Using ADDIE to Influence Teachers' Critical Consciousness in a Science Education Course

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Abstract

In this article, I describe the development and implementation of a single-semester science education course for secondary education science and math majors. The innovation lies in how the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) instructional design model helped me create an additional learning space within a tightly packed traditional teacher preparation program. Drawing upon tenets of the Rightful Presence Framework, I structured the course and assignments to challenge teachers' assumptions about the relevance of sociopolitical issues and connect them to classroom-based science teaching and learning. This paper describes how the ADDIE model was applied to course design and implementation to influence science teachers' sociopolitical awareness and inform my thinking as program coordinator. While the ADDIE model supported the use of critical frameworks in course design, implementation of the design did not result in significant changes in teachers' critical consciousness. These results indicate that factors such as the modality of the course or the initial stage of critical consciousness may also influence science and math teachers' sociopolitical development.

Introduction

The general consensus around the importance of educating all students, no matter their demographic, has contributed to widespread reform efforts in science education in the United States. Yet, findings from the field identify a number of barriers to this goal (Brown et al., 2016; Feder & Malcom, 2016). For example, while student demographics, expectations for student learning, and demands on teachers have changed, there have been few, if any, changes in teacher education programs specifically linked to educating all students (Ball & Ladson-Billings, 2020; Cochran-Smith & Reagan, 2021; Liu & Ball, 2019). In teacher education programs, mismatches among student and teacher demographics and preparation have significant implications for what is learned, when, and by whom (Danielsson & Warwick, 2014; Jones & Enriquez, 2009; Warren et al., 2020). My experience as a science teacher educator of color in a predominantly white institution mirrors one such mismatch. In an attempt to tackle this social challenge, I created a new course for science and math educators. To be clear, adding a new course to a tightly packed teacher preparation program in a location separate from their teaching does not solve the challenge of preparing teachers to educate all students. Rather, this course provides a vehicle for knowledge construction. Said differently, this course aligns with general expectations for a teacher preparation

program and has the potential to address a broader ambition of fostering teachers' intellectual curiosity about teaching science and math in a room of heterogeneously mixed students.

The Framework (National Research Council, 2012) sets forth a vision for K-12 science education that prioritizes excellence and includes equity. Scholars have further argued that excellence and equity are interdependent (Rodriguez, 1998), and some educators have relied on principles of democracy to expand their thinking and modify their practices to better serve their students, with particular attention to those underserved and underrepresented (Alim et al., 2020; Brown, 2021; Ukpokodu, 2011). Recent political controversy, particularly in institutions of higher education (Ellis, 2024), has complicated science teacher preparation that focuses on greater participation in higher levels of science learning. Book-banning policies, the targeted dismantling of programs, and the abrupt interruption of financial support illustrate some of the challenges educators now face in their work. We also know that, individually, teachers struggle to relate science knowledge construction with sociopolitical issues (Bianchini & Solomon, 2003) and could benefit from collaborative spaces for pioneering work (Martinez et al., 2016).

Thus, I developed a graduate-level course that aims to build students' sociopolitical knowledge of issues in science and math education through reflective analysis of selected topics in math, science, and computer science education. The course served as a space for teachers to connect their learning about educating all students to their learning and knowledge of science and math. My ambition of helping learners identify the relevance of socioscientific issues and democratic principles to science and math learning was addressed by incorporating specific aspects of critical frameworks into the course's design. In this article, I analyze that design and discuss some implications for other science teacher educators preparing teachers to adapt their instruction in ways that value their students' experiences.

Theoretical Framing and Course Design

Democratic principles (Dewey, 1916) remain a key goal of science education such that secondary students must be prepared to engage in "public discussion of science-related issues" (National Research Council, 2012, p. 9) and for "their roles as citizens in this technologically-rich and scientifically complex world" (National Research Council, 2012, p. 10). Typically, pre-service teachers practice facilitator skills and grapple with how best to establish a classroom environment that prepares adolescents for a citizen role within their methods course. However, with so many topics included in a teaching methods course, there is little time for conceptual change in pre-service teachers' thinking about the relevance of sociopolitical issues to their science teaching. Sociopolitical issues are key components for relevant and challenging science teaching and learning (Jackson & Knight-Manuel, 2018; Ladson-Billings, 2014; Ye et al., 2011).

