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Science Youth Action Research: Promoting Critical Science Literacy Through Relevance and Agency

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SCIENCE YOUTH ACTION RESEARCH: PROMOTING CRITICAL SCIENCE LITERACY THROUGH RELEVANCE AND AGENCY

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DEDICATION

I dedicate this dissertation to my husband, Ed Coleman. You are my best friend and my greatest supporter. Life truly is always better when we’re together.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This three-article dissertation presents complementary perspectives on Science Youth Action Research (Sci-YAR), a K-12 curriculum designed to emphasize relevance and agency to promote youth's science learning. In Sci-YAR, youth conduct action research projects to better understand science-related issues in their lives, schools, or communities, while they simultaneously document, analyze, and reflect upon their own practices as researchers. The first article defines Sci-YAR and argues for its potential to enhance youth's participation as citizens in a democratic society. The second article details findings from a case study of youth engaged in Sci-YAR, describing how the curriculum enabled and constrained youth's identity work in service of critical science agency. The third article provides guidance to science teachers in implementing student-driven curriculum and instruction by emphasizing Sci-YAR's key features as a way to promote student agency and relevance in school science.

INTRODUCTION

The Origins of my Dissertation Research

This dissertation represents my experiences with curriculum development, implementation, and research that have been ongoing for three and a half years. However, the journey of this work started long before my dissertation began and is grounded in my practices as an elementary science teacher and teacher educator. My 12 years of experience working with diverse student and teacher populations in urban schools and in informal education environments heavily influenced this work. My time as a student and faculty member at Loyola allowed me to expand my curriculum design skills, resulting in changes in my own science teaching, and then in how I prepared future science teachers. This journey has reinforced my interest and commitment to supporting youth's identity work related to science.

Specifically, my dissertation process began when my colleague, Megan Leider, a fellow doctoral student and high school science teacher, reached out to me in the fall of 2010, asking for help in developing an action-research-based project for her ninth-grade environmental science course. Although she hoped to simply get the titles of some books and articles that she could read to inform her thinking, I immediately volunteered to do more. Excited about this opportunity to collaborate, we decided that we would design and implement a curriculum together, hoping that this curriculum would counter some of her students' disconnection and disengagement with science. Although Megan and I had a connection as fellow Catholic school teachers, and we enjoyed sharing personal and professional viewpoints with one another in our doctoral classes, I do not think either of us anticipated the extensiveness of our collaboration or the powerful impact it would have on our lives.

We developed our action-research-based curriculum throughout the fall of 2010, and then prepared to pilot it in January of 2011. Having just transitioned out of the elementary classroom into a clinical faculty position at Loyola, I found myself missing the time I spent with youth and jumped at the chance to co-facilitate the curriculum with Megan, even though I had no previous experience working with high school students. Piloting our curriculum while conducting a self-study on the process proved to be one of my most powerful practitioner experiences. Having the agency to design and implement something that reflected my beliefs and values as an educator, and then seeing the impact it had on students' engagement in the science classroom further strengthened my commitment to studying youth's experiences in the curriculum and to disseminating knowledge generated from this research to both educational researchers and practitioners.

Following this first year of implementation, I knew I wanted to study our curriculum for my dissertation, but was unsure of what this process would entail. It was at this time that my advisor, Dave Ensminger, came to me with the idea of using a three-article dissertation format, where I could develop three stand-alone, yet complementary articles on the curriculum and youth's experiences engaging in it. Using this format shaped the nature of my dissertation study, in that it prompted me to: (a) conceptually define the curriculum we had developed and situate it within the literature to distinguish it from other existing science curricula, (b) study youth's identity work as they engaged in this unique curriculum, and (c) include a piece for practitioners that would share this information with them and inform their own practices. This format gave my dissertation new meaning and an authentic purpose. No longer was I simply completing a dissertation to earn a degree and title. Instead, I was completing this dissertation to establish our curriculum as a way to empower youth through science, to give youth control over their own practices of science and a voice in the science education community, and to bring this work to actual teachers in real classrooms, so that it might impact the learning and lives of others on a broader scale.

This is how the Science Youth Action Research (Sci-YAR) curriculum and my dissertation came to be. I am indebted to Dave and my other committee members, Ann Marie Ryan and Heidi Carlone, who helped me, develop and refine my ideas for conceptualizing and defining Sci-YAR, as well as focus my study on identity work in service of critical science agency. Their genuine interest in my work and their effective mentoring facilitated my transformation from doctoral student to curriculum designer and scholar.

Three-Article Dissertation Structure

My dissertation is presented using a three-article format, consisting of three independent, yet congruent articles. This format provides varying and complementary perspectives on the Sci-YAR curriculum. In addition, it offers a variety of contributions to the field that will inform the thinking of scholars, researchers, and practitioners.

Article 1: Science Youth Action Research: A Curricular Framework and Instructional Approach to Promote Democratic Citizenship

The first article, a conceptual piece, defines Science Youth Action Research (Sci-YAR) and argues for its potential to address the long-standing problem of science being taught as a specific body of knowledge and set of skills for students to acquire. This outdated approach to science instruction results in a lack of relevance and agency in school science curricula, and youth's disconnection from the discipline. Rather than promoting the current goal of increasing youth's *science literacy* (American Association for the Advancement of Science, 1990), Article 1 argues that the goal of science education should be to promote youth's *critical science literacy* (Calbrese Barton, Basu, Johnson & Tan, 2011). This means that science education must strive to go beyond simply disseminating scientific knowledge, skills, and habits of mind, and encourage students to become scientific thinkers and active agents in their own communities. Science curricula and instruction must provide youth opportunities to take on roles within science-related communities, so they might see science as a tool they can use to critically view the world and enhance their participation as citizens in a democratic society.

Following this premise, the article introduces and defines Sci-YAR, outlines its five key features that distinguish it from other forms of action research and scientific inquiry, and argues for its potential to promote youth's critical science literacy and participation as democratic citizens. Learning theories, such as Vygotsky's (1978) socio-cultural theory and Piaget's (1959) constructivist theory, are then used to show how Sci-YAR is designed to promote the development of youth's knowledge and skills. Finally, the article argues that Sci-YAR's major features can enable youth's *identity work* (Schwalbe & Mason-Schroch, 1996), particularly in service of *critical science agency* (Basu, Calabrese Barton, Clairmont, & Locke, 2009), and it describes how youth's participation in Sci-YAR might help them see science as part of their identities and as a powerful tool to address issues they encounter in their own lives.

The intended audience for this piece is education researchers, as well as curriculum developers and instructional leaders, who are interested in curricular frameworks and instructional approaches that seek to connect schooling with youth's lives and position youth as agents of change. While those in the field of science education are its key audience, scholars in any discipline may have interest in this piece. This work contributes to the literature by offering Sci-YAR as a novel curricular framework and instructional approach that can be used to promote youth in developing and becoming aware of their individual capacities to act in the world through their practices of science.

Article 2: Youth Action Research in the Science Classroom: Implications for Youth's Identity Work

The second article, an empirical piece, presents the findings from my dissertation research: a case study on youth engaged in Sci-YAR in an urban, high school science classroom. This piece details the theoretical framework and research questions that guided the study, as well as describes the context in which the study was conducted, the methodology, and the data collection and analysis procedures. The findings identify and describe components of the curriculum youth found meaningful and detail how the use of

Sci-YAR as a curricular framework and instructional approach enabled and constrained youth's identity work in service of critical science agency. Using the lenses of socio-cultural theory, positioning theory, and constructivist theory, this piece investigates how Sci-YAR enabled and constrained youth in shifting their views of science toward being a tool and a context to take action, and in viewing themselves as scientific thinkers with the ability to bring about personal and social transformation through their practices of science.

The intended audience for this piece is education researchers, as well as curriculum developers and instructional leaders, who are interested in examining cases of youth engaged in school curricula designed to promote critical science agency. This piece contributes to the literature by developing more complex understandings of how youth might engage in identity work in service of critical science agency in the science classroom.

Article 3: Making Science Learning Relevant through Principles of a Student-Driven Curriculum

The third article is an application piece for practitioners who are interested in implementing new curricular and instructional approaches in science. This piece introduces Sci-YAR to teachers and provides details about its structure and key features. It highlights each key feature by discussing its role in the curriculum and in developing youth agency, presenting data from youth describing their experiences with that feature, and detailing lessons I learned as a teacher and researcher from studying the curriculum. Finally, this article gives examples of how teachers can promote each key feature and details specific recommendations for incorporating these features in any existing science curriculum. Rather than dictate that Sci-YAR be implemented with a particular structure, the purpose of this piece is to offer Sci-YAR's key features as guiding principles that teachers can use to adapt their curriculum and instruction to fit the needs of their particular students and school contexts, while emphasizing youth agency and relevance in school science.

This article intends to disseminate knowledge generated from my dissertation study investigating youth's participation in Sci-YAR to inform the work of practicing teachers. Without this piece, the argument that Sci-YAR has the potential to address the problem of youth's disconnection with science loses its power. To fully realize Sci-YAR's benefits for youth, the curriculum and knowledge generated from studying the curriculum must be shared with those who facilitate the learning of youth on a daily basis.

Concluding Piece

In addition to these three articles that emphasize different aspects of Sci-YAR, I also incorporate a brief concluding piece that explains how the three articles fit together and offer varying, but complementary perspectives on Sci-YAR as a curricular framework and instructional approach. I also include a reflective narrative that describes my experience designing and conducting my dissertation research, in order to provide a better understanding of my own practice as an educator and researcher and to elicit *resonance* (Conle, 2003) in the reader, or the evocation of similar experiences. This narrative intends to generate new insights into my own personal and professional growth and to inform other doctoral students as they go through the process of completing a dissertation. This narrative includes a strong reflexive component on how this process of developing, conducting, and disseminating my dissertation research on Sci-YAR served as a way to facilitate my own identity work as a science educator and researcher.

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ARTICLE 1: SCIENCE YOUTH ACTION RESEARCH: A CURRICULAR FRAMEWORK AND INSTRUCTIONAL APPROACH TO PROMOTE DEMOCRATIC CITIZENSHIP

Abstract

In this article, I introduce Science Youth Action Research (Sci-YAR) as a curricular framework and instructional approach and argue for its potential to enhance youth's participation as citizens in a democratic society. I highlight and explain Sci-YAR's key features, ground Sci-YAR in the essential tenets of two learning theories, and explain how Sci-YAR is designed to help youth construct views of themselves as agents who can use science to bring about personal and social transformation. Being able to function as part of a democratic society requires that youth develop and become aware of their individual capacities to act in the world. Sci-YAR is designed to facilitate this process for youth because it: (a) integrates the learning of science content and the development of science process skills in ways that reflect essential tenets of learning theory, (b) ensures that this learning is relevant to youth's lives by creating opportunities for identity work in the science classroom that facilitate explicit connections between youth's lives and the content and practices of science, and (c) promotes youth's identity work in service of critical science agency, so that youth might see science as a tool and a context to take action in their own lives and communities.

Science education in the United States (U.S.) has a long history of problems for which it has been critiqued, as well as a multitude of reforms intended to address these ailments. A prominent issue, even at the beginning of the 20^{th} century, was articulated by John Dewey (1910), as he questioned science instruction, arguing that "science teaching has suffered because science has been so frequently presented just as so much ready-made knowledge, so much subject-matter of fact and law, rather than as the effective method of inquiry into any subject matter" (p. 124). Dewey saw science as a subject that had direct connections to people's everyday lives, however, was not being presented as such, but rather was reduced to merely the transmission of content knowledge, with the expectation that youth accumulate this knowledge. He concluded that denying youth the opportunity to generate knowledge through the sciences denies them the freedom that comes with being citizens in a democratic society. Despite his warnings, science education continues to be viewed by many as the transmission of and accumulation of facts and scientific knowledge. This approach to science education has had its pitfalls; given the sheer multitude of scientific information that could be included in a curriculum, educators are forced to arbitrarily select material to be taught and to cover topics at a very superficial level, often decreasing youth's interest and engagement in science.

Policies intended to reform science education generally have not addressed the problem of science education as a meaningless accumulation of facts. Instead, reforms have been introduced—usually following national political crises—with the intent of increasing America's performance in science, for the purpose of ensuring our viability as a nation (Kliebard, 2004; U.S. Department of Education, 2000). Some of the major policy reforms, as well as their outcomes for science teaching and learning, are outlined in Table 1. Because of the reactive nature of these reforms, they have had little impact on how science teaching and learning is practiced (DeBoer, 1991), and they have not deterred educators from using didactic, lecture-based teaching methods (Martin, Mullis, & Foy, 2008; Martin, Mullis, Gonzalez, & Chrostowski, 2004; Martin et al., 2000; Provasnik et al., 2012; U.S. Department of Education, 2000). Furthermore, when examining the cycles of reform over the past half-century, one sees separate emphasizes on either knowledge of scientific content—most often characterized by textbook-oriented curricula and rote learning—or the processes of scientific practice, characterized by active learning approaches through inquiry. Creating a separation between science content and science processes is not only an inaccurate picture of how scientists go about their work, but it tends to prioritize the importance of knowing science content, resulting in curriculum with a strict emphasis on students acquiring a plethora of science facts, concepts, and theories (Windschitl, Thompson, & Braaten, 2008).

Examining the major trends in reform, it is clear that a significant challenge in science education has been overcoming the idea that rigor in science education means developing an ever-expanding curriculum in which teachers transmit and students accumulate a large amount of science content knowledge. A major problem with this approach is that a sole focus on acquiring content knowledge often leads educators to neglect the ways in which they can help youth understand how the processes of scientific thinking and practice have lead to the development of this knowledge and how these scientific skills and ways of thinking might help them develop knowledge and take action

Table 1

Major Science Education Reforms in Response to Political Context and Events

Political Context or Major Event	Policy Reform	Actions Associated with the Reform	Outcomes of the Reform
Launching of *Sputnik*, the world's first earth-orbiting satellite (1957)	National Defense Education Act (1958)	• Emphasis on the cognitive goals of education, rather than affective or life skill goals. • Curriculum revision in science, math, and foreign language, with the primary power to develop curriculum given to national government agencies, such as the National Science Foundation (NSF). (Kliebard, 2004)	• Curricula focused on memorizing facts, laws, theorems, and presenting in-depth knowledge about very specialized fields of science. • Simple experimentation used sparingly to briefly expose students to basic inquiry process used by scientists. (McNeil, 2009)
Great Society and social reform (late 1960s, early 1970s)	Elementary and Secondary Education Act (1965)	• Federal funding for public education to initiate reform. • Science-Technology-Society movement promoting more practical applications of science through societal issue-oriented curricula. (Aikenhead, 2006; DeBoer, 1991) • Prevalence of humanistic approaches to science education focused on teaching of content through the development of active process skills, with the purpose of	• Short-lived due to a lack of support structures in place, including high costs incurred by publishers to put out curricular materials and the large amount of teacher training involved with these types of curricula. • Schools and teachers returned to more rote science learning through textbooks. (Duschl et al., 2007; McNeil, 2009)

		addressing real human issues found in society. (Duschl, Schweingruber, & Shouse, 2007)	
Height of the Cold War (1980s)	National Commission on Excellence in Education (NCEE) releases report, *A Nation At Risk: The Imperative for Educational Reform* (1983)	• Call for a more extensive and more rigorous science curriculum, particularly in high schools. • Strong emphasis on textbooks and standardized testing. (NCEE, 1983)	• Started the trend of the ever-expanding curriculum, including extensive science content; process skills; personal applications of science; as well as social and environmental implications of scientific and technological development. • Lead the way to standards-based reform. (Kliebard, 2002)
Educational Accountability (2000-present)	No Child Left Behind Act (NCLB) (2001)	• Emphasis on standardized testing and accountability measures. • Required testing in science at grades 3-5, 6-9, and 10-12; however, not included in accountability measures. • Promotion of curricula with emphases on lower-level cognitive thinking and rote learning of large amounts of content. (Au, 2007; Darling-Hammond, 1997)	• Nationwide decrease in the amount of teaching time spent on science. (Center on Education Policy, 2008) • Separation of learning science content and developing process skills, with priority given to covering large amounts of content in short periods of time to prepare students for high-stakes testing. (Windschitl, Thompson, & Braaten, 2008)

in their own lives. As Dewey argued over a century ago, relegating science to merely an accumulation of science content and presenting it to youth as such limits the ability of those youth to participate in a democratic society, as they do not know how to use or apply that knowledge in their own lives.

Thus, defining a rigorous science curriculum as one that focuses on the accumulation of facts only creates additional problems by minimizing the importance of constructing or using that knowledge through science process skills. More recent reform initiatives—beginning with the standards-based movement and the creation of national frameworks and standards, and leading up to the recent release of the Next Generation Science Standards—have emphasized the learning of science content in conjunction with process skills in order to develop youth's *science literacy* (AAAS, 1990), which entails proficiency in science content knowledge, process skills, and habits of mind or ways of thinking like a scientist. Some of the major reports reflecting this trend, as well as their outcomes for science teaching and learning, are outlined in Table 2. While these initiatives have attempted to narrow the scope of the curriculum and provide structural supports to sustain a view of science education that includes learning content *through* the processes of science, teachers still often see these as disconnected (Windschitl, Thompson, & Braaten, 2008), with science processes outlined in the frameworks and standards viewed as discrete skills that are added to the long list of content to be taught.

Table 2

Reports and Standards Emphasizing the Learning of Science Content in Conjunction with Process Skills

Reports and/or Standards	Main Ideas	Outcomes for Science Teaching and Learning
Science for All Americans (American Association for the Advancement of Science [AAAS], 1990) *Benchmarks for Science Literacy* (AAAS, 1993)	• Highlighted low performance of American students on international education studies and potential problems for our country's future. • Emphasized the importance of Americans developing science literacy. • Outlined science content, process skills, and habits of mind all Americans should have.	• Began standards-based movement and creation of national frameworks and standards. • Set the primary goal of science education as developing science literacy, which includes content, process skills, and habits of mind needed for Americans to participate fully and productively in a democratic society.
The National Science Education Standards (National Research Council [NRC], 1996)	• Emphasized inquiry as a way to promote both scientific processes and the scientific knowledge needed to be scientifically literate. (NRC, 1996)	• Promoted teaching and learning through inquiry as a way to bridge students' understanding of content with their abilities to develop the process skills of science.
Taking Science to School: Learning and Teaching Science in Grades K-8 (Duschl et al., 2007)	• Called for science curricula that better reflect the nature of science and that engage students in deepening their knowledge of scientific concepts through authentic practices of science. • Presented a new framework defining proficiency in science: The Four Strands of Science Learning.	• Pushed for the development of an organized, cohesive science curriculum to prevent *a mile wide and an inch deep* (Duschl et al., 2007, p. 20) coverage of content and to engage students in authentic scientific practices.

A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC, 2011) *Next Generation Science Standards* (NGSS) (Achieve, 2013)	• Called for the development of improved frameworks and standards for 21st century science teaching and learning. • Provided systematic organization of science content and process skills across multiple years of school, with a focus on exploring essential topics in depth and opportunities for students to engage in authentic practices of science.	• Promoting the unity and compatibility of science content and processes, as they attempt to narrow the scope of the curriculum and suggest structural supports necessary to sustain an integrated view of science teaching and learning.

This content-based, skill-based approach focuses solely on the cognitive aspects of learning, thereby neglecting the affective aspects of learning and ignoring curricula's relevance to youth and their lives. Therefore, one must consider not only the importance of *rigor* in science education, but also the importance of *relevance.* Deficiencies that have been highlighted in youth's science literacy stem, not from a lack of rigor in science curricula, but from science curricula being disconnected from everyday people and their experiences (Calabrese Barton, Ermer, Burkett & Osborne, 2003; Emdin, 2009; Roth, 2009; Roth & Lee, 2002, 2004). A fundamental cause of this disconnect between science and youth's lives is a misinterpretation of what science literacy means (Roth & Calabrese Barton, 2004). Rather than defining science literacy as a single set of knowledge, skills, and viewpoints (determined by others) that youth should acquire to be well-versed in the subject of science, youth should be encouraged to demonstrate science literacy by using scientific thinking in real-life situations and participating in scientific practices as part of their everyday lives. The goal of science education should be to involve youth in going beyond acquiring knowledge that others determine to be important, in ways that are sanctioned as "scientific" practices, and to critically question both current practices of science and the scientists engaged in those practices (Roth & Calabrese Barton, 2004). When framing the problem with science education in terms relevance, rather than rigor, it becomes clear that even if all educators seamlessly integrate emphases on youth both developing science content knowledge and science process skills, this will not be sufficient in preparing youth to embody the sense of agency needed to be democratic citizens.

