt a pedagogy that acknowledges, responds to, embraces, and celebrates all cultures. I have hoped that this pedagogy should offer full, equitable access to education for students from all cultures. Culturally responsive teaching is a pedagogy that recognizes the importance of including students' cultural references in all aspects of learning (Ladson-Billings, 1994).

Because of my passion for science education in the multicultural perspective and the growing need for educators to embrace culturally relevant teaching in an increasingly diverse world, this topic "culturally responsive pedagogy and culturally relevant teaching of science" is an extremely important one in the field of education at the present time. This educational research literature review paper aims to discuss the rationale, review eight empirical research studies, and identify knowledge gaps in culturally relevant pedagogy in science education. I have synthesized, reviewed, and compared the findings of empirical studies and categorized them into thematic heads such as similarities and differences between studies under the broad categories of professional development (PD) programs and case studies. Following these reviews, I have summarized my reflections and thoughts about the literature, and I have also tried to understand the big picture of culturally relevant pedagogy in science education. I have based my literature review on various foundational studies in this field, looking at the theoretical frameworks and standards in science education, such as Next Generation Science Standards. I plan to incorporate what I have learned from these studies in my future research which will help me to understand deeply about culturally relevant pedagogy in science education. Finally, I plan to conclude this paper by identifying knowledge gaps, listing

lingering questions, and understanding how these questions will help structure future research and streamline my own research on culturally relevant science teaching. In the two subsections of the introduction, I plan to propose my rationale for my research topic highlighting the philosophical foundations that undergird my research, as well as outline the importance of culturally relevant pedagogy in science education.

Rationale for the Research Topic and Philosophical Foundations

As a science teacher, I have always believed in inquiry-based and hands-on science experiments to increase student engagement and achievement. Additionally, I am equally committed to incorporate culturally relevant/responsive pedagogical and teaching methods for improving the learning outcomes of the increasingly diverse student population, especially the underrepresented student population, such as people of color, girls, LGBTQ+ community, immigrants, ethnic minorities, and indigenous people.

In 1994, Gloria Ladson-Billings, a researcher in the field of education, first described about culturally relevant teaching. Culturally relevant pedagogy "empowers students intellectually, socially, emotionally, and politically by using cultural referents to impart knowledge, skills, and attitudes" (Ladson-Billings, 1994, p. 18). Ladson-Billings (1995a) explains that culturally relevant teaching involves three dimensions: academic success, development of critical consciousness, and maintenance of cultural competence. For accomplishing student outcomes, every teacher should be knowledgeable about these dimensions; however, it may not be the case for some teachers. Culturally relevant teaching and multicultural education requires a strong knowledge base in the teaching methods with respect to cultural diversity (Gay, 2002). In her book, Sonia Nieto also talks about the need for understanding the socio-political contexts of teaching in diverse classrooms (Nieto, 1996). Ladson-Billings (1995b) further emphasized that teachers should not only motivate their

students for academic achievement and cultural competence, but they must also aid in students' recognition, understanding, and critiquing of ongoing inequities in the society.

I am also inspired by another foundational work by Mary Atwater and Joseph Riley about multicultural science education. Multicultural science education is a field of inquiry with constructs, methodologies, and processes aimed at providing equitable opportunities for all students to learn quality science (Atwater & Riley, 1993). One more noteworthy present-day indigenous researcher is Pauline W. U. Chinn, who has contributed a lot for the development and implementation of culturally relevant, standards-based science curricula for Native Hawaiian students. In one of her studies, pre- and in-service teachers lived with the Native Hawaiian teachers and worked together with them for a period of one year. They culturally immersed with the local population and used their knowledge to develop unique science curricula (Chinn, 2006). Culturally relevant pedagogy also provides a formalized tool for reconciling the standards to include students' native cultures (Emdin, 2011). After the groundbreaking work of the pioneers, there were many other researchers, such as Carla Johnson, Gloria Boutte, George Lee Johnson, and Charlease Kelly Jackson who have worked on culturally relevant practices for teaching science. In the next subsection, I will talk about the importance of culturally relevant pedagogy in science education.