Sociopolitical awareness is a broad, complex concept that, for some, leads to critical consciousness (Watts, Williams, & Jagers, 2003). Both involve a process for understanding the various cultural and political factors that shape identity in society (Watts et al., 2003; Sánchez Carmen et al., 2015). Much of the extant literature on critical consciousness was developed and studied among marginalized youth. Teachers' work includes supporting their students' development, ideally in ways that would allow their full participation in a global world. Such work would involve exploring socioscientific or critical mathematical issues of interest to students within the classroom. Teachers then need to develop sociopolitical awareness and critical consciousness if they are to support this more humanistic development among their students. Sociopolitical awareness is so essential that teachers progressing through teacher education programs often perceive science teaching for diversity and science teaching for understanding as disconnected (Rodriguez, 1998). This elective course was designed on the premise that classroom experiences with public discussion of science-related issues and analysis of scientific knowledge construction would support teachers' learning about the relationship between the sociopolitical environment and science learning in secondary schools.

Design for the course was informed by the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) process for instructional design (Branch, 2009), commonly used in training programs. I chose the ADDIE process for its alignment with my goal of creating a learning space that supports teachers as they connect their college classroom learning to their science teaching. It provided a template for mapping my thinking and interpretations of critical frameworks onto my choices for course instructional design. My thinking about the learning space has been strongly influenced by the Rightful Presence Framework (Calabrese Barton & Tan, 2020). It has three tenets for a justice-oriented approach to science teaching and learning, and here, I apply the second of these tenets to science teacher preparation. This tenet, focused on making justice and injustice visible, calls for explicit attention in classrooms to the intersection of science and math learning, students' lives and wisdom, and injustices and justices toward fostering more just possibilities. In this theoretical framework, Calabrese Barton & Tan (2020) argue for shifting from a host-guest relationship between the teacher and marginalized students toward collective presence as the basis for rights and shared responsibility for the classroom community. My theoretical focus centered on how teachers' presence, i.e., their choice to register for this course, could be leveraged and serve as a model for adjusting the learning process to value learners' experiences and backgrounds. I invited experiences and tensions from course participants in an effort to discuss issues they encounter. The learning process for this course involved surfacing injustices and examining our knowledge and actions in relation to them—a process necessary for sociopolitical development (Watts et al., 2003). As such, ADDIE was chosen to systematically design the course in ways that would improve my practice of incorporating critical frameworks. These frameworks informed my selection of activities that would address

some of the disconnects teachers experience with the sociopolitical component of science teaching. A tool was then used to describe and capture any changes in teachers' critical consciousness.

For this article, I outline the course design for one of five course objectives, to investigate how assumptions, frames of reference, and social structures relate to disproportionate access to opportunities and influence knowledge construction in STEM. Next, I discuss instructional outcomes that relate to the objective. Lastly, I provide reflections on these outcomes and implications for future work.

Context

The newly designed course was offered twice to students enrolled in two types of graduate programs: one leading to initial certification, and one contributing to professional certification. These graduate certification programs follow a traditional model (Olson, 2017) in that teachers pursue separate courses in the foundations of education, adolescent development, schooling for diverse learners, and, for initial certification, a teaching methods course alongside field experience. The semester-long course was an elective for graduate students who possess a bachelor's degree in math or a science discipline. The majority of the graduate students were pre-service teachers taking the course before student teaching, in addition to their science teaching methods course. The remaining graduate students were pursuing professional certification while working as classroom science and math teachers. Registrants for the course include pre-service and in-service secondary science and math teachers. For clarity in this paper, I will refer to all course participants as teachers, albeit at different career stages.