Developing Critical Science Literacy through Relevance and Agency

Calabrese Barton, Basu, Johnson, and Tan (2011) propose the concept of *critical science literacy* (p. 10) to expand upon limited definitions of science literacy focused only on content knowledge and process skills. Existing conceptions of science literacy fall short when preparing youth to participate productively as democratic citizens; therefore, critical science literacy is essential because it promotes all the basic elements of science literacy, but also "embeds essential skills to participate in a democratic society in fair and just ways" (p. 11), such as utilizing science for personal and social transformation and engaging in public debate on issues related to social justice. Currently, science education does not place enough emphasis on helping youth to understand what it means to do science, and how they might engage in science in order to bring about personal and social transformation. If we are to help youth embody this idea of critical science literacy, and therefore actively participate as citizens in a democratic society, we cannot rely on traditional measurements of success in science, which are focused solely on scientific content and processes youth have learned and can demonstrate. Instead, we must ensure that we are designing and implementing science curricula that encourage them to use the knowledge and skills they develop through their practices of science to take positive action in their own lives (i.e., agency). This sense of agency can only be developed if youth see science as relevant and meaningful to their lives, and so relevance and agency become the key components in the development of youth's critical science literacy.

Relevance and agency, therefore, are essential components to science learning that must accompany the integration of science content knowledge and process skills. Neglecting relevance in science education in the past has had specific implications for youth in the classroom. Science, and school science in particular, has a distinct culture, which does not always align with youth's cultural perspectives and practices (Aikenhead, 2001; Aikenhead & Jegede, 1999; Albright, Towndrow, Kwek, & Tan, 2008; Calabrese Barton et al., 2011; Costa, 1995; Settlage & Southerland, 2012). Particularly when science and science instruction are not presented in meaningful ways, or worse, as in direct opposition to youth's own experiences, beliefs and values, youth often experience a disconnect between their identities and practices of science (Brown, 2006; Calabrese Barton & Tan, 2010; Emdin 2009). Youth will resist or reject roles as scientists or science experts to preserve other aspects of their identity work (Brickhouse, Lowery, & Schultz, 2000; Carlone, 2004; Olitsky, 2007; Scantlebury, 2007), as evidenced in Calabrese Barton and Tan's (2010) study with youth in an afterschool program where certain youth were "clear that school carried little meaning for [them], and in particular that science was boring, and [they] took some pride in this stance" (p. 198).

Furthermore, agency is often ignored in science education. Particularly in urban schools, teachers utilize instructional practices intended to promote rigor in the science classroom, but these practices often reinforce a *culture of power* (Calabrese Barton et al., 2011; Elemsky & Tobin, 2005; Emdin, 2009), in which teachers not only exert control over students in general, but also promote specific scientific practices, such as particular methods of discourse or argumentation, that are geared towards the white middle-class

(Brown, 2006; Lemke, 1990). In many instances, much of youth's cultural capital is not acknowledged or valued and youth are not given opportunities to make decisions and practice science in ways that leverage their cultural capital to take action through science.

Neglecting relevance and agency in science education creates additional problems—even with curricula and instruction that promote both content and processes—in that educators present a limited view of science that engages only a narrow population. This has grave consequences for a democratic society. Science education, rather than developing active democratic citizens, instead reinforces inequities leading to an imbalance of power between those who have scientific knowledge and are empowered to participate actively in society, and those who do not have scientific knowledge and must passively depend on others as experts (Michaels, Shouse, & Schweingruber, 2008; Roth, 2009). Clearly, relevance and agency cannot be afterthoughts when designing science curricula; they are key elements needed in science education to foster critical science literacy and develop productive democratic citizens who have the skills to address complex problems encountered in today's society.

New Directions for Science Education

In order to provide all youth with the opportunity and the means to actively work towards becoming democratic citizens embodying critical science literacy, educators and researchers must go beyond focusing on learning solely in terms of the science content and processes youth need to acquire (Calabrese Barton et al., 2003; Calabrese Barton et al., 2011). Instead they must acknowledge and address the tensions between youth's identities and science identities often promoted in classrooms and schools (Calabrese

Barton et al., 2011; Calabrese Barton & Tan, 2010; Olitsky, 2007; Tobin, Rahm, Olitsky, & Roth, 2007) and further examine opportunities for youth to engage in science identity work where youth can construct images and understandings of themselves in relation to science. Facilitating youth's science identity work by helping them see meaningful connections between themselves and science is the first step to youth using science to take action for personal or social transformation, which can in turn promote their democratic participation. Empowering youth to engage in their own science identity work and exercise agency through science can and should begin on the classroom level through the design and execution of relevant science curricula that foster personal agency, while preparing youth to be active citizens who affect positive change in society.

Critical science agency, in which science becomes both a range of contexts and tools for youth to take action in the world (Calabrese Barton & Tan, 2010), clearly connects the ideas of relevance and agency in the context of science classrooms. Critical science agency, the central component of youth's critical science literacy, fosters youth's science identity work and empowers them to use science as a tool "to alter the world toward what they envision as being more just" (p. 195). In order to develop critical science literacy, part of youth's science identity work should focus on critical science agency, so that youth characterize themselves as agents who critically view the world, as well as powerful scientific thinkers who can envision ways to create a more socially just world and who can take action through scientific practices to enact that change (Basu, Calabrese Barton, Clairmont & Locke, 2009). This concept of critical science agency embodies the message Dewey articulated over a century ago; "to participate in the making of knowledge is the highest prerogative of man and the only warrant of his freedom" (Dewey, 1910, p. 127). Dewey (1897) encouraged designing instruction to promote youth's agency so that they might use their own powers and capacities to live a full and productive life. Reaching this lofty goal of promoting youth's freedom to live fulfilling lives requires a curriculum that guides youth in developing command of themselves—in the form of agency—and that provides youth with opportunities to use their capacities to the fullest in order to take positive action.

Figure 1 represents essential components of various science curricula, including those that embody critical science literacy and promote youth's development as democratic citizens. The three-element Venn Diagram shows the importance of addressing both science content and science process skills, present in most reforms and standards, as well as aspects of the learner—including that learner's prior knowledge, ways of thinking and doing employed in everyday life, as well as affective components like what the learner finds meaningful or compelling. In the past, many curricula have only included the non-overlapping yellow section of science content knowledge, solely emphasizing the learning of content that is determined by others (not the learner) to be meaningful to the discipline. Others have emphasized content and have separately included the non-overlapping green section of science process skills, only emphasizing practices of science that are determined by others (not the learner) to be essential to the work of scientists, and therefore deemed "scientific." Still others have attempted to include one or two of the singular overlapping sections shown in the Venn Diagram by engaging the learner with: (a) inquiry, by facilitating the learning of science content through the processes of science; (b) relevant content, by including content that is meaningful to the discipline and to the learner; (c) relevant processes, by emphasizing how scientists use particular skills and ways of thinking in their work and how the learner might develop those same skills.

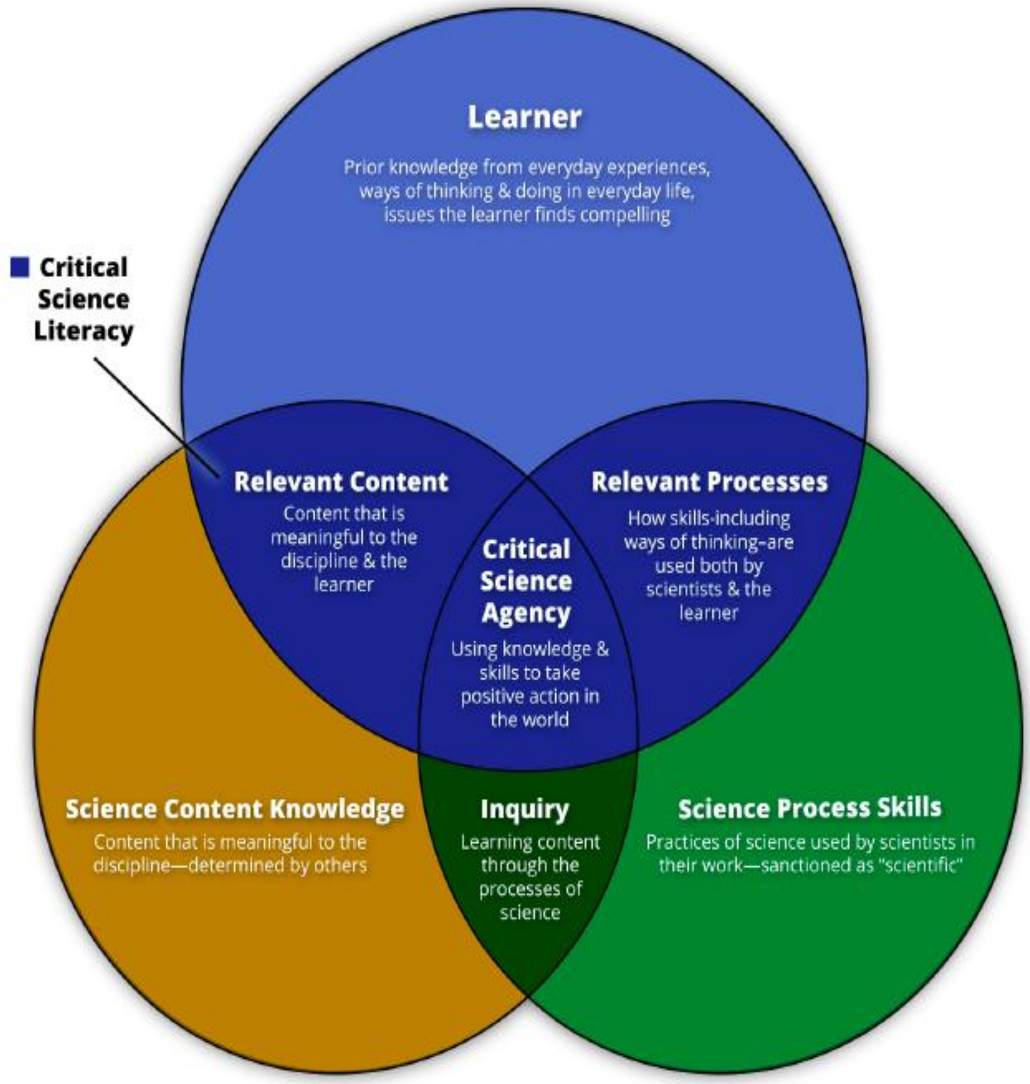

Figure 1. Essential components of a science curriculum that promotes youth's development as democratic citizens who embody critical science literacy

What has yet to be emphasized enough in science curricula is the overlapping of all of these components—critical science agency—which empowers the learner to use relevant knowledge and skills to take positive action in the world through scientific inquiry. The development of critical science agency is the key piece to achieving critical science literacy (represented in the darker blue sections of the Venn Diagram) because it helps learners critique narrow definitions of science and scientific practices defined by others, formulate deeper connections between science and their lives, and take positive action through their participation in science. Dewey (1916/1966) believed that for education to promote agency, it must guide youth in bringing to their consciousness their own abilities and goals they might contribute to society. Being able to function as part of a democratic society requires that youth be aware of their individual capacities to act in the world, as well as recognize the social and situational contexts that might enable or constrain this ability to act. Therefore, a curriculum that promotes youth's critical science agency is a curriculum that inevitably helps them embody critical science literacy, which is an essential quality necessary to be the productive democratic citizens Dewey envisioned.

From Problems to Solutions

Given the long-standing problems in science education and the need to include key components in science curricula that promote critical science literacy and prepare individuals for democratic citizenship, I argue that effective science curricula and instruction must: (a) integrate the learning of science content and the development of science process skills in ways that reflect essential tenets of learning theory, (b) ensure that this learning is relevant to youth's lives by creating opportunities for identity work in the science classroom that facilitate explicit connections between youth's lives and the content and practices of science, and (c) promote youth's identity work in service of critical science agency, so that youth might see science as a tool and a context to take action in their own lives and communities. The remainder of this article introduces the construct of Science Youth Action Research (Sci-YAR) as a curricular framework and proposes this instructional approach be used to foster youth's critical science literacy. I will first define Sci-YAR, as well as highlight and explain its key features. Next, I will ground Sci-YAR in the essential tenets of two learning theories. Finally, given its major features, I will explain how Sci-YAR promotes youth's identity work in service of critical science agency, thereby addressing the elements of critical science literacy and fostering democratic citizenship.

Defining Science Youth Action Research

I broadly define Science Youth Action Research (Sci-YAR) as a curricular framework and instructional approach used within the context of a kindergarten through grade 12 (K-12) school course to engage youth in collaborative action-based scientific inquiries connected to personal, local, or national issues of importance to them. Sci-YAR is a compilation of ideas drawn from various disciplines and is informed by definitions of scientific inquiry, as well as action research, including specific forms of action research like Youth Participatory Action Research (YPAR).

Sci-YAR and Open Inquiry

During their participation in Sci-YAR, youth work in groups to identify issues or problems found in their lives or communities related to concepts they are working with in their science course. They then pose investigable questions of interest to them and design and conduct action research projects in order to gather evidence, formulate explanations related to their questions, and evaluate their explanations in order to better understand the issues at hand. In addition, youth communicate the explanations generated and propose possible solutions, in the form of an action plan that could be undertaken to address the problem under investigation. These basic features of Sci-YAR classify it as a form of scientific inquiry because it embodies the five essential features of inquiry, as defined by the National Research Council (NRC; 2000); it involves (a) posing scientifically oriented questions, (b) giving priority to evidence, (c) developing explanations from the evidence related to those questions, (d) evaluating explanations and considering alternate explanations, and (e) communicating and justifying the proposed explanations.

While the NRC (2000) defined inquiry by its key features, it also acknowledged that variations exist within the classroom, proposing that classroom inquiry be considered a continuum, which is based on the amount of learner self-direction and amount of direction from a teacher or material during an investigation. When looking at Sci-YAR and where it would fall on this continuum, it would be classified as *open inquiry* (NRC, 2000, p. 29), since it involves more self-direction from the learner and less direction from the teacher and materials, such as a textbook or structured curriculum. Sci-YAR also requires students to provide the question, the methods, and the solution to a problem, which is how many have defined and classified open inquiry (Bell, Smetana, & Binns, 2005; Hermann & Miranda, 2010; Schwab 1962). Sci-YAR fits these criteria for open inquiry since youth have control over the questions they ask, the methods they use to address the questions, and the solutions that they propose and publically defend to others.

Open inquiry has been described as having benefits for learners, specifically in developing skills for conducting inquiry and autonomously guiding one's own learning (Roth, 1994). It also facilitates the development of critical thinking skills, as well as the habits of mind and dispositions of actual scientists (Berg, Bergendahl, Lundberg, & Tibell, 2003). Sci-YAR shares the essential features of open inquiry, and so has the potential to provide these same benefits for youth in the science classroom.

Regardless of the benefits of using open inquiry in the science classroom, it is often difficult for teachers to implement (Zion, Cohen, & Amir, 2007). Attempts to address this implementation issue have brought more organization to this type of inquiry through the use of structured questions or templates that guide teachers through the process of designing and executing open inquiry with students (Cothron, Giese, & Rezba, 2006; Hermann & Miranda, 2010). While done with the intention of increasing teachers' comfort level with open inquiry and expanding teachers' practice, these modifications simplify science by placing emphasis on control group experimental designs and quantitative data collection and analysis (Hermann & Miranda, 2010). Ultimately, these structures also reduce the authority of the students in selecting the research design or methods of data collection and analysis that would best answer their self-generated questions. Even more idealized conceptions of open inquiry that allow for the ultimate learner-directed experience often do not promote critical science literacy, as they do not emphasize critical science agency with youth taking action through their practices of science to bring about personal and social transformation. This is where Sci-YAR goes a step further than open inquiry; it goes beyond open inquiry's focus on learning science content and processes to promote youth's agency through relevant practices of science.

Sci-YAR, like open inquiry, has the goal of helping youth develop their scientific knowledge and skills by providing youth access to content, practices, and habits of mind scientists embody. However, Sci-YAR also recognizes that simply providing youth access to these elements does not aid them in understanding the complexity of what science entails and how it can be used for both personal and social transformation. Sci-YAR does not focus solely on content youth should know to increase their science literacy in service of preserving America's economic and political prosperity. Rather, Sci-YAR aligns with the viewpoint that the goal of science education should be to promote youth's critical science literacy, so youth might see science as a tool to help them view the world with a more critical mindset and to aid them in affecting positive change, both on personal and societal levels.

Sci-YAR and Action Research

In addition to drawing on principles of scientific inquiry, Sci-YAR also draws on tenets of action research, informed by various examples from the literature of youth engaging in different forms of action research. First, and most prevalent, are examples of youth engaging in youth participatory action research to investigate and critically analyze social issues and conditions. Second, are examples that include participatory forms of research, such as *critical ethnography* (Elmesky & Tobin, 2005), in order to bring youth's voices to educational research and create a richer understanding of teaching and learning, particularly in the context of low-income or marginalized urban communities. Finally, are examples of youth engaging in action research as part of school curricula, in order to enhance their academic skills and promote their personal development.

Youth participatory action research (YPAR). Youth participatory action research (YPAR), a particular form of action research, can be broadly defined as a praxis that engages youth in both studying social problems affecting their lives and taking action to address these problems (Cammarota & Fine, 2008). Proponents of YPAR (Cammarota & Fine, 2008; Duncan-Andrade & Morrell, 2008) claim that this type of action research represents not only a pedagogy for research, but also a way in which young people can affect change in their lives and the structures of society.

The term *youth action research* has also been used in the literature to describe youth engaged in action research similar to YPAR. Wright (2007) defines youth action research as a process where "young people conduct research to inform their planning and implementation of youth-led community change projects" (p. 504). The fundamental steps involved in this process are for youth to "select a relevant research topic, frame research questions, select data collection tools and methods, collect and analyze data, draw research findings and recommendations, and develop an action plan to address their identified issue" (p. 505). Youth involved in organizations, such as Youth in Focus (Silva, Zimmerman, & Erbstein, 2002) are not co-researchers participating with adults, but rather lead the research and are involved in the highest levels of leadership within the organization working for change. Adults, rather than leading and guiding every endeavor are considered *allies* (Wright, 2007) who actively support youth in developing their leadership skills within the organization. Adults do not control the direction of the action research; however, nor do they simply step aside and leave the youth without support. These allies take some opportunities to scaffold the research and leadership process for youth; at other times, they step back and allow the youth complete control.

The majority of studies involving YPAR and similar types of youth action research have taken place in out-of-school contexts, such as community organizations (Maglajlic & Tiffany, 2006; Nygreen, Kwon & Sanchez, 2006; O'Donoghue, 2006; Schensul & Berg, 2004), summer research camps and seminars (Morrell, 2006; Torre & Fine, 2006) and after-school programs (Kirshner, Pozzoboni & Jones, 2011). In addition, YPAR projects are mostly focused on social issues and concerns, without specific connections to science or academic content. Some example project topics include health issues, such as evaluating and critiquing both local health services (Amsden & VanWynsberghe, 2005) and access to public venues for people with special health needs (Burstein, Bryan & Chao, 2005); education issues, such as racial inequality in schools (Torre & Fine, 2006; Welton, 2011), social conditions that might undermine graduation and college attendance rates of youth of color (Cammarota, 2007), the educational opportunities and rights of urban youth (Fine et al., 2005; Morrell, 2006; Yang, 2009) and undocumented youth (Cerecer, Cahill & Bradley, 2011), and the impact of school closure on students (Kirshner, 2010); as well as other public policy issues, such as land use planning practices (Knowles-Yanez, 2005), the juvenile justice system (Rubin & Jones, 2007), and the effects of neighborhood gentrification (Cahill, Rios-Moore, & Threatts, 2008). School-based YPAR projects are less common (Brydon-Miller, Kral, Maguire, Noffke & Sabhlok, 2011; Irizarry, 2009) since school settings tend to provide too many institutional restrictions (Cammorota & Fine, 2008; Schensul & Berg, 2004). Despite the constraints that can accompany formal school settings, such as meeting state and national standards, preparing for high-stakes testing, and assigning letter grades for evaluative purposes, there are some successful examples of YPAR being conducted in schools.