Importance of Culturally Relevant Pedagogy in Science Education

In today's world, there are many challenges faced by schools and colleges in the US because the student population is becoming more and more ethnically and racially diverse, and this is compounded by the fact that there is also a decline in the diversity of the teacher population. In this scenario, culturally relevant teaching has become one of the most important educational considerations in the US and around the world, with ethical implications. The national science education standards (National Science Teachers Association, 2003) also defines scientific inquiry as "the diverse ways in which scientists

study the natural world and propose explanations based on the evidence derived from their work" (National Research Council, 2000, p. 23). In addition, in the USA, Next Generation Science Standards was created "by the States for the States" (Next Generation Science Standards, 2019). Within the NGSS, there are three important dimensions to learning science, namely disciplinary core ideas, science and engineering practices, and crosscutting concepts to help students develop a coherent and scientifically based view of the world around them.

> A goal for developing the NGSS was to create a set of research-based, up-to-date K–12 science standards. These standards give local educators the flexibility to design classroom learning experiences that stimulate students' interests in science and prepares them for college, careers, and citizenship. The NGSS were developed by states to improve science education for *all* students (Next Generation Science Standards, 2019).

So, to incorporate culturally relevant pedagogy, the traditional forms of curriculum, instruction, and assessment methods need to be revised or altered (Boutte, Kelly-Jackson, & Johnson, 2010). In addition, the students belonging to the underrepresented cultural groups achieve a higher level of learning. Calling them "scientists" irrespective of their age increases their self-confidence, provides activities and fosters their science identities, and makes them believe that they can achieve anything. Incorporating examples, data, photos, and information of scientists or researchers from different cultures will help reinforce and institutionalize a strong multicultural science education program in schools, colleges, and universities. This will help all students to connect and engage with the content in science classrooms.

Literature Review

The goal or purpose of my literature review of culturally relevant science teaching is to understand the existing literature (peer-reviewed studies) and present their findings in a logical and organized written report. Conducting this literature review will help me build my

knowledge in culturally relevant science pedagogy, understand the important concepts, know about common research methods and experimental techniques, and learn how to apply those concepts to real-life educational settings.

Thematic Categorization

I had selected eight empirical studies to review the culturally relevant science pedagogical strategies used by researchers. Seven of these studies were carried out in the USA, and one in New Zealand. The student population in these studies included many ethnic, cultural, and linguistic groups such as Native American, Maori, Hispanic, Latinx, and African American. All the studies were based on concepts drawn from philosophical foundations of Ladson-Billings' culturally relevant pedagogy, Vygotsky's social constructivism, and Freire's critical pedagogy. One of the studies done by Luft, Bragg, and Peters (1999) is based on the framework laid by another great educational researcher, Marilyn Cochran-Smith. These frameworks foster richer and deeper understanding of working with diverse student communities. While categorizing the studies into themes, I found many commonalities, similarities, and differences between the studies. Four studies, namely Johnson (2011), Grimberg and Gummer (2013); Tolbert (2015); and Ramirez, McCollough, and Diaz (2016) highlighted the benefits of using culturally relevant science pedagogical strategies during either professional development programs or learning events for preservice teachers. The other four studies, Luft et al. (1999), Patchen and Cox-Petersen (2008), Laughter and Adams (2012), and Morales-Doyle (2017) were all case studies, where the researchers used culturally relevant science pedagogical strategies and reported positive outcomes in the students and teachers who participated in the studies. For easy comparison, summarization of the results, and to understand the significance of the studies, I have categorized the major themes into similarities and differences where I will compare two studies at a time so that reviews of all the eight studies will be covered in this paper.