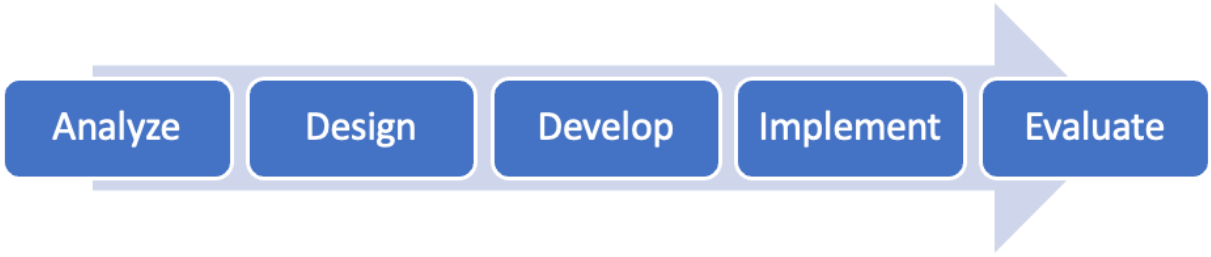
Course modality was online asynchronous, with two online synchronous meeting dates. Attendance for the online synchronous meetings was optional; 16% of teachers attended at least one meeting. A total of 18 teachers registered for the course across the two semesters, 72% were pre-service and 28% were in-service.

Course Design

In this section, I outline how the ADDIE model was used for course design. The five stages of the ADDIE model include: 1) analyze situational factors, 2) design learning objectives and assessments, 3) develop activities aligned with the learning objectives and embed assessments, 4) implement the course in ways that engage teachers and promote community, and 5) evaluate instructional outcomes for effectiveness as shown in Figure 1.

Figure 1

Five stages of the ADDIE process (Branch, 2009)



Analyze

Teachers who enroll in our programs are passionate about STEM disciplines and about education; they have also excelled in their STEM majors. Their stated goals include increasing their knowledge of equity and its relation to STEM education. Based on programmatic observations, their preferred learning styles range from learning from experts and engaging in lectures to hands-on activities. Considering my theoretical focus, I needed to encourage the teachers to recognize their own STEM learning as a source of strength, an area of expertise that they could share and build upon within the course. According to Bianchini and Solomon (2003), pre-service teachers often struggle with relating science knowledge construction to science instruction for all students. Activities, such as minute papers, recall-summary-question-comment-connect probes, and ethical dilemmas that prompt teachers to connect science knowledge to foundational education knowledge and affirming pedagogies (Alim et al., 2020; Gay, 2000; Ladson-Billings, 2014) were chosen to support my goal.

Design

The course included five instructional objectives. However, this paper focuses on a single objective (as shown in Table 1) to more specifically illustrate the innovation of incorporating specific aspects of Rightful Presence and Sociopolitical Development into this class. The course objective – to investigate how assumptions, frames of reference, and social structures relate to disproportionate access to opportunities and influence knowledge construction in STEM – connects lived experience with STEM knowledge. This objective is tied to sociopolitical development in that course participants will draw from their lived experience (e.g., a cultural factor) and explore opportunities to learn (e.g., a political factor) in dialogue with others. Further, cultural factors were considered to interrogate how they have shaped what we accept as STEM knowledge and how we recognize possession of STEM knowledge. Proficiency with this objective was assessed through teachers' responses to a critical consciousness scale, discussion prompts, and peers' posts, as well as a review of ideas shared within their written assignments and final paper. I was interested in whether these selected instructional strategies were useful for supporting changes in teachers' critical consciousness and were consistent with a shared responsibility for learning approach.

Develop

Course activities prompted them to reflect on "what" and "how" they have learned in STEM classrooms, along with "why", to facilitate a critical analysis of topics that teachers will likely have strong beliefs toward. Activities include readings from a variety of sources and authors, webinars from STEM disciplines, and discussion prompts. Prompts were constructed to elicit teachers' ideas about how scientific knowledge is generated and reproduced and to foster teachers' reflexivity. My development of the prompts was guided

by principles of onto-epistemic heterogeneity, horizontality in particular (Warren et al., 2020), and Rightful Presence (Calabrese Barton & Tan, 2020). Horizontality "highlights the boundless variety of places, cultural contexts, and practices through which people learn" (Warren et al., 2020, p. 283). For example, teachers viewed a YouTube video about indigenous knowledge as science. They were then prompted to consider how indigenous knowledge is shared, who the audience for the video may be, what parallels the speaker draws between indigenous knowledge and science, and, based on the video, implications for science teaching in their classrooms. I developed these prompts to encourage teachers to think about how learning happens for students spanning at least two cultural contexts (indigenous culture and science classroom culture). In thinking about these cultural contexts as repertoires of support for secondary students and discussing their implications for students' science learning, we are attending to horizontality in our work. Lastly, informal meetings and short written assignments provided tools and spaces for teachers to connect different perspectives on science and math teaching and learning to their own experiences and practices.