One notable example of YPAR taking place in a school setting and making direct connections to science involves a high school agricultural management course, described by Brydon-Miller and colleagues (2011). The teacher, who was employed as the high school science teacher, was frustrated with her students investigating unauthentic scientific problems that had already been solved. When one of her students showed an interest in addressing the problem of the school lunches having low-nutritional value, she encouraged that student to generate a possible solution. He suggested the idea of starting a school garden in which fresh produce could be grown to enhance the nutritional value of the school's lunches. Together with interested students, the teacher developed an agricultural management elective course and used an action research format for the course curriculum, where students worked with the support of community members to plan, build, and operate a school greenhouse and garden. This example shows that youth engaging in action research can be an integral and valuable part of a school science curriculum. It further shows that, despite YPAR's enactment mainly in settings outside of school, one can work within the institutional barriers of a school and engage youth in action research as part of the formal curriculum.

YPAR is similar to Sci-YAR in that they both promote youth taking action in their communities to address issues relevant to their lives. Both follow the same basic format of allowing youth to select a research topic of interest to them, pose investigable research questions, select data collection tools and methods, collect and analyze a variety of data, publically share their findings and recommendations, and develop an action plan that could be executed to address their researched issue. In Sci-YAR, youth and adults also take on roles similar to YPAR projects where youth are given control of the direction of the research and adults act as allies, although different examples of YPAR reflect various levels of participation by youth.

Youth as educational researchers. Certain researchers (Calabrese Barton, 2001; Elmesky & Tobin, 2005; La Van, 2004; Wassell, 2004) have seen value in bringing youth voice to educational research in order to challenge the status quo in schools, break down power structures between youth and adults, and redefine the traditional roles of student and researcher. Including youth as members of research teams investigating teaching and learning in urban settings allows for their perspective and interpretations to create richer accounts of teaching and learning (Steinberg & Kincheloe, 1998). At the same time, this research works to challenge hegemonic views of educating urban youth and to counter explanations that deficits inherent in individuals or communities cause the challenges these youth face in schools (Elmesky & Tobin, 2005).

Elmesky and Tobin's (2005) study serves as a prominent example of youth acting as educational researchers by conducting critical ethnographies on their schooling experiences. While this youth research was conducted in the context of urban science education, it is important to note that it did not serve as the primary curricular framework or instructional approach for teaching science within the classroom. Instead, youth's critical ethnographies focused on issues of teaching and learning in schools and how schools might positively acknowledge and draw upon youth's cultural capital in the science classroom. Youth did take the skills, such as how to collect and analyze data, as well as the deeper self-understandings that they developed through conducting *self-ethnographies* (Elmesky & Tobin, 2005) on their cultural capital and identities enacted both inside and outside of school, and they applied it to their science learning; however, youth's inclusion in research teams took place outside of the regular school day and year, and the issues investigated by youth were not always integrated with the science instruction taking place in the classroom.

Critical ethnographies such as this one inform many aspects of Sci-YAR. First, the purpose of enhancing youth voice in schools and empowering them to take action to better their lives and improve their communities is a common goal between critical ethnography and Sci-YAR. Second, both have a strong reflective component, where youth document and constantly examine their own practices, reflecting on how engaging in research impacts them on a personal level. In this way, both include a focus on how youth's identities are formed and re-formed, both within the science classroom and their communities (Elmesky & Tobin, 2005). It is the role of Sci-YAR as the primary curricular framework and instructional approach within the science classroom that makes it distinct from youth conducting critical ethnographies.

Pupil-led research in schools. Developing action research curricular materials and using action research as an instructional approach in schools is a practice that has been established, primarily in countries such as England (Burton, Smith & Woods, 2010; Economic & Social Research Council [ESRC], 2002; Fielding & Bragg, 2003; Kellett, 2005b), Scotland (Brownlie, Anderson, & Ormston, 2006) and Hungary (Jeager & Zsolnai, 2005). Action research has been touted as having benefits for youth's academic development since it requires metacognition and critical thinking (Jeager & Zsolnai, 2005; Kellett, 2005a; Smith, Davis & Bhowmik, 2010), public speaking skills (Jeager & Zsolnai, 2005; Rubin & Jones, 2007), as well as higher order thinking skills and mathematical skills (Kellett, Forrest, Dent, & Ward, 2004). In addition, action research has benefits for youth's personal development, as it increases their confidence, self-esteem, and the view that they can have a voice in schools and bring about change (Kirby, 2004). Overall, engaging youth in action research within the classroom can emphasize the civic purposes of education (Fielding & Bragg, 2003), as it helps "foster civic identity among students that connects youth to their communities" (Rubin & Jones, 2007, p. 367).

Engaging youth in action research as part of a school curriculum, often referred to as *pupil-led research* (Burton, Smith & Woods, 2010) or *Students as Researchers* (SAR; Fielding & Bragg, 2003), has been documented in the literature, with the focus being on the level of ownership and decision-making that each individual youth has while engaging in research. The level of youth participation in pupil-led action research has been described as a *ladder* (Burton, Smith & Woods, 2010; ESRC, 2002; Hart, 1997), with rungs ranging from youth not being consulted at all to youth being full co-researchers. These studies promote action research on any rung of the participation ladder as supporting youth's academic and personal development, giving them a voice within schools, and allowing them to translate their learning into taking action to affect positive change in their schools and communities.

Examples of pupil-led research show the possibilities of engaging students in action research as a curricular framework and instructional approach within K-12 schools and how this experience might benefit both youth and the surrounding community. While the instances of pupil-led research documented in the literature all fall somewhere on the participation ladder described earlier, Sci-YAR adds another rung to this ladder: youth as primary researchers with adults as consultants or allies there for support. This provides a new level of ownership for youth in the research process within a classroom, which prior examples of pupil-led research do not provide. For instance, Burton, Smith, and Woods' (2010) describe their efforts to engage students at two schools in the UK in whole-class pupil-led action research where educational psychologists (EPs) instructed students in action research methods and where students helped the teachers and EPs generate and select topic ideas to investigate through the research process. While the students did have a high level of ownership in this process, the adults had a clear role in determining what would be a topic of importance related to school concerns. For example, one school had a group of staff members focused on refurbishing the playground, and so they selected this topic for the students to research. In addition, each school selected a topic that an entire class had to examine together. This significantly limited the options available to students. The authors argue that:

> it may never be possible, however, to relinquish control of the research process completely to children and young people, due to ethical responsibilities relating to pupil confidentiality and the risk of potential harm to pupils, and also because of the unfeasibility of transferring responsibilities for which children have not yet developed the prerequisite skills. (Burton, Smith & Woods, 2010, p. 92)

While it may not be possible to offer students the opportunity to investigate absolutely any issue they desire, mainly for the ethical and practical reasons argued above, Sci-YAR allows youth more control over selecting their issue to research, as adults are not directing students to investigate a singular, particular topic aligned with teacher or school interests. In this sense, Sci-YAR can be described not only as *pupil-led*, but also as *pupil-generated*. Beyond promoting the skill development of youth in areas such as problem-solving, cooperative group work, and speaking and listening (Burton, Smith & Woods, 2010), Sci-YAR emphasizes more personal connections to the research being conducted by youth, which, in turn, has the potential to promote more personal reflection related to that research.

Despite certain limitations, what these studies have done is promote action research as a curricular framework and instructional approach that supports youth's academic and personal development, gives them a voice within schools, and allows them to translate their learning into taking action to effect positive change in their schools and communities. For instance, the students involved in the playground refurbishment project helped design spaces to promote safe, positive interactions between students, and they were integral in instituting active programs, such as dance classes, to engage older students not interested in utilizing the playground (Burton, Smith & Woods, 2010). Similarly, Sci-YAR promotes youth taking action. By connecting science learning with youth's lived experiences and empowering them to use their expertise to effect change, Sci-YAR promotes agency, in that it impacts not only youth as persons, but also the surrounding community.

Key Features of Sci-YAR

As stated earlier, I define science youth action research (Sci-YAR) as a curricular framework and instructional approach used within the context of a K-12 school science course to engage youth in collaborative action-based scientific inquiries connected to personal, local, or national issues of importance to them. Sci-YAR projects are youth-generated and youth-lead, as teachers and other adults involved act as facilitators, supporting students as they collaborate with their peers in the decision-making and actions involved in their research. In addition to the action youth are encouraged to take to address issues they investigate related to their lives and/or surrounding communities, youth also document, analyze, and reflect upon their own practices and experiences as researchers, as well as their own personal growth throughout the process. As evidenced in the foundational literature outlined above, this definition of Sci-YAR is informed by many documented instances of youth engaged in scientific inquiry and action research, all of which share *some* features of Sci-YAR, but not *all* of the features outlined in this definition. Therefore, the design of Sci-YAR is influenced by ideas from a variety of disciplines and areas of action research, with the intention that it will promote youth's critical science literacy by allowing them to take action through science and reflect on that action in meaningful ways. While Sci-YAR could potentially be applied as a curriculum for other academic subjects or as an interdisciplinary curricular framework, for the purpose of this article, its key features will be conceptualized and described within the context of a school science course. Regardless of the discipline in which it is applied, Sci-YAR's key features include youth: (a) using science as a way of knowing and taking action, (b) participating in relevant practices of science through action research, (c) engaging in extensive personal reflection, (d) collaborating through collective research, and (e) conducing research that is youth-generated and youth-led. These features are not mutually exclusive, as they overlap and intertwine together to define the curriculum and inform its structure. However, for the purpose of clearly defining Sci-YAR as a distinct curriculum, each feature will be discussed separately. Examples of how each feature is enacted within the Sci-YAR curriculum are also provided in Table 3.

Using science as a way of knowing and taking action. Sci-YAR includes an explicit focus on youth using science as a way of knowing and acting in the world, so that they may better understand issues under investigation through research. In the context of Sci-YAR, science is defined, not just as content within a particular area, such as life sciences, physical sciences, and earth/space sciences. Instead, it refers to the systematic processes of generating knowledge by posing investigable questions, collecting empirical

Table 3

Key Features of Sci-YAR

Key Feature	Examples
Using science as a way of knowing and taking action	• Youth engage in instruction, discussion, and reflection related to these essential questions: ○ What is science? Who are scientists? ○ How do scientists work together to answer questions and solve problems? ○ How can we generate and communicate scientific knowledge for the benefit of others? ○ How can science be used as a tool to help address areas of concern in our city, community, and/or neighborhood? • Youth continuously reflect on these questions as they design and conduct their own research on the topic they choose and as they develop a plan for future action based on the findings of their research.
Participating in relevant practices of science through action research	• Youth are introduced to action research and are given the opportunity to explore connections they see between scientific inquiry and action research. • Youth engage in instruction, discussion, and reflection on how they already use scientific process skills in their own lives, and how they might use these skills to conduct research that benefits others. • Youth select and research their own topics related to their lived experiences. • Youth develop their own definitions of what constitutes scientific research, and they use criteria negotiated among themselves (and the instructor) to design, conduct, and critique research.
Engaging in extensive personal reflection	• Youth engage in self-documentation throughout their participation in the curriculum, selecting whatever medium (or media) they prefer, such as writing, art, photography, film-making, blogs, or other social media. • Youth keep an ongoing reflection journal where they reflect on ideas presented or generated during the research process, as well as their experiences engaging in the

	curriculum. • Youth periodically analyze the data they collect throughout their self-documentation and journaling to make assertions about their personal growth and the development of their practices of science throughout the research process.
Collaborating through collective research	• Youth dialogue with peers in the class to discuss how their issues of interest might be related, and youth form research teams based on common interests. • Youth work in teams to develop research questions and a research plan, and they execute that plan, including data collection and analysis, as a team. • Periodically throughout the research process, teams present their research plans, the progress they have made on data collection, and their preliminary findings to the class. The class (including the instructor) provides teams with brief oral feedback, as well as written feedback in the form of peer assessments that offer suggestions for each team's research. Teams are encouraged to incorporate the feedback they receive as they move forward with their research.

Conducting research that is youth-generated and youth-led	• Youth select their own topics, generate their own research questions, and develop research plans with data collection and analysis procedures that they select.
	• Youth take the initiative to seek out sources and develop tools for data collection. This may include:
	  ○ Designing interview protocols and finding participants to interview
	  ○ Developing and distributing surveys
	  ○ Designing controlled tests
	  ○ Finding detailed and accurate ways to observe and/or measure phenomena related to the topic under investigation

data, analyzing the data, and making interpretations based on the analysis. Broadly envisioning science as the systematic processes of gathering and interpreting data to generate knowledge regarding a specific phenomenon allows one to see its close connection with forms of research, such as action research.

In Sci-YAR, youth engage in science as a way of knowing, but they also continuously take and reflect on action. Similar to action research, youth investigate ongoing actions taking place in a particular setting and focus on examining actions that they and others have taken, are taking, or intend to take (Herr & Anderson, 2005). Youth use science as a way of taking action when they design and execute their own research to investigate problematic situations taking place in their school or surrounding community. In addition, they envision possibilities for future action by developing, disseminating, and getting feedback on an action plan they or others could take in order to address the problem or issue under investigation.

Participating in relevant practices of science through action research. On a basic level, Sci-YAR emphasizes relevant science because youth select their own topics and conduct research to address problems and issues related to their own lived experiences. However, Sci-YAR also encourages youth to view science as relevant on a deeper level because it promotes science as the venue through which youth come to more deeply understand themselves and the world around them. Youth are encouraged to use their practices of science as a way to achieve these deeper understandings, as well as take action to bring about personal and social transformation. This conceptualization of science emphasized in Sci-YAR also broadens youth's view of what can be considered "scientific," making room for youth to both critique narrow definitions of science and develop scientific practices that value the ways of knowing and acting that they employ in their everyday lives. Rather than presenting science as an accumulation of facts or skills disconnected from youth's lives, Sci-YAR explicitly promotes a relevant view of science as a tool and a context for youth to take action in the world.

Engaging in extensive personal reflection. Youth develop deeper understandings of science and of themselves by using research as a venue through which to engage in extensive personal reflection. While youth are investigating ongoing actions taking place in their school or surrounding community related to their research topic, on another level, they are also investigating their own ongoing actions within the science classroom as they document, analyze, and reflect upon their practices of science and their own personal development as they engage in the curriculum. This further aligns Sci-YAR with action research because it emphasizes the investigation of one's own practice in order to both improve and create knowledge around that practice (McNiff & Whitehead, 2010). Sci-YAR does this by engaging youth in *reflection-in-action*, *reflection-on-action* (Schön, 1983), and *reflection-for-action* (Killion & Todnem, 1991) as ways to improve their practices of science, create knowledge regarding those specific practices in relationship to themselves, and plan future action based on this knowledge.

Sci-YAR takes the same approach to reflection as action research; it "is different from isolated, spontaneous reflection in that it is deliberately and systematically undertaken and generally requires that some form of evidence be presented to support assertions" (Herr & Anderson, 2005, p. 3). In Sci-YAR, reflection is more than just a superficial requirement tacked onto the end of a scientific investigation. Youth's documentation of their experiences during Sci-YAR is an integral part of the curriculum, which is deliberately and systematically conducted and analyzed throughout. Part of youth's findings that are presented publically at the conclusion of the curriculum include their assertions about their growth throughout the process of conducting research—including insights generated regarding how they may contribute to the problem under investigation and how they may take action to enact the proposed solutions from their findings—and specifically about how their practices of science changed (or did not change), supported by evidence from their documentation. Along with selecting their own topics to investigate, this systematic reflection affords youth another way to incorporate themselves more fully into the curriculum.

Collaborating through collective research. Youth develop the view of science as a way of knowing and taking action, and they construct knowledge of their own science practices in relationship to themselves through collaboration with others. In Sci-YAR, youth conduct research in collaboration with peers, as they work in teams to pose questions regarding issues of personal meaning and importance to them, design investigations and collect data together, and check one another's interpretations of that data. In addition, youth continuously share, discuss, and reflect upon their self-documentation with peers as they conduct their research, and they may even include collective documentation of meaningful group experiences. Throughout the curriculum, youth also collaborate with adult allies who act as facilitators, resources, and even data collection sources for youth. These adult allies support youth and guide them through their research and through the process of documenting, deconstructing, and reflecting on their practices of science and their personal growth throughout the research process. This extensive collaboration with a variety of people facilitates the co-construction of knowledge related to both science and the youth themselves.

Conducting research that is youth-generated and youth-led. A final key feature of Sci-YAR is that it is youth-generated and youth-led, emphasizing the agency of the youth involved. Similar to YPAR—a specific form of action research emphasizing youth empowerment through participation in action research—Sci-YAR also supports engaging youth in research as a way to exercise agency and facilitate change in their lives and communities. Sci-YAR does this by allowing youth to begin the action research initiative from scratch and to make the decisions that impact the focus and direction of their investigation as they take ownership of the research's design and execution. This encourages the development of unique youth-adult relationships when enacting Sci-YAR as an instructional approach. Adults' knowledge and expertise is not valued over youth's. Full decision-making responsibilities are assumed by the youth conducting the project, thereby facilitating youth's sense of agency in the classroom.

Highlighting the key features of Sci-YAR emphasizes aspects of the curriculum that are essential in order to overcome deficiencies with curricula that have focused on only the development of science content knowledge and process skills. These features are fundamental aspects of Sci-YAR that are used to promote youth's development as democratic citizens who embody critical science literacy. For a specific example of the overall Sci-YAR curriculum structure, which includes all of the key features outlined above (see Appendix A).

Science Youth Action Research to Promote Democratic Citizenship through Critical Science Literacy

With Sci-YAR defined and its key features illustrated and explained, one must now consider how this type of curriculum might promote youth's development of critical science literacy, thereby helping them to act as productive citizens in a democratic society. As argued earlier, to accomplish this goal, science curricula and instruction must: (a) integrate the learning of science content and the development of science process skills in ways that reflect essential tenets of learning theory, (b) ensure that this learning is relevant to youth's lives by creating opportunities for identity work in the science classroom that facilitate explicit connections between youth's lives and practices of science, and c) promote youth's identity work in service of critical science agency, so that youth might see science as a tool and a context to take action in their own lives and communities. Sci-YAR is designed to meet each of these criteria, in order to address the long-standing problems with science education being viewed as learning a multitude of facts and skills disconnected from youth's everyday experiences. Sci-YAR's potential to meet each of these major criteria will be discussed in turn.

Sci-YAR as a Curricular Framework and Instructional Approach

Sci-YAR is a curricular framework and instructional approach grounded in learning theory. This section describes how Sci-YAR's key features align with various learning theories, and in particular, how Piaget's (1959) constructivist theory and

Vygotsky's (1978) socio-cultural theory are manifested in the enactment of Sci-YAR as a curricular framework and instructional approach.

Piaget's constructivist theory. When articulating his theory of learning, Piaget (2000) promoted a constructivist view of knowledge by arguing that:

> Progress in knowledge occurs neither as simple addition nor as additive stratification, as if richer knowledge came along merely to augment weaker knowledge, but that this progress rests equally on the continual recasting and correction of earlier points of view through a process which is as retroactive as it is additive. (p. 244)

This view of learning directly aligns with the goals of using Sci-YAR as a curricular framework and instructional approach. Sci-YAR aligns with Piaget's view of learning because it is based on the assumption that knowledge is not a static entity to be "added" to a person's mind. Instead, learning is a process of constructing understanding, continuously examining that understanding through reflection, and then revising and reconstructing that understanding based on new experiences and insights. This idea of learners actively reflecting on and constructing their own knowledge, rather than passively having it added to their minds, is evident in the design of Sci-YAR. Sci-YAR operates from an active learning perspective by engaging youth in designing and conducting their own research, as well as requiring continuous reflection on the research process and on their growth as persons and researchers.