Similarities in Research on PD Programs. Effective professional development programs enable educators to develop the knowledge and skills they need to address students' learning challenges. In the selected empirical studies, I found that Grimberg and Gummer's (2013) and Johnson's (2011) studies were very similar because both focused on science teachers participating in professional development programs and how this program affected their science teaching practices for different ethnic or cultural groups. In Grinberg and Gummer's study, which was conducted over three years, the focus of the study was on a professional development (PD) program for science teachers who belonged to "25 K-8 schools near or on the reservations of the Native American Indian tribes in the Cheyenne, Crow, and Flathead Reservations in Montana" (Grimberg & Gummer, 2013, p. 19). Similarly, Johnson's study (2011) was a longitudinal 3-year study focusing and following two science teachers of low-performing, urban-district middle schools that had a growing Hispanic, ELL student population. They had participated in a PD program utilizing the "transformative professional development (TPD) model" (Johnson, 2011, p. 174). The data collection methods of both studies were also identical, mainly classroom observations, surveys, and interviews. Findings of Grimberg and Gummer indicated that after the teachers completed two years in the program, they changed their practices of teaching and what they believed to be their science-teaching ability. This change had resulted in implementation and practice of equitable instruction which had a positive impact on students' performance. Similarly, Johnson's findings showed that transformational PD program helped the participant teachers to use culturally relevant science pedagogical techniques to transform their teaching practice that resulted in more productive instructional surroundings for their ELL students.

The next two studies based on PD programs that I am going to compare are those of Tolbert (2015) and Ramirez et al. (2016). Even though both studies were conducted in

different parts of the world, there were commonalities. The study conducted by Ramirez et al. in a southwestern city of USA with a large, fast-growing Latino population, describes the implementation of culturally relevant science and math content program by "preservice teachers (PSTs) at Family Math/Science Learning Events (FM/SLEs)" (Ramirez et al., 2016, p. 43). This event informed the PSTs about the importance of connecting with Latino families' language and culture both in- and after-school environments. Data collected were questionnaires filled out by the PSTs before the event, interviews of the PSTs after the event, recorded interactions between the PSTs and parents during the event, and interviews with non-English speaking Latino parents after the event. Similarly, Tolbert's study shares the results of an impactful professional development (PD) program called Te Kotahitanga (TK) conducted in New Zealand. The participants of the study included four science teachers and four mentors (facilitators) at four different schools for a period of one year focusing on Year 9 and Year 10 science classrooms. TK program was an educational research development project that had remarkably influenced how secondary schools had successfully retained Maori students while also increasing their participation and achievement. The researcher investigated how TK mentors engaged the science teachers (novice and experienced) in "reflective conversations around culturally sustaining equitable science instruction for indigenous students" (Tolbert, 2015, p. 1325). The data collected were videotaped classroom observations and recorded mentoring conversations between the science teachers and the TK mentors, which were transcribed and coded. Semi-structured individual interviews of the science teachers and the TK mentors and reflections from both the groups were also done and transcribed. Data analysis was done to look for "culturally sustaining pedagogy in science" by analyzing video recordings and coding the transcripts of the interviews and mentoring conversation (Tolbert, 2015, p. 1339). Results of both studies confirm that PD programs do influence the student and teacher outcomes. For example, in the study of Ramirez et al.,

results strongly indicated that preservice science/math teachers' perceptions of Latino parents can be changed by participating in these types of events. Similarly, in Tolbert's study, the findings indicated that mentoring conversations can be powerful tools in helping teachers become better educators of minoritized students in science.

Differences in Research on PD Programs. Research studies were different in a number of ways too. Grimberg and Gummer's (2013) study is a quantitative study, where the students in focus were Native Americans. Whereas, Johnson's (2011) study, which is a qualitative one, focused on Hispanic students. In Grimberg and Gummer's study, the methods of quantitative analysis used were ANOVA and multiple regression. The researchers found that when the teachers employed and believed on strategies focused on equity, the students were motivated to connect issues of real-life with science with hands-on experiments; this explained the variance (36.7%) in the students' science test scores between treatment classrooms and control classrooms. In Johnson's study, the qualitative method of analysis used was coding. All the data collected were coded using broad themes such as teachers' beliefs in students' success, community-development activities in schools, developing critical scientific thinking in students using CRP, scaffolding of instruction for students, and using various techniques to assess learning and understanding of students.