Implement

The course was implemented according to its design. Weekly review of the course blueprint ensured alignment with the objective. Regular confirmation that materials and assignments were available, provided timely access to teachers. Any questions posted to the open forum were also reviewed weekly. Submissions were evaluated, and teachers received individual feedback to further their thinking. Lastly, informal meetings were held and provided a space for more personal interaction. In addition to these transactional instructor duties, I documented observations of teacher learning and reflections in memos.

Evaluation

Assessments were evaluated for alignment with the objective. Discussion threads and assignments were monitored, and teacher responses were considered so that upcoming material could be adapted. My aim was for teachers to confront ideas about sociopolitical issues and make connections to science and math teaching and learning. Prior research has demonstrated that critical consciousness may be a measurable component of developing sociopolitical awareness (Baker & Brookins, 2014; Christens et al., 2016; Diemer et al., 2016). To determine the course's influence on developing science teachers' sociopolitical awareness, I selected a survey instrument validated for measuring critical consciousness. The survey measured three distinct components of critical consciousness. Critical reflection describes teachers' analysis of socioeconomic, racial/ethnic, and gender inequalities. Critical motivation measures teachers' perceived ability and responsibility for engaging in social action. Third, critical action speaks to teachers' participation in social action. While validation of the Short Critical Consciousness Scale indicates the instrument efficiently detects changes across a wide range of critical consciousness levels (Diemer et al., 2020), the small number of course participants limits any broad generalizations about science teachers' critical consciousness. This Short Critical Consciousness Scale (Diemer et al., 2020) was administered to describe teachers' critical consciousness and to detect any changes.

Reflections

Assessments of the course objective include teachers' responses to the critical consciousness scale, discussion prompts, and their peers' posts, as well as their ideas captured in written assignments and the final paper. Table 1 lists specific aspects of the instructional objective in column 1, corresponding activities in column 2, and excerpts of teachers' responses in column 3. Sample responses illustrate how teachers wrestled with their own assumptions about recognition in a STEM community. In addition,

teachers considered factors that influence why few adolescents & young adults pursue existing pathways for advanced science knowledge. Finally, they discussed how that recognition influences what scientific ideas people know.

Table 1
Data of student responses to two course objectives

Course Objective	Course Activities	Excerpts from Teachers' Posts and Assignments
Investigate how assumptions and social structures relate to disproportionate access to opportunities and influence knowledge construction in STEM.	Readings, STEM lectures/webinars, discussions, and optional synchronous meetings	T1: "As a woman myself in [geology], I love to see other women succeed in research-based exploration of geology. Being able to see myself in the lecturer really made me love my degree more. Seeing other women succeed in male-dominated fields is a highlight of the times that we live in."
		T2: "I also know that students with disabilities are not inherently incapable of achieving a higher level of science [knowledge] and the influence of the expectancy effect on those students."
		T3 to T2: I also believe that if the teacher knows there is a student with a disability who wants to take their class, the teacher would allow it 9 times out of 10... it would be a challenge."
		T4: "The idea that I knew more about turbulence than an average person, simply because I am a STEM educator and have taken one physics class in the past, is an idea that I had to grapple with as I watched the webinar."
		T5: "When I think of representation in STEM, I think back to learning about some of the great scientists throughout my educational journey. I think of names like Albert Einstein, Hershey, Chase, Oppenheimer (the movie was awesome), pretty much a ton of white men. Now, I am not saying these men were not skilled in their fields…It wouldn't take much digging to find the work of Albert Einstein, but it would be harder to find the truth of someone like Henrietta Lacks."
		T6 to T5: "Now that I look back on my education, I completely agree, all the scientists I learned about in school were mostly old white men. I really appreciate you saying this because this really opened my eyes into how white men in particular have been plastered all over history. Meanwhile, there is an abundance of people of color who have made just as important contributions to science and society as white men, and it is wrong that they do not receive the recognition they rightfully deserve."