Piaget (2000) supported this view of active learning, arguing that "there is a much more productive form of instruction: the so-called 'active' schools endeavour to create situations that, while not ‘spontaneous’ in themselves, evoke spontaneous elaboration on the part of the child” (p. 252). In Sci-YAR, youth spontaneously elaborate when addressing problematic social conditions, using scientific practices to understand phenomena, and reflecting on the process and themselves. For example, youth must decide what data will enhance their understanding of their particular research topic, decide how and when to collect this data, as well as continuously negotiate their interpretations of the data with one another as they address their research questions. While engaging in Sci-YAR, youth are in charge of actively constructing their own meaning and understanding by elaborating on their prior knowledge and integrating new experiences as they build on that knowledge.

Piaget’s ideas of assimilation and accommodation play a major role in Sci-YAR’s instructional approach. When youth actively design and execute their own action research, they must both *assimilate*, or incorporate new ideas into their existing schema, and *accommodate*, or modify their existing schema to fit new ideas that they encounter during the process. While assimilation and accommodation tend to be labeled and identified separately, they cannot be isolated since “both processes are going on together, indissolubly linked. It is through their joint action that… [youth] can achieve both continuity and novelty” (Donaldson, 1978, p. 141). In Sci-YAR, youth engage in assimilating and accommodating new information simultaneously. For instance, youth might assimilate information as they make connections between science and their own lives, recognizing the continuity between the two; at the same time they might have to accommodate their existing schemas as they rethink existing problems in their communities, gaining novel insights into these issues and developing ways to participate in science in order to address these issues. Furthermore, Sci-YAR's specific emphasis on reflection helps promote this process of accommodation, as youth develop new viewpoints on both their topic and on what participation in science entails.

Piaget's concepts of *equilibrium* and *disequilibrium* are also key ideas to consider when analyzing the use of Sci-YAR as both a curricular framework and an instructional approach. While some form of equilibrium—which occurs when an individual reaches a level of understanding characterized by stability in the processes of assimilation and accommodation—is likely to occur when youth engage in Sci-YAR, its uniqueness stems from its ability to create disequilibrium or the "mental discomfort that spurs [youth] to try to make sense of what they are observing" (Ormrod, 2011, p. 29). As youth assimilate new ideas into their existing schema and accommodate their existing schema to fit what they are encountering, this state of disequilibrium can potentially occur on two levels. Disequilibrium can come about as youth attempt to work through misconceptions they hold and develop more precise understandings of scientific phenomena, but it can also come about as youth attempt to make sense of the world and their roles as agents of change within it. By identifying issues in their own lives and communities to be addressed through systematic investigation, youth experience disequilibrium as they observe their conditions more closely and attempt to make sense of how these problems came about and how they, themselves, might address them. Sci-YAR encourages youth to look at the world differently and take action based on the knowledge generated to address the issues under investigation; this aspect of Sci-YAR embodies Dewey's notion of democratic citizenship. This re-envisioning of reality is a form of disequilibrium that occurs when youth must modify, adapt, or rearrange their existing schemas of how the world works, as well as reformulate their roles in this world while using their new knowledge to bring about change.

The process of *equilibration*, or moving between equilibrium and disequilibrium, comes about while youth engage in Sci-YAR. Because of this, Sci-YAR has the potential to "promote the development of more complex levels of thought and knowledge" (Ormrod, 2011, p. 29). Furthermore, the flexibility of mind that youth develop while going through the process of equilibration (Donaldson, 1978) is key for them to develop the habits of mind and practices of actual scientists, such as exhibiting openness to new ideas and incorporating new evidence that arises into scientific explanations (AAAS, 1990). In contrast to forms of science curricula and instructional approaches that focus on filling youth's minds with accurate scientific knowledge, Sci-YAR's focus is for youth to develop and use critical scientific skills and habits of mind, such as considering multiple perspectives on an issue. Because Sci-YAR promotes equilibration, it facilitates this higher-order thinking in the science classroom, thereby promoting a constructivist view of education.

Vygotsky's sociocultural theory. In addition to examining Sci-YAR through a constructivist lens, one can also view it through a socio-cultural lens, emphasizing the opportunities it provides youth to construct meaning through experiences with others. The main tenet of Vygotsky's (1978) socio-cultural theory asserts that learning is a fundamentally social and cultural process. This means that youth construct meaning and understanding through their interactions with others, particularly when more experienced individuals can mediate a learning experience for them. Vygotsky argued that "every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, *between* people (*interpsychological*), and then *inside* the child (*intrapsychological*)" (p. 57). This means that if our goal is for youth to internalize understandings and develop on the intrapsychological plane, then we must first give them opportunities to construct that understanding with others on the interpsychological plane. Sci-YAR provides youth just such opportunities to participate in science as a social and cultural endeavor. Youth engage in scientific practices collectively with others, and they make connections between science, their own lives, and essential issues in their communities.

Vygotsky (1978) also emphasized the role that speech plays in learning, arguing that speech facilitates learning by helping to organize one's thoughts and communicate one's ideas. He believed that "*the most significant moment in the course of intellectual development…occurs when speech and practical activity, two previously completely independent lines of development, converge*" (p. 24). Just as Piaget sees thought and action to be directly connected, so does Vygotsky see a close relationship between speech and action. Taking into account both Piaget's and Vygotsky's viewpoints supports strong interrelationships between thought, speech, and action, which are all key aspects of Sci-YAR. While conducting their action research, youth engage in continuous cycles of action and reflection where they individually and collectively reflect upon problematic conditions in their communities, take action with others to investigate these issues that are important to them, dialog with their peers and others in the community, as well as engage in extensive self-communication through personal reflection to continuously progress their thinking and inform their future actions. In Sci-YAR thought, speech, and action are consistently interwoven.

To further emphasize the use of speech in learning, Vygotsky (1978) made three points regarding how speech specifically facilitates learning, as seen when solving a practical problem. The first point Vygotsky made when examining how speech facilitates one's problem-solving capabilities is how it is essential for the creation of a plan. According to Vygotsky (1978), youth, by using language, can reach "a much broader range of activity, applying as *tools* not only those objects that lie near at hand, *but searching for and preparing such stimuli as can be useful in the solution of the task, and planning future actions*" (p. 26). Using Sci-YAR as an instructional approach encourages collaborative learning where youth identify problems in their own lives or communities and collectively dialog with others to formulate a plan to investigate and address the issue at hand. Their use of language to first identify and understand the nature of the problem, and then formulate a plan of action to investigate the problem, emphasizes the importance of speech in furthering youth's thinking and preparing them to take action. Through these interactions and their use of language, youth also have the opportunity to use science as a tool in their planning to address the problem under investigation, a sign of youth's developing critical science agency.

The second point Vygotsky (1978) makes is that speech plays a role in the autonomy of individuals and can empower future action. Vygotsky claimed that with language "direct manipulation is replaced by a complex psychological process through which inner motivation and intentions, postponed in time, stimulate their own development and realization" (p. 26). As Vygotsky stated, speech—both written and oral—is a key way to construct and further one's thinking, facilitating the development of the individual and bringing one to a higher level of consciousness, which can lead to the carrying out of future action. Vygotsky's idea reflects an essential goal of Sci-YAR: to increase youth's awareness of themselves in relationship to the issues in their communities, so that they may take action through science to address them. The collaborative nature of Sci-YAR facilitates youth's use of speech in furthering their thinking on scientific concepts, as well as increasing their awareness of themselves and of issues they can address using scientific knowledge and practices. Furthermore, engaging in collaborative research and extensive personal reflection prompts youth's action toward addressing the problems that exist in their communities, a sign of Sci-YAR's role in developing critical science agency.

Finally, Vygotsky (1978) made the point that speech directly impacts one's behavior. Vygotsky argued that "speech not only facilitates the child's effective manipulation of objects but also controls *the child's own behavior*" (p. 26). This further emphasizes the argument that speech is related to agency, since speech is a way to directly influence one's own ability to take action. This view of speech is embodied in Sci-YAR, as youth vocalize their concerns and consistently dialogue to socially construct possible solutions to these problems. In addition, youth share their research publically at a school-wide research symposium, where they present the results of their research to others, as well as their plans for taking future action. Following Vygotsky's line of thinking, these opportunities to vocalize potential solutions and future plans help youth direct their action toward achieving these solutions. Emphasizing Vygotsky's three points regarding speech shows how Sci-YAR—which asks youth to problem solve about relevant practical issues—facilitates the use of language in social interactions and allows youth to take ownership of both their own learning and their scientific practices as they address issues in their own lives and communities.

Bridging learning theories. Piaget's ideas regarding constructivism and Vygotsky's ideas regarding the social nature of learning, while often seen as separate, actually coincide and compliment one another. Like Vygotsky, "Piaget recognizes the importance of the exchange of ideas for the development of thought—and in particular for strengthening the awareness of the existence of other points of view" (Donaldson, 1978, p. 152). If youth are to achieve equilibration by incorporating multiple viewpoints and shifting their thinking based on continuously evolving understanding, this necessarily requires that youth exchange ideas with others and constantly dialogue in order to support their learning. In fact, Piaget supported this type of social learning even when speaking of his own research: "You must have contacts, and you must, especially, have people who contradict you. You have to have a group. I believe in interdisciplinary research and collective research" (Bringuier, 1980, p. 18). This description reflects Sci-YAR's approach to research. Sci-YAR is designed to engage youth in collective research and to question pre-existing notions regarding the origins of problematic social conditions, as well as knowledge and skills sanctioned by others as "scientific". Sci-YAR allows youth to both connect their own research to the collective practices of other scientists and to critique and challenge existing points of view in science.

Examining Sci-YAR through both the lenses of constructivist theory and socio-cultural theory emphasizes the importance of individually constructing and reflecting on knowledge, while working as a collective and dialoging with others in order to facilitate that learning process. Vygotsky (1978) emphasized that "learning awakens a variety of internal developmental processes that are able to operate only when the child is interacting with people in his environment and in cooperation with his peers" (p. 90). This is a unique attribute of using Sci-YAR as an instructional approach; youth are internally constructing meaning and reflecting on their personal growth as they work collectively with peers, as well as adults, to design and execute their own research, allowing them to "*grow into the intellectual life of those around them*" (p. 88).

Learning theory and identity work. Using Sci-YAR as a curricular framework and instructional approach has the potential to facilitate identity work, first and foremost, because it emphasizes constructivism, which is a distinct way of viewing the acquisition and application of scientific knowledge. Knowledge, rather than a body of facts to be absorbed, becomes something that is negotiated and constructed between youth, their peers, their teachers, and their community, thereby allowing youth to take on a more active role in the learning process. In addition, Sci-YAR creates disequilibrium in youth's thinking, particularly with regards to their social roles in their schools and communities. Equilibration can then be achieved if youth engage in identity work in a way that shifts their views of themselves as disenfranchised students to agents of change in their own communities. Finally, the ways that Sci-YAR promotes youth using speech and taking action make a space for youth to engage in this type of identity work, which has the potential to enhance both their learning and their agency, meaning their ability to act on this knowledge they are constructing. Learning theory supports using Sci-YAR as a curricular framework and instructional approach, which not only highlights its potential to facilitate effective science teaching and learning, but also supports the argument that Sci-YAR has the potential to influence youth's identity work in service of critical science agency.

Promoting Youth's Identity Work through Sci-YAR

As presented earlier, while engaging youth in scientific inquiry might work towards increasing their science literacy, it does not specifically address how engaging in science can be used to promote youth's critical science literacy. In order to examine youth's development of critical science literacy, one must consider more than test scores and performance assessments to see how youth are progressing towards the goals of adopting a critical stance towards the world and "considering oneself as [a] powerful scientific thinker and doer of science" (Calabrese Barton et al., 2011, p. 7). Educational researchers must also attend to the roles youth both accept and reject in science-related communities, such as classrooms (Calabrese Barton et al., 2011), while examining why youth participate in these communities in particular ways. This entails examining youth's identity work while engaged in specific forms of science curricula and instruction. Specifically, we need to determine whether youth are able to leverage certain aspects of their identity to engage in further identity work through their participation in science, thereby expanding the possible roles they can take on both in and out of the classroom (Basu et al., 2011). In addition, educational researchers must better understand the relationship youth perceive between these roles they take on and practices of science (Calabrese Barton et al., 2011). Therefore, science curricula and instruction should provide youth opportunities to draw on aspects of their existing identities and help them see the connections between these aspects and their participation in science, while still allowing youth to expand upon their identities; Sci-YAR's intention is to do exactly this.

By using a constructivist and socio-cultural framework to define and analyze learning, Sci-YAR assumes that learning science *is* identity work. Consequently, many of the features of Sci-YAR make it conducive to promoting youth's identity work. First, Sci-YAR is collaborative and youth engage in it collectively, thereby creating *communities of practice* (Lave & Wenger, 1991; Wenger, 1998), in which youth have the opportunity to construct their identities. Second, identity work involves the continuous examination of one's identity and how it changes (Basu et al., 2011), which is why the reflective component of Sci-YAR is critical as a way for youth to engage in identity work while participating in the curriculum. This aspect of Sci-YAR emphasizes the individual's role in identity work, as it requires self-examination of one's identity as a researcher. By engaging in this introspective action, youth interact with their previously held views of self, based on the social context and position they have experienced while participating in Sci-YAR. Finally, the level of ownership that youth take on when generating and leading their own Sci-YAR projects allows youth more freedom both in the choices they make and in the roles they adopt. For example, while youth are engaged in Sci-YAR, they are not limited to adopting the role of "student," which in traditional models of education means "being consumers of knowledge who are expected to memorize facts selected as important by the teacher" (Calabrese Barton et al., 2011, p. 6). Instead, Sci-YAR promotes shared and transformational authority (Calabrese Barton et al., 2011) by students and teachers, thereby expanding the roles that youth can adopt while participating in the curriculum and promoting youth's identity work through science learning.

Promoting Youth's Critical Science Agency through Sci-YAR

Sci-YAR has the potential to shape youth's identity work in service of critical science agency because it offers youth opportunities to engage in identity work, while using science as a space and a tool for critically viewing the world, investigating problems they see in the world, and working to address those problems using scientific thinking and practices. Specifically, it meets several criteria Basu and colleagues (2009) use to describe critical science agency enacted in curricula. First, since youth design questions around and conduct long-term investigations addressing issues connected to the course content, they have opportunities to gain not only deep understandings of the content, but also process skills and experience with practices used in the particular discipline. Second, Sci-YAR positions youth as experts in science—and more specifically in their particular action research topic—putting the responsibility on them to make important decisions regarding their research, to interact with participants and equipment as they collect data, and to present their findings and defend them in a public forum. Finally, Sci-YAR asks youth to use science as a foundation for change. Youth are encouraged to use the knowledge constructed throughout the research process to suggest and act on ways they can bring about social change, even after the research is complete. Basu and colleagues (2009) argue that using science as a foundation for change in this way makes a space in science classrooms so that youth's "identity develops, their position in the world advances, and/or they alter the world towards what they envision as more just" (p. 346). For these reasons, Sci-YAR has the potential to shape youth's identity work in service of critical science agency.

By saying that Sci-YAR may promote youth's identity work in service of critical science agency, I mean that the features of Sci-YAR provide not only the conditions to promote identity work, but also that Sci-YAR has the potential to promote youth's critical science agency, and that agency can help youth expand their identity in particular ways (Basu et al., 2011). I argue that by promoting youth's critical science agency, Sci-YAR has the potential to help youth leverage aspects of their identities to form others (Basu et al., 2011), which could shape youth's projective identities and their possibilities for future action. In addition, by requiring youth to document and reflect upon their practices as researchers, Sci-YAR facilitates youth in making meaning of the social and cultural context that is a part of Sci-YAR. In this way, Sci-YAR requires identity work to be an active part of the curriculum, unlike other forms of science instruction, which might only address it in passive or peripheral ways.

Sci-YAR as a Model for Promoting Identity Work in Service of Critical Science Agency

Sci-YAR is intended to promote youth's identity work in service of critical science agency in two major ways, which are grounded in the theoretical perspectives of socio-cultural theory and positioning theory. First, Sci-YAR emphasizes socio-cultural views of learning because it encourages connections to youth's lives. Analyzing science education and practices of science in schools from a socio-cultural viewpoint supports the idea of connecting science with youth's lived experiences. When examining Sci-YAR through a socio-cultural lens, one can emphasize the opportunities it provides youth to construct meaning through experiences with others. Since learning involves a social and cultural process (Gutiérrez & Rogoff, 2003; Lee, 2008; Nasir, Rosebery, Warren & Lee, 2006), and youth construct meaning and understanding through their interactions with others, one can argue for the benefits of engaging youth in the collective systematic investigation of a problem. Sci-YAR emphasizes the social nature of science learning because scientific practices become something that one does in a community. Additionally, it emphasizes the cultural nature of science learning since youth are encouraged to use their prior knowledge, experiences, beliefs, and values, to enhance and enrich their participation in science. Furthermore, youth conduct their research in their local context, identifying a problem in their lives, school, or surrounding community they wish to investigate, so that they might develop, implement, and reexamine possible solutions. Sci-YAR as an instructional strategy has the potential to provide youth with opportunities to participate in science as a social, as well as a cultural endeavor.

When used as a curricular framework and instructional approach, Sci-YAR also has the potential to influence the positioning of youth in the classroom. Harre and Moghaddam (2003) define positions as “loose set[s] of rights and duties that limit the possibilities of action” (p. 5), which constantly causes one’s repertoire of actions to change, depending on the context of a social situation. When examining Sci-YAR through the lens of positioning theory, one can emphasize how engaging students in Sci-YAR within a formal school setting might position youth in a way that fosters their identity work in service of critical science agency. Engaging students in Sci-YAR involves positioning students as leaders and change agents, rather than as followers who must conform to school policies, rules, and a set curriculum, potentially impacting youth’s identity work in service of critical science agency. Positioning theory emphasizes how the players (students, teachers, community members, etc.) in the social episodes that unfold during the involvement in Sci-YAR share rights and duties associated with this type of instruction and how these interactions contribute to youth being positioned as scientists engaged in actual scientific practice. Positioning theory is vital in the examination of what influence Sci-YAR might have on youth’s identity work in service of critical science agency.

Since Sci-YAR emphasizes both socio-cultural perspectives on learning, as well as the importance of positioning within a social context, it aligns with the dialogic perspective of identity described in the introduction. By encouraging connections between science and youth’s lives and by influencing the positioning of youth within the classroom, Sci-YAR attempts to create conditions that will facilitate youth’s identity work in service of critical science agency. However, as mentioned earlier, Sci-YAR intends not only to create conditions that support youth's identity work; it also requires youth to engage in a level of individual reflection not present in other forms of science curricula and instruction. It is the interaction between both the context created by Sci-YAR and the concrete processes developed in the individual through the reflective component that gives Sci-YAR the potential to promote identity work in service of critical science agency.

Figure 2 is a representation of the Sci-YAR curriculum, showing its uniqueness in comparison to other science curricula, and emphasizing its potential to promote youth's identity work in service of critical science agency. Again, a three-element Venn Diagram is used to represent various elements of the curriculum; however, the learner is the largest circle, indicating it is the central focus in Sci-YAR. Sci-YAR values and draws upon learners' prior knowledge and ways of thinking and doing enacted in their everyday lives, and it encourages learners to investigate issues they find meaningful. The lines between the learner and relevant science content knowledge and process skills are dashed to show how Sci-YAR encourages connections between science and learners' lives. In Sci-YAR, learners select the content, deciding what is meaningful to them and how that is related to the discipline of science. Sci-YAR also promotes the development of learners' scientific practices—including ways of thinking—emphasizing both the processes used by scientists and how their own ways of doing and thinking in their lives might aid them conducting their own scientific research. While not all youth will make the same connections between their experiences of engaging in science through Sci-YAR and their own lives, by promoting identity work through practices of science, Sci-YAR has the potential to help youth see deeper connections between science learning, their everyday lives, and themselves as persons.