In the other two research studies, Ramirez et al. (2016) and Tolbert (2015), the main difference is that they were conducted in completely different settings, the former in an urban southwestern city of the USA and the latter in New Zealand. Ramirez et al. focused on Latino students, and in this research, preservice teachers learned that their perceptions about the Latino parents changed by attending Family Math/Science Learning Events. Whereas, Tolbert's study focused on Maori students, and this research confirmed that mentoring science teachers helped them become better teachers of indigenous students in a culturally sustaining environment.

Similarities in Case Study Research. I found that the two case studies of Luft et al. (1999) and Morales-Doyle (2017) were quite similar in location and method because both were conducted in urban western cities of the USA, and both were qualitative studies. In the study of Luft et al., the predominant student body was Hispanic American, with a few African Americans and Native Americans. Similarly, in Morales-Doyle's study, the study subjects were nine students of color (African American and Latinx). Luft et al.'s study examines teaching experiences of a student teacher who is an avid enthusiast of multicultural science education. She wanted to incorporate culturally relevant, inquiry-based, science instruction inclusive of all her students "consistent with the National Science Education Standards (National Research Council, 1996)" (Luft et al., 1999, p. 528). This case study furthers the research knowledge about student teachers who are learning to teach science in a different cultural setting other than their own. In Morales-Doyle's case study too, the researcher attempts to address the racial and class-related inequities in science education, which are longstanding issues; this study explored the effects of a justice-centered AP chemistry class on students' academic success while also addressing the critical environmental and social issues of justice determined by local communities. Both of the studies had the theoretical framework of "culturally relevant pedagogy" by Ladson-Billings. The data collected of both studies were similar, such as in-depth interviews, weekly observations by the participants, by studying student artifacts, discussions with the student teacher after the classroom observations of science teaching, and reflective journal entries of the student teacher or the researcher about their teaching experiences. Even data analysis was identical, which was qualitative data analysis with coding of transcripts of interviews. Results of Luft et al. revealed that the student teacher experienced "an unfamiliarity with her students and their life experiences, a marginalization of herself as she tried to create new lessons for students in science, and a desire for her science instruction to be more relevant to her

students" (Luft et al., 1999, p. 527). The student teacher did not receive any support from her colleagues and felt marginalized and constrained. The complexities of learning to teach in a culturally different environments are revealed in this research. Quite similarly, the findings of Morales-Doyle's study revealed that science curriculum organized around an environmental racism issue augmented academic achievement of students greater than what is expected in a typical high school AP chemistry course. The findings also emphasized how the justice-centered curriculum gave the students opportunities to go beyond academic achievement to becoming transformative intellectuals, who can display complex critical thinking about social justice and scientific issues. It also made them committed towards their own communities and cultures and lent credibility to them.

Differences in Case Study Research. There were two case studies which were different in their approaches, namely Laughter and Adams (2012) and Patchen and Cox-Petersen (2008). Laughter and Adams's study was conducted in an urban Title I school in a southeastern city of the USA. The school had students from "low-income neighborhoods" and 51% of its students were from "low socioeconomic status" (Laughter & Adams, 2012, p. 1118). The school had predominantly white students (76%) and the other students were racially diverse. There was also a growing ELL student population. The study focused on culturally relevant science teaching employed by a student teacher, teaching science in five classrooms of sixth graders (average of 30 students in each class) to incorporate the issues of bias and social justice into her science lessons. Whereas, Patchen and Cox-Petersen's case study was conducted in an elementary school in an urban western city of the USA. Two teachers, who teach science for classrooms with 100% Hispanic and African American students from grade 2 through grade 4 were selected for this case study (Patchen & Cox-Petersen, 2008). The main premise of Laughter and Adams's study was culturally relevant pedagogy (CRP) by Ladson-Billings (1995). Whereas, Patchen and Cox-Petersen's study