Supporting Sociopolitical Development

A repeated measures ANOVA was conducted in R to evaluate changes in teachers' critical consciousness at two time points during the course. This statistical test was appropriate for comparing two groups that violate the assumption of independent samples. Results are shown in Table 2. No statistically significant difference in pre-test and post-test scores for critical reflection, $F(1, 30) = 0.764$, $p = 0.39$, critical motivation, $F(1, 30) = 0.131$, $p = 0.72$, or critical action, $F(1, 30) = 1.049$, $p = 0.31$ was found. These results indicate that this course failed to significantly change teachers' critical consciousness. However, the descriptive characteristics revealed an interesting finding. By the end of the course, the mean scores for teachers' critical reflection and critical action were high (5.03 and 4.54, respectively), indicating that teachers attributed societal inequalities to more structural and systemic factors and participated more frequently and consistently in social activism. Yet, teachers' mean critical motivation score was very low (1.28), indicating that teachers perceived their capacity to engage in social action as low.

Table 2

Repeated measures ANOVA for short critical consciousness survey

	df	Sum Sq	Mean Sq	F	p-value
Critical Reflection	1	0.99	0.9944	0.764	0.389
	30	39.05	1.3015		
Critical Motivation	1	0.02	0.0170	0.131	0.720
	30	3.87	0.1290		
Critical Action	1	0.28	0.2773	1.049	0.314
	30	7.93	0.2645		

Conclusion

The ADDIE process provided a structure for course design and has been helpful for analyzing my practice as a science teacher educator. The process revealed both strengths and shortcomings in my approach of offering a new course for teachers to connect their learning about educating all students to their learning and knowledge of STEM. The process also helped to assess my ambition to build teachers' sociopolitical knowledge of issues in STEM education through reflective analysis.

First, the strengths of this course design were found in alignment and support structures. Assessments were aligned with the course objective. Assignments were closely linked to both the objective and assessment tasks. This alignment led to data on teachers' ideas about what adolescents need to learn science, how recognition in STEM communities may be determined, and why needs and recognition matter for science teaching. The support structures included the layout for the online modules, prompts, the open discussion forum, and informal meetings. These support structures helped to elicit teachers' ideas and promote engagement in the course. Engagement in the course resulted in public discussion of science-related issues and provided teachers with experiences they could incorporate into their classrooms.

However, the course fell short in its impact on teachers' critical consciousness. Results from the evaluation stage of the ADDIE process indicate that the development of teachers' critical consciousness likely involves more than what this course modality provided. Course modality may also explain the lack of significant change in teachers' levels of critical reflection and critical action at the end of the course. Notably, teachers entered the course with high levels of critical reflection and critical action, indicating that self-selection into the course may be influencing the results. Similarly, there were no significant changes in teachers' low levels of critical motivation, and these low levels of perceived capacity for social action were surprising. The assessments and activities were not designed to elicit teachers' beliefs, which may have provided more insight into their low perception. As the majority of the teachers were in the pre-service stage, their self-efficacy with science teaching is underdeveloped and may underlie their low perception of their ability to enact change. Upon reflection, these science teachers were reluctant in the beginning of the course to acknowledge expertise within their own work/experience. Initially, this reluctance prompted me to think about teachers' self-efficacy. Later, the descriptive statistics for the ShoCCS resurfaced my thoughts about teachers' self-efficacy and could be an interesting avenue for future research.

In conclusion, the ADDIE process for designing a course that develops teachers' sociopolitical awareness revealed that measurable changes seem to require more than what this single course provided, due in part to self-selection and course modality. Instead, the ADDIE process has helped refine my reflective lens toward a different course aim for future iterations. Students' self-selection for the course reflects an interpersonal phase of development. Harro (2010) describes building community with people both similar and different from one another as a supportive mechanism for social change, and the course served as a vehicle for interaction among people with both shared and different racial identities. Carefully constructed spaces for building community are an essential component for sociopolitical development beyond an individual level (Sánchez Carmen et al., 2015). I now think of the course as one way to support teachers' efforts toward forming a collective to develop their own capacity for change. A collective that began by supporting their sociopolitical development, specifically their critical motivation, by connecting the teachers to one another through the course. Future iterations of the course would attend to teachers' need to develop their perceived capacity for change. One mechanism to support this aspect of teachers' sociopolitical development would involve changing the course modality to require more synchronous meetings to create a space for teachers to construct the community. Given that this single, online asynchronous course was insufficient to capture measurable change and the ongoing constraints of traditional teacher preparation programs, what would creating more spaces for teachers to build collective capacity entail?

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