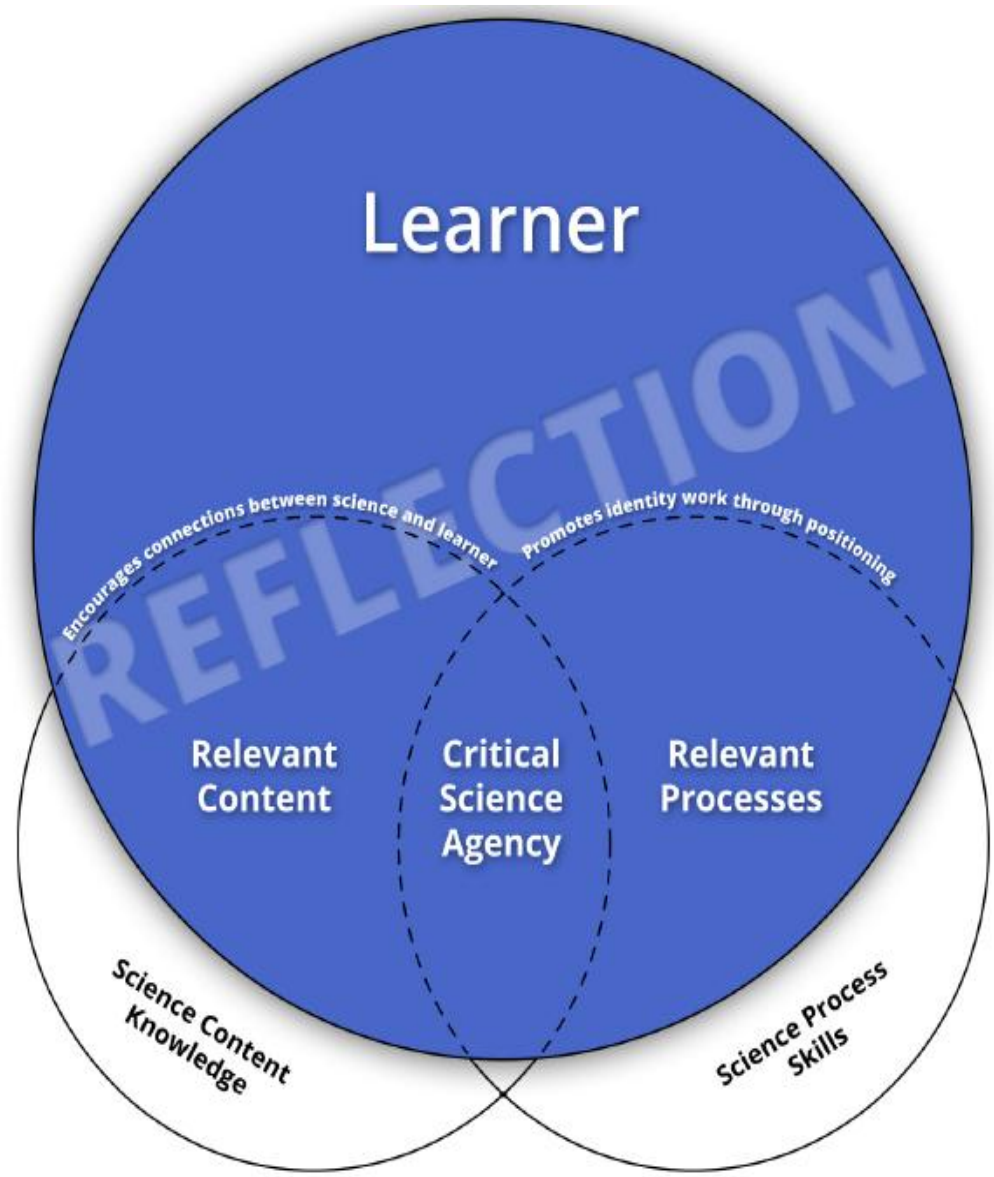

Figure 2. Sci-YAR's potential to promote youth's development as democratic citizens who embody critical science literacy

As Sci-YAR engages learners in inquiry to develop deeper understandings of relevant content through relevant practices of science, it also positions learners in particular ways that promote their identity work and help them develop deeper understandings of themselves. The ways in which Sci-YAR promotes learners' identity work are varied and cannot be pre-determined, as learners will draw on different aspects of their experience in Sci-YAR that will inform their identity work in unique ways. However, because of the positioning taking place within Sci-YAR, promoting youth's identity work in service of critical science agency is still a central focus of the curriculum. Sci-YAR specifically positions learners as agents who can use their knowledge and skills, developed and honed through their participation in science, to take positive action in the world.

The underlying foundation of Sci-YAR is the extensive reflection involved on many different levels throughout the curriculum (represented by the background shading in Figure 2). Sci-YAR is able to emphasize relevant science content and processes because the learner is required to think deeply about what is meaningful to them and to reflect on how science might relate to their own lives. Reflection is also a key way that learners are positioned within Sci-YAR; engaging learners in extensive self-reflection positions them in ways that give them the opportunity to build a sense of self through the experience of conducting their own science research. Furthermore, by positioning learners in ways that promote their identity work in service of critical science agency, Sci-YAR has the potential to address the larger goal of cultivating learners' critical science literacy, an essential component to enacting their roles as active citizens in a democratic society.

Conclusion

Science Youth Action Research (Sci-YAR) has been introduced here as a curricular framework and instructional approach with the potential to promote youth's identity work in service of critical science agency, which in turn leads to youth's development of critical science literacy, a key component influencing their abilities to participate as citizens in a democratic society. Articulated over a century ago, Dewey's vision of citizens taking positive action through science to enhance democratic participation is still an essential goal today as we continue to face complex societal and global problems that require equally complex levels of thinking and action in order to work towards solutions. Sci-YAR is an example of the type of curriculum and instruction we as science educators must promote in order to move away from an oversimplified view of science education as merely the accumulation of facts, or as the development of science content knowledge and discrete science process skills. Because of Sci-YAR's potential, which has been described here, research is necessary to see in what ways various youth experience and make meaning of their participation in Sci-YAR, and in particular, how their participation might influence their identity work in service of critical science agency. As educators, we must make it our mission to help youth shift their views of science—so that they see it as a tool and a context to take action towards personal and social transformation—and then aid them in actually *using* their science knowledge and skills in their own lives to bring about this transformation. Only then will we realize Dewey's vision of a true democratic society where all are full participants and active citizens, empowered through science to take positive action.

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ARTICLE II: YOUTH ACTION RESEARCH IN THE SCIENCE CLASSROOM: IMPLICATIONS FOR YOUTH'S IDENTITY WORK

Abstract

This study examines how youth experienced and made meaning of their participation in a curriculum called Science Youth Action Research (Sci-YAR), which was designed to emphasize relevance and agency to promote youth's science learning. In Sci-YAR, youth conduct action research projects to better understand science-related issues in their lives, schools, or communities, while they simultaneously document, analyze, and reflect upon their own practices as researchers. Using a case study of youth engaged in Sci-YAR in an urban, high school classroom, this research identifies and describes components of the curriculum youth found meaningful. In addition, this study investigates how the use of Sci-YAR as a curricular framework and instructional approach enabled and constrained youth's identity work in service of critical science agency. Using the lenses of socio-cultural theory, positioning theory, and constructivist theory, this study analyzes how Sci-YAR enabled and constrained youth in shifting their views of science toward being a tool and a context to take action, and in viewing themselves as scientific thinkers with the ability to bring about personal and social transformation through their practices of science.

Historically, science education has promoted primarily content-based, skill-based approaches, focusing on the cognitive aspects of learning and neglecting the affective aspects of learning and curricula's relevance to youth and their lives (Calabrese Barton, Ermer, Burkett & Osborne, 2003; Coleman, n.d.; Emdin, 2009; Roth, 2009; Roth & Lee, 2002, 2004). Insisting that youth acquire a single set of knowledge, skills, and viewpoints determined by others, current practices in science education do not encourage youth to use scientific thinking in real-life situations and participate in scientific practices as part of their everyday lives (Roth & Calabrese Barton, 2004). Not emphasized enough in science curricula and instruction, relevance and agency are essential components to science learning that must accompany the integration of science content knowledge and process skills.

Neglecting relevance in science education in the past has had specific implications for youth in the classroom. Science, and school science in particular, has a distinct culture, which does not always align with youth's cultural perspectives and practices (Aikenhead, 2001; Albright, Towndrow, Kwek, & Tan, 2008; Calabrese Barton, Basu, Johnson, & Tan, 2011). When science and science instruction are separated from, or worse, are in direct opposition to youth's own experiences, beliefs, and values, youth often experience a disconnect between their identities and practices of science (Brown, 2006; Emdin 2009; Calabrese Barton & Tan, 2010). This disconnect results in youth resisting or rejecting roles as scientists or scientific thinkers in order to preserve other aspects of their identity work (Brickhouse, Lowery, & Schultz, 2000; Calabrese Barton &

Tan, 2010; Carlone, 2004; Olitsky, 2007; Scantlebury, 2007). Failure to take on these roles can result in youth's inability to take action within their environment.

Agency is often ignored in science education. Particularly in urban schools, teachers utilize instructional practices intended to promote rigor in the science classroom, but instead reinforce a *culture of power* (Calabrese Barton et al., 2011; Elemsky & Tobin, 2005; Emdin, 2009), in which they not only exert control over students in general, but also promote specific scientific practices, such as particular methods of discourse or argumentation, that are geared towards the white middle-class (Brown, 2006; Lemke, 1990). In many instances, much of youth's cultural capital is not acknowledged or valued, and youth are not given opportunities to make decisions and practice science in ways that leverage their cultural capital to take action through science. This approach to science education has resulted is youth's general disconnection with school science and their inability to use science in order to address meaningful problems encountered in their everyday lives, particularly among urban youth.

This study investigates youth's experiences while participating in Science Youth Action Research (Sci-YAR), a curriculum designed to address the lack of relevance and agency found in many science curricula (Coleman, n.d.). In Sci-YAR, youth conduct action research projects to better understand science-related issues in their lives, schools, or communities, while they simultaneously document, analyze, and reflect upon their own practices as researchers. In order to address urban youth's disconnection with school science, curricula must promote their identity work toward seeing themselves as scientific thinkers and doers who can "alter the world toward what they envision as being more just" (Calabrese Barton & Tan, 2010, p. 195). This study examines one particular curriculum's ability to influence this type of identity work.

Relevant Literature

Identity

Identity work, broadly defined, is described as "anything people do, individually or collectively, to give meaning to themselves or others" (Schwalbe & Mason-Schroch, 1996, p. 115). Identity work is both an individual process, where individuals construct images and understandings of themselves, but it is also a social process, when individual work is done through interaction with one's context and with others in that context (Nasir, 2010; Schwalbe & Mason-Schroch, 1996). While individuals develop accounts of their own identity through this work, others can also influence individuals' own identity work by recognizing (or choosing not to recognize) identity claims made by individuals (Gee, 2005; Holland, Lachicotte, Skinner, & Cain, 1998; Luehmann, 2007; Nasir, 2010). Meaning, individuals continuously check their identity work against others' views in order to substantiate or redefine that work. Although the term identity work shares these common features with other terms, such as identity development and authoring identity, the term identity work is used in this study to emphasize the active nature of this process and how this process can be contested and/or resisted, both by individuals themselves and by others.

In addition to this broad conception of identity work, the definition of identity work employed in this study draws on some of the key common characteristics of situated and social constructivist conceptions of identity (Holland et al., 1998; Luehmann, 2007). A *dialogic perspective* is taken on identity, embracing both the cultural and constructivist aspects of identity work (Holland et al., 1998). Consequently, in this study, multiple lenses are simultaneously used to make sense of youth's identity work. The lens of socio-cultural theory is used to analyze how cultural forces, such as the culture of the school, influence how youth construct meaning while engaging in science, as well as how this enables or constrains their identity work in service of critical science agency. In addition, the lens of positioning theory is used to analyze how the immediate social positioning taking place within the Sci-YAR curriculum enables or constrains this identity work.

This approach intends to recognize both the dynamic and interactive aspects of identity work. First, aspects of identity work are dynamic because one's identity is constantly formed and re-formed (Roth et al., 2004) and can consist of interrelated, overlapping, and sometimes conflicting conceptions of self (Nasir, 2010). Second, part of identity work is an interactive, social and cultural process where individuals are in dialogue with the surrounding context and others in that context (Elemsky & Tobin, 2005). Identity work is not done solely on a personal level, as having others to interpret and recognize one's identity claims is integral to identity work (Luehmann, 2007; Taylor, 1992). However, this is not to say there is no stability in one's identity or one's identity is solely determined by outside forces. Rather, according to Elemsky and Tobin, (2005), identity is "the dialectical interplay between how one defines him/herself and the way that others in the community define him or her" (p. 817).

Nasir (2010) argues that analyses of identity in research on teaching and learning must consider participants' own role in shaping their identities and their own interpretations of self, as well as others' influence in shaping those identities, including others' interpretations of participants' identities. In this study, analysis of youth's identity work highlights both youth's interpretations of self, as well as my interpretations of their identity work, as charted in our dialogue over the course of a five-month curriculum. Included are youth's accounts of their lived experiences participating in Sci-YAR as they described their perceptions of who they were and who they hoped to be. Also provided is more in-depth analysis regarding my observations of youth engaging in identity work over a period of time, charting how they constructed new understandings and views of themselves, both individually and with others while engaging in science.

Identity and Agency

The conceptualization of identity work used in this study, similar to authoring identity (Holland et al., 1998) emphasizes the agency of persons in making meaning of the world and of their relationship to the world. This study employs Calabrese Barton and Vora's (2006) description of agency as youth "giving significance to the world in purposeful ways, with the aim of creating, impacting and/or transforming themselves and/or the conditions of their lives" (p. 209). Identity work and agency are interactive; identity work is a way to exercise personal and social agency (Holland et al., 1998) and agency is a key part of engaging in identity work (Basu, Calabrese Barton, Clairmont, & Locke, 2009; Calabrese Barton & Tan, 2010). Holland and colleagues (1998) argue that authoring one's identity is a form of agency because one is constantly in dialogue with the world and finding ways to navigate "power, position, and privilege" (p. 191) in order to find one's own voice. Agency is also a key aspect of identity work since, according to Calabrese Barton and Tan (2010), "agency is at once the possibility of imagining and asserting a new self in [the] world at the same time as it is about using one's identity to imagine a new and different world" (p. 192). According to this definition, agency can be the action taken by youth, based on both their immediate interpretation of their identity, as well as the potential of what their identity could become by taking that action. In this sense, youth navigate two states at once: the current state of their identity that shapes their current agency or action they will take, as well as their potential identity from taking the tentative action, which is still to be determined.

Critical Science Agency

Critical science agency, in which science becomes both a range of contexts and tools for youth to exercise agency (Calabrese Barton & Tan, 2010), clearly connects these ideas of identity work and agency in the context of science classrooms. Basu and colleagues (2009) argue that critical science agency is closely related to identity work since part of youth's identity work can potentially be to construct themselves as agents who critically view the world, as well as powerful scientific thinkers who can envision ways to create a more socially just world and who can take action through scientific practices to enact that change. Because engaging in identity work affords youth the opportunity to expand their identities by imagining and acting on projective identities (Gee, 2003), the promotion of identity work in science classrooms has the potential to shape youth as critical science agents who position themselves differently in the world and influence the world towards what they envision as more equitable and just (Calabrese

Barton & Tan, 2010). Overcoming youth's disconnection with science education requires a curriculum that promotes relevance and supports their identity work in service of critical science agency.

In this study, critical science agency was used as a framework to examine youth's identity work while engaging in the Sci-YAR curriculum. Analysis of youth's identity work focused on their development in (a) viewing science as a tool and a context to take action, (b) viewing themselves as scientific thinkers and doers, and (c) their ability to take action through practices of science to positively impact their lives or their communities (Basu et al., 2009). Examining youth's changing (or unchanging) perceptions of science was essential because identity work takes place not solely within the individual, but also involves them developing perceptions of themselves in relationship to the world. Engaging in identity work in service of critical science agency, then, involves youth shifting their perceptions of science as a discipline and how they might see themselves in relationship to that discipline. Youth will not engage in identity work to construct images of themselves as scientific thinkers and doers if they do not see science as a range of tools and contexts related to their own lives, which might help them take meaningful action. Finally, examining youth's identity work in service of critical science agency requires an examination of how youth envision their possibilities for taking action through science to bring about personal or social transformation.

School Curricula Promoting Critical Science Agency

Significant studies conducted individually by Basu (2008a, 2008b) and in conjunction with her colleagues (2009) have been key in developing the framework for critical science agency and examining specific curricula and instructional practices that promote youth's critical science agency in the physics classroom. Basu's (2008a) study of how students' development and enactment of lessons in their physics class were ways of engaging in identity work and asserting agency reinforced the finding that:

> when youth expressed voice through the design of physics lessons, they described and developed their identities—they made progress towards future aspirations such as career goals and connected lesson design and enactment with their intellectual and social identities and beliefs re: science. (p. 895)

Basu argued that providing youth spaces in the science classroom to express their voices has the potential to increase their engagement in science, as they connect understandings of themselves to the science content they are learning. She also concluded that this process can lead youth to better understandings of both themselves and the subject matter under study.

Basu's (2008b) complementary study on youth's development as critical agents in the physics classroom further defined critical agency as youth's directed action toward change regarding personal or global issues, which includes some focus on calling out and working to change existing power structures in society. Basu further extended this concept of critical agency to apply to particular subject areas, defining *critical subject-matter agency* as evidenced when "students become powerful learners and deep thinkers in a subject, while articulating and enacting a vision of change" (p. 255). She illuminated this concept by examining cases of youth who developed this critical mindset while engaging in their high school physics course, finding that their goals for (a) learning, (b) expressing their voice, (c) constructing relationships with others, and (d) bringing about change in the world reflected these youth's stance of critical physics agency. In addition to developing the groundwork for the construct of critical science agency and showing how it could be fostered within science classrooms (rather than out-of-school contexts), Basu's recommendations for science curricula were to focus on youth's personal and local contexts and goals, rather than global issues, in order to foster youth's identity as powerful learners and critical agents.

Basu and colleagues' (2009) study further developed a framework for critical science agency, again through the examination of cases of youth in a high school physics course. This study established essential components of critical science agency, including how it is an iterative and generative process inextricably linked with identity work:

> Because engaging in agency involves reflection and the development of awareness, it necessitates that individuals continually examine their identities—who they are and how they change. Issues of identity—and how one positions oneself (or is positioned) through practice and identity building—are central to making sense of how one seeks to pursue one's goals. (p. 360)

The authors also described critical science agency as it was enacted in a particular classroom by examining youth's positioning within school science and their ability to take on new roles in this context. Key in helping youth develop realizations of themselves in relationship to their practices of science were youth's metalogues, where they were "invited to write reflections about their life histories, their experiences with science in school, what they learned in physics, their long-term and short-term goals, and their ideas for improving physics education" (Basu et al., 2009, p. 349). The authors concluded that giving youth opportunities to use science as a foundation for change created a space in science classrooms so that youth's "identity develops, their position in the world advances, and/or they alter the world towards what they envision as more just" (p. 346).