borrows frameworks from "two theories, social constructivism (SC) by Vygotsky and culturally relevant pedagogy (CRP) by Ladson-Billings" (Patchen & Cox-Petersen, 2008, p. 995). Both the studies had different viewpoints with respect to their findings. Laughter and Adams based their study on the three tenets and three goals of CRP for which all teachers should aim for, and the findings revealed that the student teacher's lesson did substantiate the tenets of culturally relevant science teaching for academic success, socio-political consciousness, and cultural competence of students. However, Patchen and Cox-Petersen used theories of social constructivism and culturally relevant pedagogy because these two theories are identified as the mechanisms for diminishing the "disparities in science education" (Patchen & Cox-Petersen, 2008, p. 994). Their findings indicate that the two teachers successfully modified their science teaching practices to better meet the needs of their ethnically diverse students.

My Reflections and Summarization of Major Findings

When I attempted to review eight empirical studies, I wanted to accomplish two main things: a) consolidate my understanding of the theoretical frameworks of culturally relevant pedagogy in science education, and b) study these primary research studies in detail to understand them and explore whether these studies can answer some of my questions about multicultural science education. I want to convey my thoughts and opinions in the ensuing paragraphs, after having compared all the studies with each other. I would also like to point some of the limitations of the studies which could lead to future research.

In Grimberg and Gummer's (2013) study, the findings reiterated the point that when students are taught in a culturally responsive way, they learn better and their test scores improve. In addition, the teachers' beliefs and culturally relevant teaching practices also improved after this PD program. I learned that the combination of local tribal/cultural practices and science teaching methods utilizing the collective wisdom of the community had

resulted in the success of the PD program. The limitation of this study was that it was done for a period of 5 years where demographic changes in the teacher and student population could have affected the result. Another limitation could be that most of the teachers (79%-89% in both the cohorts) were females, and gender-related differences in teaching beliefs and practices could be a matter of contention in these types of PD programs.

Since my focus of my research is going to be on using CRP in science education, Johnson's (2011) study provided great insights about the foundational principles and components that I must focus on in my own research. I learned that using CRP is quite beneficial to teachers who teach ELL students. In addition, as the Hispanic student population is on the rise in USA, we need more research studies to understand the effectiveness of instruction for this group of students. However, some limitations do exist while attempting these kinds of studies. TPD is a "time-intensive program"; this study required over "300 hours of support for teachers" and consistent and committed support from the school district to reform the teachers' practices (Johnson, 2011, p. 171). This kind of support and cooperation from institutions may or may not be possible for all teachers of all school districts. Other limitations are the scope, validity, and reliability of this study where only two teachers were followed. So, extrapolating the results of just two subjects to the whole teaching community might not be appropriate because qualitative studies have transferable, but not generalizable, findings.

From Laughter and Adams's study, I learned a lot because by just tying up a single lesson with issues of racism and social justice, the science teacher was successful in eliciting encouraging responses from students which adhered to the tenets of CRP. So, there is a lot of potential for incorporating CRP into daily science lessons. I learned that CRP used in science education can develop students' insights about the importance of science in their own lives, and it can make students understand that they can make a difference in society with their

scientific knowledge. The teachers of STEM education could also support issues of social justice by using the scientific method and problem-solving techniques. However, an important distinction and a disappointing limitation of this study was that this study focused on a single lesson completed in just three days, instead of a wider incorporation into the sixth-grade science curriculum of the school. So, although this study is temporally and spatially limited, it has reiterated the beneficial effects of CRP in science education.

I learned from Luft et al.'s (1999) study that there were four implications identified for teacher educators from this study: future teachers should become familiar with the culture of the students they are likely to instruct; preservice teacher education programs should provide pragmatic approaches to student teachers to work effectively in multicultural classrooms; student teachers should be paired up with conducive schools and cooperating teachers who allow the student teacher to pursue with multicultural science teaching practices; and the student teacher should have a close "other" or a confidante (such as student's peers and instructors) so that the student teacher can confide in them and consider them as guides and reflective partners. I also found a limitation that the study focuses on only one student teacher, and it is difficult to extrapolate the findings of this study to the vast teaching community, but the results can be considered transferable to a similar context at the individual level. The study generated more questions than answering them.

For my future research, the findings of Morales-Doyle's (2017) research study are significant since my prime area of interest is culturally relevant science pedagogy focusing on social justice and diversity. The research study has implications for educational researchers, preservice teachers, practicing teachers, and teacher educators who want to incorporate "science education as a catalyst for social transformation" (Morales-Doyle, 2017, p. 1034). However, the limitation of this study is that only nine students were studied. Cochran-Smith

and Lytle (2009) also lament that the teacher education research has not been able to aggregate findings across studies (Morales-Doyle, 2017, p. 1056).

From Patchen and Cox-Petersen's (2008) study, I learned that both SC and CRP theories aided the teachers in this study to better understand their students and modify their classroom practices to suit the needs of their students. The implications of this study show that culturally relevant pedagogy increases access to scientific and technological fields for marginalized students. I also aim to focus on similar goals for my future research. However, the limitation was that students' outcomes were not measured. Only the teachers' practices were studied and found to improve.

Being a science teacher and researcher, I was curious to know about the results of Ramirez et al.'s (2016) study because of its deep connection to culturally relevant science and math pedagogy. I have experienced that interactions with parents remove the inherent biases that may be present in teachers, and the interactions improve the relationships in and beyond the classroom. Implications of this study for programs for teacher preparation include, giving the PSTs ample opportunities to participate in FM/SLEs that teach them how to plan and teach, and incorporate culturally relevant math and science activities in class. Another gain from this study is that it encourages the model of acceptance where the PSTs can identify and revisit the perceptions and misconceptions about the parents of their students from a different ethnic group. The limitation of this study is that it was only concentrating on the Latino parents who don't speak English. However, knowledge base about many other ethnic groups is also lacking, so studies encompassing more diverse participant groups should be done to learn about the overall implications of those studies in the education field.

I learned from Tolbert's (2015) study that the topic of culturally relevant teacher mentoring/PD programs is underrepresented, and less literature is available for science

education researchers. Because of the growing diversity in the student population, these types of studies help us understand how to retain and ensure success for indigenous students in science classrooms. The study has further implications for teacher educators for becoming more culturally responsible mentors. One limitation that I identified is that this study did not concentrate on other ethnic groups, probably it was because it was conducted in an area which has a high Maori population. Even the percentages of school dropout rates were not given in the study. More studies are warranted to learn more about these types of PD programs.

Conclusion

After summarizing the major findings of the selected literature, I am now confident that my goal of literature review has been fulfilled. I now have a solid background knowledge about the theoretical frameworks available in this educational domain. In the following paragraphs, I would like to present the benefits of using CRP in science education, knowledge gaps, and questions that could be posed by future researchers for using CRP in science education.

Benefits of Culturally Relevant Science Teaching

There are many benefits of culturally relevant teaching. Firstly, research points to a marked increase in academic scores when teachers employ culturally relevant instruction methods (Au & Kawakami, 1994). Secondly, because many minority students (whose communities have either been oppressed or suppressed in the past) must spend their lives trying to adapt to the dominant culture, employing culturally relevant teaching methods will encourage and support their values and identities. These methods make minority students feel safe and motivate them to excel in their chosen field. Scaffolding of learning for these minority students helps them to be more engaged in learning and to advance in their paths (Butler, Burnett, Renfrew, Renfrew, & Smith, 2017). Additionally, justice-centered science

pedagogy, which is also a significant talking point in education, applies culturally relevant pedagogy to counter inequities (Morales-Doyle, 2017). As pointed out by the literature review, culturally relevant science pedagogy will help students develop stronger identities and new perspectives, help them engage more in learning science, will increase their critical thinking skills, will improve their learning outcomes, and ultimately help them consider a career in the sciences.