Other researchers, such as Mallya, Mensah, Contento, Koch, and Calabrese Barton (2012), have recently studied additional examples of school science curricula designed to promote youth's development of agency through practices of science. Mallya and colleagues examined the *Choice, Control and Change (C3)* curriculum's enactment with seventh grade students in New York City to determine how youth were able to extend their understandings of science both in and out of the classroom. The authors found that this science and nutrition curriculum facilitated students in critically analyzing the food choices available in their environment, reflecting on their own food and activity choices impacting their health, and envisioning ways in which they could expand the food and activity options available to them and their community. Through their participation in *C3*, youth were able to "work toward finding ways to transform themselves and the conditions of their lives through an understanding of the science or content they learn from the *C3* curriculum" (Mallya et al., 2012, p. 263). These findings further established the ability of school science curricula to facilitate youth in applying the science they learn in school to situations they encounter in their everyday lives. Furthermore, the authors argued for the continued examination of how educators might create meaningful and relevant learning opportunities for youth through the design of curricula that facilitate them in connecting their school science experiences with issues of personal and social significance. They stated that part of this deeper examination will involve studies that more clearly and descriptively link identity work and critical science agency, which is what this particular study aims to do. Building upon the prior work outlined here, this study seeks to further investigate how other school curricula might encourage youth to use science as a foundation for personal and social change.

Science Youth Action Research

The specific curriculum examined in this study is Science Youth Action Research (Sci-YAR), which has been defined as a curricular framework used within a K-12 school science course to engage youth in collaborative action-based scientific inquiries connected to personal, local, or national issues of importance to them (Coleman, n.d.). Sci-YAR projects are youth-generated and youth-lead, as teachers and other adults involved act as facilitators, supporting students as they collaborate with their peers in the decision-making and actions involved in conducting research. In addition to the action youth are encouraged to take to address issues they investigate related to their lives and/or surrounding communities, youth also document, analyze, and reflect upon their own practices and experiences as researchers, as well as their own personal growth throughout the process. The key features of Sci-YAR examined in this study, as well as descriptions of how each is evidenced in the curriculum, are presented in Table 1.

During participation in Sci-YAR, these key features are emphasized as youth work in groups to identify issues in their communities related to science concepts they have been working with in their course, pose investigable questions of interest to them, and then conduct action research projects in order to better understand the issues and propose possible solutions. While conducting their research, youth employ a variety of data collection methods that are not limited to controlled experimental trials; for example they might conduct both quantitative and qualitative observations of natural phenomena, interview experts on different facets of their topics, as well as survey school and community members. In addition, youth engage in *self-documentation* (Reeve & Bell, 2009) of their experiences—through the use of media such as photography, film-making, blogs, or other social media—and analyze these personal experiences and practices of science while engaging in the curriculum. At the conclusion of the curriculum, students develop an action plan based on their findings that could be implemented in the future to address the problem they had been researching, and they disseminate the results of their research to the school community. In this forum, youth share the findings of their research, their proposed action plans, as well as the analyses of their own practices of science and their personal growth experienced while conducting research.

Similar to the school science curricula examined in prior studies, Sci-YAR intends to provide youth the spaces and the autonomy to engage in relevant practices of science, thereby creating deeper personal connections to the content being studied and facilitating youth's identity work in service of critical science agency. Distinct from these other curricula is that Sci-YAR intends to facilitate this process by providing youth opportunities to design, conduct, and extensively reflect on their own research. The Sci-YAR curriculum is informed by findings from these prior studies, which indicate the

Table 1

Key Features of Sci-YAR

Key Feature	How It Is Evidenced in Sci-YAR
Using science as a way of knowing and taking action	• Youth engage in science as a way of knowing, and they continuously take and reflect on action as they engage in practices of science. • Youth design and execute their own research to investigate problematic situations taking place in their school or surrounding community. • Youth envision possibilities for future action by developing and disseminating an action plan that addresses the problem or issue under investigation.
Participating in relevant practices of science through action research	• Youth are asked to more broadly conceptualize science and what activities can be considered "scientific". • Youth are given opportunities to critique narrow definitions of science and develop scientific practices that value the ways of knowing and acting that they employ in their everyday lives. • Youth conduct relevant research to address problems and issues related to their lives. • Youth are encouraged to use their practices of science to take action to bring about personal and social transformation.
Engaging in extensive personal reflection	• Youth investigate their ongoing actions as they document, analyze, and reflect upon their practices of science and their own personal development while conducting their research. • Youth engage in *reflection-in-action*, *reflection-on-action* (Schön, 1983), and *reflection-for-action* (Killion & Todnem, 1991) as ways to improve their practices of science, create knowledge regarding those specific practices in relationship to themselves, and plan future action based on this knowledge. • Youth's documentation of their experiences is an integral part of the curriculum, which is deliberately and systematically conducted and analyzed throughout.
Collaborating through collective research	• Youth conduct research in collaboration with peers, as they work in teams to pose questions regarding issues of personal meaning and importance to them, design

	investigations and collect data together, and check one another’s interpretations of that data. • Youth continuously share, discuss, and reflect upon their self-documentation with peers as they conduct their research, and they may even include collective documentation of meaningful group experiences. • Youth collaborate with adult allies who support youth and guide them through their research and through the process of documenting, deconstructing, and reflecting on their practices of science and their personal growth.
Conducting research that is youth-generated and youth-led	• Youth begin their action research initiatives from scratch and make the decisions that impact the focus and direction of their investigation as they take ownership of the research’s design and execution. • Youth assume full decision-making responsibility while conducting their research, emphasizing youth’s sense of agency in the classroom.

importance of youth practicing science related to their local contexts, as they investigate personal issues in their lives, schools, and communities to solve problems or reach goals relevant to these contexts. However, Sci-YAR is designed to provide youth more extensive opportunities to assert their agency and actively participate in making their science learning personally and socially relevant, especially since youth are the ones generating their research topics and questions, arguing for their research's applicability to science and their lives, and directing their own scientific practices towards facilitating change. Accepting the assumption that agency and subject knowledge are not goals that must be at odds in the science classroom (Basu et al., 2009), Sci-YAR's design provides opportunities for youth to gain not only deep understandings of the science content under study, but also authentic ways to utilize their scientific knowledge and skills to take action in their lives.

In addition, Sci-YAR explicitly promotes reflection as an essential process of scientific work. This extensive reflection is one way Sci-YAR is designed to position youth as scientific thinkers and doers, and therefore promotes their identity work while learning science. Sci-YAR is also designed to facilitate youth's identity work in service of critical science agency by affording youth opportunities to take on a variety of roles in the science classroom. Youth are asked to broaden their conceptions of science and the actions involved in practicing science as they draw on their everyday ways of thinking and acting to direct their own science learning toward positive action. Building on conceptualizations of critical science agency developed in prior studies, this research seeks to investigate how Sci-YAR—a school science curriculum with these particular features—enables or constrains youth's identity work in service of critical science agency.

Theoretical Framework

To understand the development of youth's identity work in service of critical science agency, it is necessary to examine the underlying aspects of learning that contribute to this development. The Sci-YAR curriculum has been established as a curricular framework and instructional approach aligned with learning theories (Coleman, n.d.), including Piaget's (1959) constructivist theory and Vygotsky's (1978) socio-cultural theory. These theories also served as the lenses through which youth participants' identity work was analyzed in order to make sense of how they experienced and made meaning of their participation in Sci-YAR. Additionally, positioning theory (Harre & Moghaddam, 2003) was used as a lens to examine how youth's identity work was enabled or constrained in particular ways based on the roles they did or did not accept. Using socio-cultural and positioning theories allowed for the examination of the social nature and the contested nature of youth's identity work in the science classroom, and using constructivist theory allowed for the examination of the individual nature of youth's identity work as they constructed images and understandings of themselves in relationship to science. Each of these will be briefly discussed in turn to highlight what they enabled when analyzing youth's identity work in service of critical science agency.

Vygotsky's Sociocultural Theory

Viewing youth's identity work through a socio-cultural lens emphasizes how youth construct meaning regarding themselves and their experiences through interaction with others. By approaching an analysis of identity work assuming that both learning and identity work are fundamentally social and cultural processes, learning science can be viewed as a specific form of identity work (Aikenhead, 2006; Calabrese Barton et al., 2011; Carlone, 2004; Lave & Wenger, 1991), as learning involves "ways of talking, acting, being in the world, describing oneself, or relating to others" (Carlone, 2004, p. 396). This means that as youth engage in learning science, they construct meaning and understanding through their interactions with others—both regarding science and themselves—particularly when other individuals can mediate these learning experiences for them. In analyzing youth's identity work, I examined how youth internalized understandings of science and themselves, first by negotiating these understandings with others, and then with themselves through extensive reflection. Vygotsky's (1978) ideas regarding the relationship between thought, speech, and action also guided analyses on how youth's dialogue with themselves and others served as a form of identity work, as youth furthered their thinking on their identities in relationship to science, bringing them to a higher level of consciousness regarding themselves and their place in the world. Finally, I examined youth's identity work looking for how this dialogue with themselves and others directed their actions and prepared youth to take future action.

Positioning Theory

Viewing youth's identity work through the lens of positioning theory also emphasized the social nature of identity work, as well as its dynamic and contested nature. Examining how youth took up and rejected certain roles or positions while engaging in Sci-YAR allowed for another way to view youth engaged in identity work within a social context. When examining the roles youth took on during their participation in Sci-YAR, I conceptualized these roles as less static and more fluid in line with Harre and Moghaddam's (2003) definition of positions as "loose set[s] of rights and duties that limit the possibilities of action" (p. 5). When viewing youth's identity work through the lens of positioning theory, it highlighted how certain features of Sci-YAR influenced youth in taking on particular roles, as well as the rights and duties accompanying these roles, which in turn enabled and constrained youth in developing deeper understandings of themselves through engagement in science. Positioning theory allowed for the examination of ways youth positioned themselves in their social interactions and in their personal reflection, in order to construct a sense of self through engagement in science.

Piaget's Constructivist Theory

Viewing youth's identity work through the lens of constructivist theory allowed for an emphasis on the individual nature of identity work, as youth actively constructed understandings of themselves in relationship to science, continuously examined those understandings through reflection, and then revised and reconstructed those understandings based on new experiences and insights. Examining identity work from a constructivist lens emphasized how youth were actively constructing their own meaning and understandings of themselves and science by elaborating on their prior knowledge and integrating new experiences and perspectives as they built on that knowledge through their participation in Sci-YAR.

Piaget's (1959) ideas of assimilation and accommodation played a major role in analyzing youth's identity work. I examined how youth simultaneously both *assimilated*, or incorporated new ideas into their existing schema regarding science, and *accommodated*, or modified their existing schema to fit new ideas that they encountered during the process. I also looked at how aspects of the Sci-YAR curriculum enabled and constrained these processes of assimilation and accommodation, as youth developed (or did not develop) new viewpoints on science and their relationship to it. The concepts of *equilibrium* and *disequilibrium* also aided in the analysis of youth's identity work while engaged in Sci-YAR. This lens helped me view instances where Sci-YAR created disequilibrium or the "mental discomfort that spurs [youth] to try to make sense of what they are observing" (Ormrod, 2011, p. 29), which disturbed their equilibrium or the stability they had in thinking about science and themselves. Using a constructivist lens also aided me in identifying instances where youth's disequilibrium, and ensuing *equilibration* (moving between equilibrium and disequilibrium) was a key component of youth's identity work, as they attempted to make sense of their mental discomfort, at times by shifting their perceptions of science and themselves in relationship to science, and by attempting to make sense of the world and their roles as agents of change within it.

Purpose

The purpose of this study is to build upon prior work regarding school science curricula's promotion of youth's critical science agency. This study aims to identify what aspects of the Sci-YAR curriculum are meaningful to youth and investigate how the use of Sci-YAR as a curricular framework and instructional approach enables and constrains youth's identity work in service of critical science agency. By using the lenses of socio-cultural theory, positioning theory, and constructivist theory to analyze youth's identity work, it intends to aid in developing more complex understandings of how youth might engage in identity work to assert themselves as powerful scientific thinkers and doers who can enact their science learning in their everyday lives to bring about personal and social transformation. In order to foster youth's growth in the science classroom, opportunities that facilitate their identity work should be provided, particularly in service of constructing themselves as agents who critically view the world, as well as powerful scientific thinkers who can envision ways to create a more socially just world and who can take action through scientific practices to enact that change (Basu, Calabrese Barton, Clairmont, & Locke, 2009). This study examines how engaging youth in a particular curriculum, Sci-YAR, might both facilitate and hinder this process of identity work in the science classroom.

Research Questions

In line with this purpose, this study addresses the following research questions:

- In what ways do youth experience and make meaning of their participation in science youth action research?
- What components of science youth action research as an enacted curriculum do youth recognize as meaningful?

- How does the use of science youth action research as a curricular framework and instructional approach enable or constrain youth's identity work in service of critical science agency?

Methodology

Case study methodology was used to examine youth's experiences engaging in Sci-YAR within the context of a particular science classroom. This study had a phenomenological aspect to it because its purpose was to emphasize individual lived experiences with regards to a particular phenomenon (van Manen, 1990), which in this case was Sci-YAR. Furthermore, this study examined the "immediate and local meanings of actions" (Erickson, 1986, p. 119), as defined by youth participants' point of view.

Case Study

This case study represents "an in-depth description and analysis of a bounded system" (Merriam, 2009, p. 40), which occurred on two levels. The science classroom was the larger bounded system under study. In addition, each youth participant from that classroom served as a bounded case, as their individual experiences engaging in Sci-YAR were investigated. Although this case study did have a phenomenological aspect to it, what made this research primarily a case study is that it was not necessarily defined by the focus of the study, but rather the unit of analysis (Merriam, 2009). This study did not intend to generally examine science curricula similar to Sci-YAR. Instead, its purpose was to look at Sci-YAR being enacted within a *particular* classroom, and being done by *particular* individuals to highlight their lived experiences. This research matched an essential feature of case study, in that it was *particularistic* (Merriam, 2009) or focused on a particular case involving Sci-YAR.

In addition, this study aims to be: (1) *intensive* (Flyvbjerg, 2011) and *descriptive* (Merriam, 2009), including rich detail about the cases, (2) *heuristic* (Merriam, 2009) in that the goal is to inform the reader's understanding, and (3) focused on the participants' relationship to the context (Flyvbjerg, 2011), with the context being the bounded system under study, or the classroom engaged in Sci-YAR. Case study is an appropriate methodology to use when examining concepts such as identity work because of its ability to capture and provide interpretation of complex phenomena (Stake, 2007, as cited in Merriam, 2009). This methodology provided a holistic view of the complex process of youth's identity work in service of critical science agency, in order to describe and interpret what was taking place within youth's lived experiences.

Phenomenology

This case study had a phenomenological aspect to it because it focused on youth participants' lived experiences or *life-worlds* (Erickson, 1986), and it attempted to uncover how particular youth directly and immediately experienced the world (van Manen, 1990). Phenomenology aims to describe a particular phenomenon as it appears to the consciousness of the person experiencing it, in order to get at its essences, or the internal meaning structures, of that lived experience (van Manen, 1990). This study intends to describe the essences of youth experiencing Sci-YAR as a phenomenon, in order to understand how youth made meaning of their participation in this curriculum.

Including ideas related to phenomenology is appropriate because this research attends to phenomena related to teaching and learning, which is an everyday, practical concern (van Manen, 1990). In addition, it is also compatible with examining processes like identity work. van Manen argued that phenomenology is the search for what it means to be human, because as we uncover and describe lived experiences, we come to a fuller understanding of who we are in the world. By analyzing youth's lived experiences and examining their identity work in service of critical science agency, this study intends to facilitate a deeper understanding of how we as humans can become "more fully who we are" (p. 12).

Context

Sci-YAR at St. Timothy High School[1]

This study was conducted within the context of a ninth-grade biology class in an urban high school classroom. St. Timothy High School is an established all-boys, Catholic school located on the south side of Chicago. Smaller than many of the public high schools in the area, St. Timothy has an enrollment of approximately 650 students, consisting of approximately 45% White, 30% African American, 20% Latino, and 5% Biracial students. While St. Timothy advertises its college preparatory curriculum as a prominent focus of the school, it is most known in the community for its emphasis on athletics. In order to attract a wide variety of athletes to attend, the school offers a significant amount of financial assistance, with 78% of the student body receiving some form of scholarship or financial aid. As a result, St. Timothy draws students from around

[1]All names of places and participants are pseudonyms.

70 different neighborhoods all over the city of Chicago. This results in a diverse student body, not only in terms of geographic location in the city, but also in terms of race, ethnicity, language, and socio-economic status, which distinguishes it from many of the Catholic high schools in Chicago. Because around 90% of the student body participates in at least one sport at St. Timothy, athletics permeate the school culture, with constant "spirit days" where students can dress out of uniform to wear the athletic jersey of their sport, daily announcements about the outcomes of games or matches played against long-time rivals, and constant discussion among the students about games, practices, lifting, and other commitments related to their athletic endeavors.

The biology class that was the focus of this research was a required course for incoming freshman, and it had an enrollment of approximately 30 students. For the first semester of the course, students engaged in the required school curriculum, which consisted of textbook readings, interactive PowerPoint lectures and discussions, as well as labs where students would explore some concepts more deeply. Because the classroom teacher, Ms. McAteer, and I had designed the Sci-YAR curriculum in conjunction several years prior, she had also integrated certain practices into the first semester to prepare students for the Sci-YAR curriculum, such as keeping a reflection journal where students wrote about topics like their prior experiences in school science, their perceptions of school and the biology class, and their recommendations for her teaching. This study was conducted during the second semester of the course, as students engaged in the Sci-YAR curriculum.

During their participation in Sci-YAR, students selected topics of interest related to the course in some way, and over the four-month period, they designed and conducted their own research on these issues. During this time, students posed research questions, designed and executed data collection plans, analyzed their data, and presented their findings at a school-wide research symposium. Students were required to complete certain assessments as part of the Sci-YAR curriculum, such as written research plans and reflections. In addition, students engaged in self-documentation, as they recorded and analyzed their practices of science using a variety of media. At the conclusion of the semester, students developed an action plan based on their research findings, and they disseminated this with the results of their research at the symposium.

Prior to this study, Ms. McAteer and I had worked together over several years developing the Sci-YAR curriculum and implementing it with her former classes. We both took an equal role in developing the structure of the Sci-YAR curriculum, and we acted as co-facilitators in the classroom, but Ms. McAteer had the primary responsibility for making modifications to the daily curriculum, instruction, and assessments, as well as the sole responsibility for evaluating students' work and assigning grades. The year this study was conducted was our third iteration of Sci-YAR's implementation, and the second year implementing it with students at St. Timothy.

From January through May, I attended Ms. McAteer's two biology classes on a weekly basis and helped with the implementation of the curriculum. At first, the curriculum was only taught one to two days per week, as it was gradually integrated in with the required course of study. As students' data collection and analysis progressed, they participated in Sci-YAR three to four days per week. During the final month leading up to the research symposium, students worked on their research in class five days a week. Throughout the semester, my role was to work with students while in their groups and facilitate the development and execution of their action research projects, but I also took on other roles at times, such as co-teaching lessons with Ms. McAteer, developing additional classroom activities and assessments, and even chaperoning field trips.

Youth Participants

Youth participants for this study were all males, ages 14-15, recruited from Ms. McAteer's second-period biology class. All students in this class were invited to participate in the study, and seven agreed to be a part of research activities taking place outside of class. From these seven, five participants were used as in-depth cases for analysis. These cases were selected because the participants were able to talk most descriptively about their experiences in Sci-YAR. Data from Robert and Wasalu were used in analysis where there was confidence interpreting their experiences; however, these were limited instances, and so analysis focused on the experiences of the following participants.

Dan. Dan describes himself as hard-working and goal-oriented, particularly when it comes to athletics. He both wrestles and plays baseball (although this sport is secondary to his participation in wrestling), and he prides himself on the consistent effort he puts into these sports, which even earned him a special award from his wrestling coach. Dan maintains a high level of focus and commitment, even in the face of adversity, such as when he sustained a serious injury in a wrestling match the prior year.

Dan also sees his creativity as a strength, which comes out mainly in his break dancing and his participation in hip hop. Dan and his group decided to study various sports injuries in Sci-YAR, since he and many of his group members played sports, had watched professional athletes deal with injuries, and had experienced injuries themselves. Dan described his group as working well together because of their ability to communicate, and he identified particularly liking the self-documentation when he could share personal artifacts, like his wrestling jersey, in class.

Cameron. Cameron describes himself as a focused student whose goal is getting A's in all of his classes. Grades are a primary motivator for Cameron because he eventually wants to get a college scholarship for sports and academics. Cameron likes sports because they keep his mind and body active, and he particularly enjoys fast-paced sports, such as football and volleyball. Being an athlete is a source of pride for Cameron because he feels that success comes naturally to him in this area, and it distinguishes him from others, such as being the only freshman to make the varsity volleyball team. Cameron joined a group studying household chemicals for their Sci-YAR research, hoping that he could make a chemical reaction and see an explosion. While Cameron described his group as getting along well, he thought that he often had to do the majority of the work leading his group and getting them involved in the research. Cameron was most excited about doing his self-documentation, as his group filmed their work together on the project, and he enjoyed opportunities to share his interest in sports with others, because it highlighted his competencies.

Aaron. Aaron describes himself as a practical person who has experienced a lot of growth since he started high school. Previously unmotivated in school, Aaron says his new philosophy is that he should not waste his time and, instead, take the opportunity to learn. However, he admits that this new attitude is difficult to sustain because in order to keep his attention, something has to relate to his life in a meaningful way. Aaron sees most school subjects as unrelated to his experiences now or in the future, and so he finds it hard to stay motivated. He has a passion for fixing cars and engaging in tasks that require him to engineer a solution to a problem because he sees these as building skills that will be useful in his life. For example, Aaron prides himself on never having to rely on a mechanic to get things fixed, because he can do it himself. For his Sci-YAR research, Aaron decided to study muscle growth, which came from an existing goal he had set to be more muscular through weightlifting. He thought his group worked well together because they all had their own expertise to contribute, but were all interested in the common goal of becoming stronger. What Aaron liked most about participating in Sci-YAR was doing work in class related to his outside interests.

James. James describes himself as confident and constantly working hard to reach his goals and become a better person every day. He is actively involved in sports, including baseball and football, to the point that he says his participation in sports runs his life at times. James values being a part of sports teams because he can have fun with teammates, but still works hard with them to achieve success. An important part of sports for James is being a leader, as he has been captain of many of his teams. As captain, he sees his role as making decisions that help the whole team, rather than just himself. James chose to study household chemicals for his Sci-YAR research, and he led his group members in selecting this topic because he thought it would benefit the whole group by helping them learn more about their surroundings. He saw his group as successful because they established a good balance between working and having fun. James also took the lead in filming for the group's self-documentation, which was an enjoyable part of the project for him.

George. George describes himself as a positive person who is goofy and likes to entertain others. He thinks that sometimes these qualities as well as his lack of patience to develop his thoughts, causes him to be a somewhat unfocused student in class. George is competitive and mainly applies this quality to his participation in soccer, which is an activity he really enjoys. He uses playing soccer as motivation to keep his grades good enough, so that he is eligible to play. George recognizes conflicting views of himself. In some endeavors like soccer, he sees himself as motivated, serious, and focused, but at other times he is distracted and unfocused on what he needs to do to complete a task or reach a goal. George chose his group's topic of studying nutrition and food safety for their Sci-YAR project. He fell ill with food poisoning a few weeks prior to the start of the project, and that made him want to examine the nutrition and food safety practices in his own school cafeteria. Even though George worked with his friends, he did not think his group worked well together, as they were not focused on the project at all, which caused him to complete the majority of tasks. George most enjoyed interviewing the cafeteria staff at his school and doing nutrition tests on some of the food there because it was active and he learned a lot of interesting information that he shared with others at the symposium.

Data Collection

Attending class two to five times a week between January and June of 2013, I positioned myself as a participant observer in Ms. McAteer's biology class, helping her plan and execute the Sci-YAR curriculum, aiding all students in conducting their research, as well as observing participants engaged in particular interactions related to the curriculum. Field notes from these extensive observations were used to inform a series of in-depth interviews conducted with participants during the course of the semester. These four semi-structured interviews occurred approximately once a month from February through June, and they served as the major source of data collection. In these interviews participants were asked to identify what they thought were meaningful or not meaningful components of Sci-YAR, as well as discuss how they experienced these components. Questions accessed participants' thinking about how they were constructing images and understandings of themselves, participating in the curriculum in particular ways, and how they were accepting or rejecting roles within the Sci-YAR curriculum. Finally, in order to better understand Sci-YAR's influence on participants' identity work in service of critical science agency, participants were continuously asked how they conceptualized science and scientific thinkers, how they accessed or did not access resources within the curriculum, how they were able or were not able to take action in their lives through their practices of science, and how they envisioned or did not envision using science as a context and tool for current or future action.

Throughout the interview process, document analyses of artifacts created by participants during their participation in the Sci-YAR curriculum were also conducted. These, as well as informal conversations with participants during observations, were used for triangulation to support findings drawn from the analysis of interview data. In addition, these artifacts helped mitigate certain challenges that arose when interviewing male adolescents. In particular instances, simply posing questions in an interview were not a sufficient means for encouraging participants to talk descriptively about their identity work and experiences in Sci-YAR. Artifacts produced during participants' self-documentation not only served as part of the Sci-YAR curriculum, but they also became rich data sources and ways to stimulate deep, meaningful conversations with youth about their identity work (Clark-Ibanez, 2004).

Data Analysis

In order to make sense of participants' ongoing experiences and identity work taking place within Sci-YAR, I engaged in continuous analytic induction (Erickson, 1986), both during and after data collection. After each round of interviews, I used WebspirationPRO™ software (http://www.webspirationpro.com/) to concept map data related to participants' experiences and their ongoing identity work, looking for emergent patterns both within each case and across cases. This process also informed future interviews with participants, where I was able to clarify how they made meaning of their experiences and to collect both confirming and disconfirming evidence to support initial interpretations.

In addition to these preliminary analyses, after data collection was complete, continued analysis occurred as I reviewed and coded transcripts of each interview using initial codes generated from literature on identity work and critical science agency. Using the constant comparison technique (Corbin & Strauss, 2008), I also identified several emergent codes and sub-codes. I then reviewed each coded case in succession, generating initial overarching themes related to the research questions, as well as seeking out confirming and disconfirming evidence to support those themes. Using this working list of initial themes, I retrieved the coded data from each subsequent case, identifying the emergent themes prevalent in a majority of cases. This process aided in editing the initial list of themes by collapsing themes, distinguishing and separating themes, or removing those that were not supported across the majority of cases. The most salient themes with sufficient supporting evidence were included in the findings. While writing about overarching themes found across the majority of cases, several cases were selected that clearly illustrated particular themes and provided more detail regarding those participants' experiences. The phenomenological aspect of this study is most evidenced in these cases, as the participants' voices were used to represent how they made meaning of their experiences in Sci-YAR. Highlighting certain cases also provided the opportunity to share themes that were unique to particular participants' identity work, which provided additional insights to complement the findings across cases.

To ensure trustworthiness (Lincoln & Guba, 1986) in this account of youth participants' experiences in Sci-YAR, I took care not to privilege my account of what I observed and how I made meaning of it over how the participants made meaning of their own experiences. While analyzing data and formulating findings, I: (a) ensured there were adequate amounts of evidence to support the claims made, as well as a variety of kinds of evidence to allow for triangulation of data; (b) engaged in member checks to confirm interpretations with participants; (c) searched for sufficient disconfirming evidence, and d) provided an examination of multiple discrepant cases to show a variety of interpretations and experiences within Sci-YAR. (Erickson, 1986; Merriam, 2009)

Considerations Regarding Generalizability

Because of the nature of phenomenological research and its attention to the life-world, which changes moment to moment, this research is not concerned with generalizing the experiences of the participants to future classrooms and students (Erickson, 1986). Instead, this research provides *naturalistic generalizations* (Stake, 2005), which are conclusions the reader derives from personal or vicarious experiences. This supports the idea that “knowledge may be transferable even where it is not formally generalizable” (Flyvbjerg, 2011, p. 305). The idea of generalizing findings to other contexts is placed in the hands of the readers, as they have knowledge of their own particular situations (Flyvbjerg, 2011; Merriam, 2009; Stake, 2005;Willis, 2007), and can choose aspects of the research that resonate with them in a way that enables them, in turn, to inform their thinking or practice. This aligns with a human science research approach, in that its goal is to produce *action sensitive knowledge* (van Manen, 1990), which is generated from the reader interacting with the text and responding to it. In fact, Stake (1981) argues that naturalistic generalizations are formed and applied so immediately by readers that they are part of the knowledge generated by case studies, directly contributing to the significance of the research. This study aims to contribute to the research, not by generalizing these findings to all youth, but by building on other particularistic case studies of youth's development of critical science agency and adding new perspectives on how identity work in service of critical science agency was fostered in one particular classroom engaged in Sci-YAR.

Findings: Youth Experiencing Sci-YAR in Meaningful Ways

Overall, youth participants recognized three distinct components as meaningful to their participation in Sci-YAR, each of which aligns with one or more key features of the curriculum. Most meaningful to participants were the collaborative nature of the curriculum, the autonomy they had to make their learning relevant to their lives, as well as the reflection they engaged in, most notably, through their self-documentation.

Collaborative Nature of Sci-YAR

Collaborating with peers. Participants found various components related to the collaborative nature of the curriculum compelling, indicating that *collaborating through collective research* is a meaningful feature of Sci-YAR. Foremost, many participants spoke about the positive aspects of being able to work in a group with their peers, identifying collaboration as essential for success in conducting their own research. A major academic benefit mentioned was that having multiple members in a group allowed more ideas to be generated throughout the research process. Participants preferred generating ideas as a group, rather than individually, and they found the social interaction conducive to developing productive ideas to guide their research. Several participants discussed the benefits of working in groups, noting that they achieved greater confidence in their ideas when peers validated or substantiated their thinking:

> I feel it's easier to work in a group of kids than individually….[or] even like [a group of two], with me and a partner. I like [having] four to five kids [in a group] because [with a group of two] you could have you and your partner agree on the same [idea], but only if two people out of the whole class agree, you're like, well okay… But if you have five strong people that backed [the idea] up with facts and stuff like that, you feel more… You know [the idea's] right. You have a better feeling about it that it's right. (James)

Participants recognized the importance of having one's claims (ideas) backed up with evidence (facts), and they indicated that more people contributing to a group allowed more evidence to be generated to support the group's claims. This collective understanding increased participants' perceptions that their ideas had value and were worth sharing with a larger audience.

Participants found the collaborative aspects of Sci-YAR more meaningful than prior science learning experiences because they could discover what others were thinking about specific science topics and gain exposure to different points of view on a variety of ideas related to these topics:

> [Sci-YAR's] just one of the favorite- it's one of my best things I've done so far in science. Because [before] all we did really was labs about [topics], which was okay, but [Sci-YAR] is fun…and cool because we get to figure out what other people are thinking about specific [topics] and broader [ideas]. (D)

Participants valued the opportunities they had in Sci-YAR to construct meaning through their research experiences with peers, and they used the opportunities to dialogue with one another as a way to further their thinking on scientific topics. Collaborating on research also allowed participants to develop their skills related to dialoguing about their ideas with peers. Most participants reported having little to no prior experience working in collaborative groups in school, especially during their science classes, stating that they had few opportunities to debate ideas and make decisions as a group. Participants described how conducting research with their peers was meaningful because it helped them construct and internalize new understandings of science as a collaborative endeavor:

> I see science now as a team effort, to be honest. Like when a scientist does something, I realize he's not doing it by himself. He's got other people throwing in their opinions or helping him. So now I realize that you can't do a [research] project by yourself, and that in science you need a team, just like how you need a team for everything in life. (James)

Participants recognized the importance of collaboration to attain success in conducting scientific research, and they found working together as a team to be a meaningful part of their participation in Sci-YAR.

Making work public. In addition to working collaboratively with their peers, all youth participants identified their participation in the school-wide research symposium, where they disseminated the results of their research to their families and the school community, as a meaningful component of Sci-YAR. Participants reported that the symposium was an opportunity for them to answer difficult questions from adults, causing them to feel like experts regarding their topics. George recounted his experience of being positioned as an expert by a university professor at the symposium:

> Researcher: And how did you feel as you were presenting at the symposium?
>
> George: Knowledgeable, I guess. Excited about like -- when people were asking me something and I actually knew the answer, I would be like, "Oh, I told an adult." A lot of people were surprised about [information we shared]. So many people were surprised. I don't know if I -- I think I told [new information] to your professor.
>
> Researcher: Yeah, I think so.
>
> George: He said he was impressed.

For participants, the chance to share information they had learned with knowledgeable adults was a powerful experience that put them more directly in the role of scientific thinkers and doers. They had the opportunity to act as experts on their research topic and impress those who they considered to be of higher intellectual status (such as a professor)—a challenge that helped them recognize and reflect on the knowledge and skills they had gained throughout the process of conducting their own research. In addition, taking on the role of information givers made the symposium a fun part of the research process for participants. They found it enjoyable when adult audience members showed interest in their topic and the research they conducted:

> Cameron: I think [the symposium] was pretty fun, actually. Because a lot of the parents actually enjoyed our [project], so they were asking us a bunch of

> questions, and we knew a lot about [the topic], so I actually enjoyed this part of [Sci-YAR] because it made us look really smart, like even when they asked us a bunch of questions, we would already know what's going on. So it wasn't hard to answer back to it.
>
> Researcher: That's good. And you felt like people were engaged, like they were interested in what you were presenting and what you had to say?
>
> Cameron: Yeah. I remember a few of the parents would bring people over and tell them, "Watch this," and [have them watch the video we made of the chemical reaction and] the explosion, and they were like, "I never knew that could happen from household chemicals." So I thought it was pretty fun….That was probably the best part.

Cameron enjoyed the fact that his group could answer difficult questions from adults and capture their attention and interest at the symposium with videos they had made during their research on household chemicals and chemical reactions. These videos were a source of pride for Cameron and his group, as they were able to draw audience members to their project, often resulting in large crowds around their display board, waiting to see the video of the group creating a chemical reaction that expanded and exploded a plastic water bottle. Being able to keep the attention of a crowd for a sustained period of time was fun for Cameron, and it helped him view his group's project as a success. Cameron's experience mirrored many participants' experiences presenting at the symposium, which were meaningful because they were positioned, not as novice students, but as knowledgeable experts who had a voice in teaching adults about science.

The positive interactions occurring during the symposium made it an enjoyable school experience for participants, in contrast to other passive learning experiences, such as lectures, where they claimed they would "sleep and be bored" (Aaron). Overall, the public sharing facilitated these positive interactions between youth and others—both their peers and adults—and was recognized as a meaningful part of the Sci-YAR experience.

Youth Autonomy to Promote Relevance

Youth participants also reported the autonomy component of Sci-YAR as meaningful since it allowed them to make their projects personally relevant. This indicates that participants found *conducting research that is youth-generated and youth-led* and *participating in relevant practices of science through action research* as other meaningful key features of Sci-YAR. Participants recognized that they had the primary responsibility for decision-making as they designed and conducted their own research. All youth participants found some aspect of this autonomy meaningful, as they felt increased ownership over their science learning. While participants discussed exercising autonomy in a variety of ways within Sci-YAR, most referenced selecting their own topic to research as an essential way for them to exercise their autonomy. Participants who reported valuing this control over choosing their research topic all selected topics connected to their own lives, thereby making their research relevant and personally meaningful. For example, several participants chose topics that directly related to problems or settings they encountered in their everyday lives. James described how his group came up with the idea of studying the effects of household chemicals on people and the environment, deciding to make this the focus of their research:

> Everyone thought [researching household chemicals] was a good idea because we are in our houses pretty much 24/7. And the fact that it would be better to know more [about] places you live in [and to] have more knowledge of where you actually are than where you could be, or the odds aren't so high where you're going to be. Because…you know you're going to be at home most of your life.
>
> And we [decided] that it'd be better to have better knowledge on that topic.

Participants saw the importance of selecting topics related to their surroundings, in that studying an issue of local significance was more likely to help them in the future, than if they studied something "the odds aren't so high" they would encounter in their lives. Having control over selecting their topics helped these participants conduct research that would practically help them navigate the settings of their daily lives.

Some participants selected topics to research based on an interest in investigating a particular practice they thought would help them meet a practical goal related to their lives outside of school. For example, Aaron had decided before the Sci-YAR curriculum began that he wanted to improve his weightlifting practice and become more muscular, and so he saw conducting research as a chance to help him reach both this personal goal and his academic goals. He saw his decision to study muscle growth as a good, practical use of his time: "I'm actually really happy about this project. Because I always try to get my friends to work out with me. Now I get to work out and I get a grade for it" (Aaron). Aaron was able to use his research to achieve multiple goals, which included a) making time to lift weights and regulating his protein intake to increase his muscle mass, b) convincing his friends in the group to be a part of this endeavor and workout with him, and c) using his time wisely by overlapping his physical goal with his schoolwork, so that he could do what he enjoyed and still “get a grade for it.” Participants who exercised their autonomy by selecting topics that were relevant to their own lives found conducting their Sci-YAR research to be meaningful because they could study problems and issues connected to their own lives, use their time wisely to meet multiple life goals, as well as engage in practices they personally enjoyed. Participants who reported selecting their own research topics as a particularly compelling component of Sci-YAR spoke about being more interested in their research and more motivated to complete it, since it was deeply connected to their interests, experiences, and future goals.

Engaging in Reflection

Participants identified reflection as significant by describing their enjoyment while participating in self-documentation, a particular concrete process that promoted reflection in Sci-YAR. This indicates that *engaging in extensive personal reflection*, another key feature of Sci-YAR, was a meaningful component of the curriculum for participants. While they identified various reflective elements of the curriculum as beneficial, such as engaging in peer and self-assessments to reflect on what their group members and they themselves had contributed to the research process, most participants spoke about engaging in self-documentation as the primary facilitator of reflective thinking in Sci-YAR.

Reflection to promote identity work. Youth’s self-documentation occurred throughout the Sci-YAR curriculum in a variety of ways. In class, youth were introduced to the practice of self-documentation, where one represents oneself and one’s experiences through media such as photography, video, or art. Periodically, youth were required to engage in different forms of self-documentation, modeled by their teachers in class. For instance, one structured self-documentation activity participants identified as meaningful was creating “picture frames” to represent themselves. This entailed youth either bringing photographs into class or drawing pictures that they felt represented themselves in some way. They then wrote four statements to create a border along each edge of the photograph/picture and “frame” it with their analysis of how their personal expertise might aid them in conducting their research. Youth wrote statements indicating: a) what object or action was depicted in the photograph/picture, and why they selected to photograph/draw that in particular; b) what the photograph/picture represented about them, c) what skill(s) they had related to the photograph/picture, and d) how they could use those skills as they conducted their research (see Figure 1 for an example of a “picture frame” created by a student during the Sci-YAR curriculum.)