Questions for Future Research

Many researchers have added on to our knowledge of culturally responsive teaching. The methods formulated by them could effectively be used to improve the student outcomes in a diverse classroom setting. When reviewing the research studies on CRP, I found that there were many knowledge gaps, as there are not many research studies being done in this field. So, these gaps could lead to questions being posed for future researchers, including me. The purpose of my proposed research is to develop workable protocols for multicultural science education and qualitatively analyzing them for effectiveness. I am planning on research work that could potentially help present/future science teachers apply culturally relevant pedagogical methods in their classrooms. The questions that I came up with when reviewing the literature are as follows:

1. How can we extrapolate the results of long-duration studies (5 years or more) where demographic changes in the teacher and student population could affect the results?
2. Could gender-related differences in teaching beliefs and practices be a matter of contention in science teachers' PD programs? How can we generalize those findings to a wider, non-gender specific science teacher population?
3. What are current societal, political, economic, and macro-policy trends that have implications for schools, teachers, and students who are following the CRP protocol for science education?

4. What are the characteristics of learning environments and teaching practices that best support science learning in multicultural classrooms? How can we navigate educational policies and mainstream practices to ensure inclusion of ALL students in science classrooms?
5. How can we conduct large controlled studies to investigate ideas derived from small-scale studies that used culturally responsive science pedagogy? How can we address research limitations such as scope, validity, and reliability of existing studies in which only two or three teachers' experiences are studied?
6. What are the most challenging hurdles to be overcome to implement CRP in science classrooms? When, how, and where does change to following the CRP protocol typically occur?
7. What principles of culturally responsive science pedagogy apply across groups and across national boundaries so that educators in diverse cultural and national contexts can learn appropriately from each other's work? Can countries such as the USA follow some of the international examples and have teacher mentors and confidantes to improve the overall teaching of science?
8. How do different school contexts support culturally relevant science pedagogy? What implications do these broad trends and school- and teacher-level processes have for teachers' practices and students' opportunities to learn?
9. What do we know about the preservice and in-service strategies that can support the development of different aspects of culturally responsive science pedagogy in different contexts and for a range of population?
10. Will time-intensive science/math/STEM PD programs get the support and cooperation from participating institutions or governments/school districts? How can we ensure

that science teachers are prepared and well informed to incorporate CRP strategies in their classrooms?

11. Is it possible to incorporate the CRP science lesson plans for all grade levels in all school districts rather than following them only for certain test classrooms? How do we overcome spatial and temporal limitations of such case studies having a narrow scope?
12. How can preservice teacher education programs provide pragmatic approaches to student teachers to work effectively in multicultural classrooms? What strategies are to be used by policy makers and administrators to ensure student teachers are paired up with conducive schools and cooperating teachers who allow the student teacher to pursue with multicultural science teaching practices? What are the hurdles and challenges for such an operation?
13. How can teachers of STEM education support issues of social justice by using the scientific method and problem-solving techniques? How can we measure the student outcomes at the societal level?
14. How can we improve the knowledge base about ethnic or cultural groups to teach science? Will studies encompassing more diverse participant groups help to learn about their overall implications in science education?
15. What new types of assessment strategies are to be used for assessing students in multicultural classrooms?

Finally, considering the various knowledge gaps and lack of adequate number to research studies in the field of culturally relevant science pedagogy, extensive research studies are needed to arrive at reliable conclusions, and more detailed research studies for a wider teaching population are warranted too. To consolidate knowledge about the underrepresented ethnic communities, more research studies are needed to understand how to best address the

needs of the increasingly diverse student body. These generic problems of incorporating culturally relevant pedagogy for any subject/stream of study is very much applicable to science pedagogy too. Keeping all of this in mind, I hope and aim to contribute towards culturally relevant pedagogy in science education in my future research!

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