Participants reported enjoying this form of self-documentation because it gave them an opportunity to share personal information about themselves in the science classroom. Aaron, who sketched out drawings related to his expertise in mechanics and fixing cars said, “I liked [making the picture frames], because everyone likes saying stuff about themselves. I like doing that. I [also] like drawing cars and motorcycles, so I just threw that in there too.” Participants used this form of self-documentation as an opportunity to reflect on their past and present experiences and how the activities they enjoy might be useful to them in science class. For example, Aaron saw his skills as a mechanic—including diagnosing and fixing problems with cars and motorcycles—as

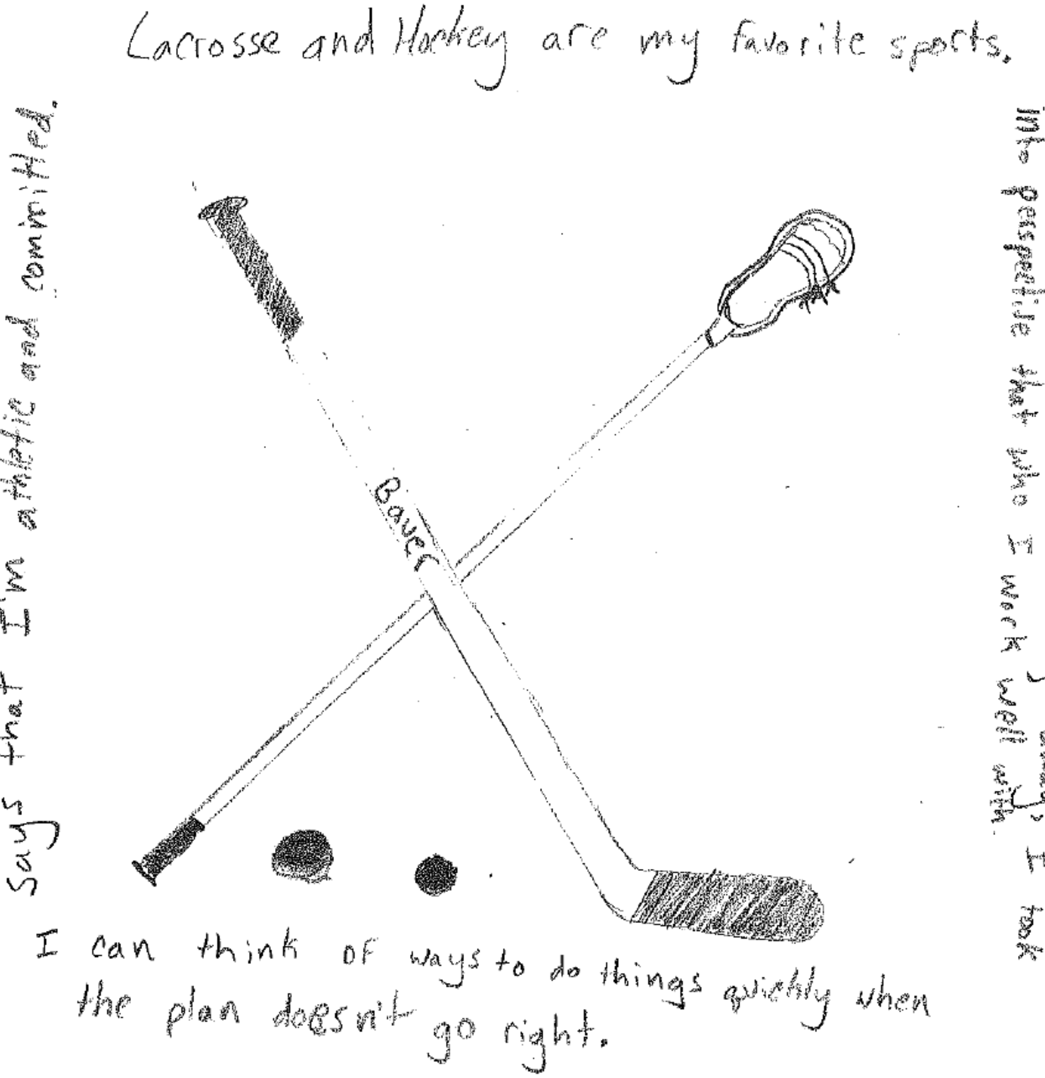

Figure 1. A "picture frame" created by a participant during the Sci-YAR curriculum as part of his self-documentation.

useful to his research because, “When something goes wrong [in my research] and things don’t work out [the way I planned], I can fix it.” These structured self-documentation experiences allowed youth opportunities to recognize and emphasize aspects of their identity—such as being “mechanically advanced” (Aaron)—while reflecting on how these skills and qualities might be beneficial to their participation in scientific research. Consequently, engaging in this form of reflection positioned youth as adept persons whose expertise could aid them in conducting scientific research, helping many participants to build a stronger sense of themselves as scientific thinkers and doers.

Reflection to improve practice. In addition to the structured self-documentation activities done in class, youth also selected a medium of choice to document themselves and their research process throughout the Sci-YAR curriculum. Many youth chose to take photos and videos (often using their smart phones) to document their personal experiences and their group’s progress throughout their research. Several youth participants described how they were able to use their self-documentation videos to record, reflect on, improve, and share both their practices as researchers and their development of scientific understandings. For example, James and Cameron’s group, studying household chemicals and chemical reactions, videoed themselves conducting pH tests of various household chemicals and demonstrating basic chemical reactions, as well as discussing what they observed, how the reactions they saw could be explained scientifically, and how household chemicals might impact both people’s health and the surrounding environment. The group enjoyed using videos as a way to keep a record of their research including the procedures they used and how they were thinking about the data they were collecting. James said that the video, “helps us reflect on everything that we did [for our testing], and it helps us hit all the key points that happened during the experiment.” Videoing themselves during their research also helped these participants later reflect on the effectiveness of their methods. According to James, “when we failed the first time or the second time [we conducted our experiment], we could see where we messed up on it.” Because youth found documenting themselves through video to be meaningful, they made time after their various tests to film group discussions regarding what they had done and the data they collected, which also helped create a context in which youth could collaboratively construct scientific explanations.

This group continuously revisited their videos throughout the research process, which helped the participants recognize what they were learning about household chemicals and chemical reactions throughout their research. Additionally, this group used their videos as a tool to help prepare them to share their learning with an audience at the research symposium. Cameron described how they used their self-documentation videos:

> Yeah, [the videos were helpful] because we had to look back at all of [them] and see like, “Okay, so if [the audience] ask[s] us any questions [about] our [display] board, what do we actually do?” So even that video [of us making a chemical reaction], looking back at it—I still have it on my phone—but looking back at it just helped me explain [our project] better. Like from hearing [us talk] about the day that we did [the testing], instead of trying to remember what we actually did, was easier. So it helped.

Reviewing their self-documentation videos helped Cameron's group better explain to an audience the procedures they had used and the scientific explanations behind what they did, aiding them in taking on the role of expert at the symposium, which was described earlier as another meaningful component of Sci-YAR.

Using the videos of their preliminary tests in class also spurred this group to video themselves outside of school as they designed their own tests (under the supervision of their parents) to create chemical reactions with various household items. The group videoed both successful and unsuccessful attempts to create a chemical reaction that had become popular for youth in their neighborhood to attempt, video, and post on YouTube, in which hydrochloric acid (toilet bowl cleaner) and aluminum are combined in a plastic water bottle, producing hydrogen gas and causing the bottle to explode. Unsuccessful attempts resulted in conversations about variables that might have affected the outcome, such as the thickness of the plastic bottle used. Participants also discussed safety concerns involved, telling viewers about precautions that should be taken when conducting this test to ensure one's safety. Creating their own videos of this experience helped Cameron and James reflect on the potential dangers of doing something like copying a YouTube video of an explosion without understanding the science behind it:

> After seeing that explosion, like how loud it is when you're actually there, it [was] a lot louder than in the [YouTube] video….So I kind of like [act] more careful, I guess, [with] what I'm actually doing. (Cameron)

Although these videos made outside of school were less focused on the scientific explanations behind the chemical reactions they were producing, these participants used their self-documentation as an opportunity to reflect on the effectiveness of their procedures and the potential implications for conducting this experiment if done in unsafe ways. Seeing others' videos on YouTube was not sufficient for these youth to internalize the hazards involved with mixing chemicals together to create an exciting effect, like an explosion. Instead, it took personally experiencing, documenting, and reflecting on these chemical reactions for participants to come to the realization that they must take care when handling chemicals or when trying to replicate something they see online. For these participants, videoing themselves as a form of self-documentation helped them reflect on their growth as researchers by more closely examining and evaluating their methods, prompting them to analyze, discuss, and reflect upon their results, as well as consider the implications of their findings for their own lives.

While the participants described here used their self-documentation to promote reflection, as well as shared it extensively at the research symposium, it is important to note that other participants who reported enjoying the self-documentation used it sparingly within the project. Some participants liked creating photos and videos of their out-of-school expertise or their research process, but did not revisit or reflect on the documentation to guide their research, nor did they share it with an audience. While this might have occurred for a variety of reasons, several participants reported problems with sharing their self-documentation at the symposium because they did not know how to incorporate it into the discussion of their topic, and they questioned whether the audience would understand its purpose and relevance to the project:

> I don't know if anyone even knew what [the self-documentation] was for, though, because they were probably wondering what the pictures [we drew to represent ourselves] were for. They probably were like, "Oh, well, this is probably not right because it's nothing." [They see] there's a picture of a motorcycle, a lacrosse stick, and a computer [objects they had drawn to represent themselves]. They're probably like, "What does this have to do with [our topic of] muscle growth?" (Aaron)

Participants identified engaging in self-documentation as enjoyable, and they spoke of it as an important way to help people better understand who they were and why they were studying their particular topics. However, ultimately many participants still had difficulty explaining the role of their self-documentation to others outside of the project. As a result, not many instances of self-documentation were shared by youth during the culminating research symposium.

Youth's Identity Work in Service of Critical Science Agency

While Sci-YAR's collaborative, autonomous, and reflective features have been discussed thus far as meaningful to youth participants, these, along with Sci-YAR's other key features—*using science as a way of knowing and taking action*, and *participating in relevant practices of science through action research*—also influenced youth's identity work in particular ways. Using socio-cultural theory, positioning theory, and constructivist theory as lenses through which to view identity work, what follows are findings related to how the Sci-YAR curriculum both enabled and constrained youth's identity work in service of critical science agency.

Youth's Shifting Views of Science

Sci-YAR's emphasis on science as a way of knowing and taking action, and its promotion of relevant practices of science through action research, enabled youth participants to shift their perceptions of science from being an abstract construct consisting of isolated topics to being a set of specific practices that they employed in their own lives. When participants were initially asked to define science, the majority listed isolated topics they felt somehow related to science, using words such as "Earth," "gravity," "muscles," "protein," "body systems," and "friction" (Dan, George, Aaron, James) in their definitions. These descriptions were often quite abstract and vague, indicating many participants' uncertainty of what science is and how it might be concretely manifested or applied in their own lives. For example, Dan spoke of his initial idea of science:

> [Science] is basically like what the Earth is basically. Gravity is from [the] center of the Earth. It pulls you down. [Science is] in our minds that we learned how to move. So it's science. We taught-- in science we taught ourselves how to move by the people growing from like monkeys and we learn more things over the year.

Dan's initial definition of science, like most participants', was a scattered and confusing list of terms and concepts he had learned in classes, and therefore associated with science. Absent from many participants' initial definitions of science were references to practices or ways of thinking, indicating that participants did not view science was a way of knowing or taking action.

Sci-YAR’s key features were designed to address this issue of youth’s vague understanding of science and often disconnection from it as an abstract idea unrelated to their lives. First, in order to emphasize science as a way of knowing and taking action, explicit class instruction and discussion focused on what science is and what role it might play in youth’s lives. Many participants, such as Dan, referenced examples of the explicit instruction provided on how science was related to their lives, indicating its importance in the process of developing these connections:

> Dan: [In] science class we've been going over different [ideas about science] and they all come back to the certain, specific thing. It's just life basically.
>
> Researcher: Did your teacher try and help you see that too? Like make connections, or give you real world examples or stuff like that that helped?
>
> Dan: Yeah. Like Ms. McAteer showed Michael Jordan slam dunking, and she said, “Name this many things that has to do with science.” And we named [things] like gravity, how he jumps up, how he flies in the sky.

In addition to these experiences where youth were asked to explicitly point out where science was at work in their lives or interests, they engaged in extensive personal reflection which was also intended to shift their views of science. Youth were asked to write and talk about their definitions of science, explain them to others, as well as reflect upon them and revise them over time as they were exposed to new ideas regarding what science could entail. Participants specifically mentioned these reflective components of Sci-YAR as helping them develop new realizations about science’s connectedness to their lives:

> Well, I actually like Ms. McAteer's class because she asks us about how we use science in everyday life in our journals and stuff. And once we started doing those, I kind of started realizing, "Wow, I actually use science all the time." Other than that, I never thought I really used science. (Aaron)

Certain participants like Aaron saw their reflection journals as prompting them to think about the utility of science, enabling them to better connect science with their own lives.

Explicitly thinking about what science is and continuously reflecting on the connections between science and their own lives helped participants begin to see science as something more connected or useful to their lives; however, before conducting their own research, participants still generated rather vague definitions of science, saying things like it was "everything" or "everywhere" (George). For many participants, it took participating in relevant practices of science through action research to finally move away from vague, abstract perceptions of science and towards seeing science as a tool and a context to take action in their everyday lives.

Throughout the research process, all youth participants reported that they enjoyed actively investigating their chosen topics, as they found it more engaging to test out their ideas, rather than just look up information in books or on the Internet. Beyond the enjoyment and interest it generated for participants, though, conducting active and relevant research also helped them begin to develop more concrete understandings of science as a way of approaching questions or problems, thinking through them, and taking action to better understand the world around them. As participants progressed through the curriculum and, with their groups, actually posed their own research questions, collected and analyzed their data, and formulated their findings, they began to include the thinking and actions they engaged in as part of their definitions of science. After participating in Sci-YAR, not only did participants articulate more clearly the thinking and actions involved in science, but they were also able to connect them to thinking and actions they engaged in during their daily lives. For example, instead of simply saying that science is “everywhere”, George elaborated on this definition:

> Well, some of [science] is everyday tasks that could also be put into science, like working with others, listening to other points of view, reflecting on work [you’ve done], asking questions. I do that a lot.

Other ways of thinking and actions participants described as part of science included, but were not limited to, “consider[ing] different perspective,” “debating,” “forming a hypothesis,” “observing,” “interviewing sources…to verify statements,” “collecting data,” “recording data,” “figuring out answers to questions,” “sharing research,” “explain[ing] what you did,” and “reflecting…and changing….what you actually think of the whole experiment” (Cameron, Aaron, James, George, Robert, Wasalu). Participants also reported that engaging in these practices was a way to “figure stuff out” (Robert), indicating that these were tools they could use to better understand the world around them. This shows that participants began to view science not just as a tool, but also as a variety of contexts in which they could take action to make sense of issues in their own lives.

Youth Viewing Themselves as Scientific Thinkers and Doers

Youth participants shifting their views of science from a compilation of isolated, abstract concepts to a set of tools and contexts to take action were a significant part of their identity work in Sci-YAR, as it influenced participants' views of themselves in relationship to science. Designing and conducting their own research on a topic of interest and engaging in consistent reflection throughout the process further helped participants see how they used scientific thinking and skills in their everyday lives, which brought them to a greater level of self-awareness regarding their abilities to be scientific thinkers and doers.

Identity work through social positioning. While conducting their research, participants spoke of the parallels they saw between themselves and scientists, indicating that they were engaging in identity work specific to science. Participants also shifted their perceptions of themselves toward being scientific thinkers and doers. Taking on the role of scientists aided participants in recognizing connections between what they were doing in their own research and what scientists do in their work:

> Everyone [doing Sci-YAR] has the qualities of a scientist…Because [both scientists and we are] doing the same kind of work. Well, that's in my opinion. But, we're all researching, which scientists do. We're all experimenting, which scientists do. Some of us are interviewing, which scientists do. So, it's like tying [us and scientists] together. (George)

The connections participants made between their research and practices of professional scientists were initiated and reinforced through the context of the Sci-YAR curriculum; as youth conducted their research, the teachers who facilitated this work promoted a variety of practices that youth might not have before considered scientific, such as interviewing and reflecting, and they positioned youth and their work as professional and scientific. As discussed earlier, a significant experience in Sci-YAR that involved the explicit positioning of youth as scientific thinkers and doers was the culminating research symposium, where youth shared their research with the school community, including their peers, other teachers, and their families. This experience created an authentic context in which participants positioned themselves as scientific experts regarding their own research topic, which enabled them to view themselves as scientific thinkers and doers. When sharing their research with an authentic audience, participants described the experience as making them feel "like we know everything about the topic [we researched]" (Dan). As discussed earlier, participants enjoyed being able to answer difficult questions from those they saw as having higher intellectual status, such as adults. Participants further described experiences where their research was challenged by adult audience members, requiring them to defend the work they had done and the findings they had generated:

> I wouldn't say [at the research symposium] I was pressured per se. But I felt challenged. But being challenged is never a bad thing…. [like when] people challenge you with intelligence or challenge you with what their opinion is. Honestly, I love debates…. [because] these people [at the symposium] make their point and they go through a lot to [question your work], but in the end it's like you achieved that goal [of defending what you did]. So when we were talking to your

> professor, and….to have him ask us questions and to have us shooting [ideas] back and forth and back and forth, to finally…nail it, and then impress him, it seems like, "Wow, that was good." (James)

Defending their research successfully to knowledgeable others was a challenging endeavor that positioned youth in ways that enabled their identity work; they were pushed to display their scientific knowledge, thinking, and skills so that their findings would be accepted by others in the community. Taking on scientific ways of thinking and talking in the symposium, successfully defending their research, and impressing adult audience members reinforced participants' perceptions of themselves as capable scientific thinkers and doers.

Identity work through cognitive dissonance. Participants' identity work toward becoming scientific thinkers and doers did not occur only as they were socially positioned in venues, such as the research symposium. As they participated in self-documentation and other reflective venues, several participants engaged in identity work as they tried to make sense of how they might use the same type of scientific thinking and practices employed in their Sci-YAR research in their everyday lives. Developing views of themselves that included embodying the qualities of scientists was both a social and an individual process that involved a significant amount of time and mental discomfort for youth. Aaron's case is a salient example of how some participants struggled in modifying their existing schemas of what scientific practices entailed to include versions of those practices they employed in their everyday lives. For example, Aaron spoke about trying to make sense of ways he might be a scientific thinker and doer by collecting data in his own life:

> I do think science is more useful. [But], the one thing I don't see with it… In my everyday life, I'm not going to be collecting data and stuff. Maybe I am, but it's like on home projects that I'm doing [like fixing a car], where I'm collecting data. I look up more information on [the] car or something. That is useful [for specific projects], but on my every day, just normal stuff that I do, I'm using science, but I'm not really thinking [about] it….I'm using science, but I'm not aware that I'm using it. Maybe I'm just not thinking about it.

Participants attempted to work through their disequilibrium and to establish equilibrium in their thinking about scientific practices and how they might be connected to other parts of their lives. This process is evidenced here in Aaron's description of experiencing equilibration regarding ways he collected data in his life outside of the science classroom. To make sense of how this scientific practice of collecting data might fit into his existing schema of everyday activities, Aaron created two levels of real life scientific practices; the more formal, such as when he collected data by gathering information to diagnose and fix a mechanical problem in his car, and the less formal, which were subconscious ways that Aaron gathered information on a daily basis, like casually observing his surroundings and making decisions based on this information. Engaging in this type of thinking helped Aaron to make sense of how scientific practices could fit into every aspect of his life. Aaron engaged in identity work related to being a scientific thinker and doer and did not need to significantly change his personality, attributes, or activities he was involved in; he only needed to shift his thinking of what might constitute scientific practices employed in everyday life.

The extended time spent engaging in scientific practices and reflecting on these practices allowed participants to assimilate these ways of doing and thinking into their perceptions of self. Once participants began to articulate and work through their disequilibrium regarding how they embodied scientific thinking and practices in their own lives, they were able to generate realizations about how they had always used scientific thinking and skills in their lives, but did not become aware of it until engaging in the Sci-YAR curriculum:

> [Doing science used to be] second nature [to me] and now [I] think about it, thinking about doing all that stuff [scientific practices] and how to put it in words….Yeah, because [doing science] was second nature, so it just came natural to me. And then thinking about [doing science in my life], it's like whoa! This threw me off a little bit. I'm not used to this. (Aaron)

Here, Aaron reiterated the disequilibrium he experienced when he was asked to think about how he might be doing science in his own life, saying it "threw him off" at first. While science had previously been "second nature" because it had been a part of his life without his awareness, he described how working through his disequilibrium brought him to a new level of consciousness regarding his everyday scientific thinking and practices. Because of the reflective components of Sci-YAR, Aaron had to "put it in words" by dialoging with himself about ways science was a part of his life and then describing this thinking to others. Youth actively constructing realizations—both with themselves and with others—about the science they were engaging in as a part of their everyday lives was a significant way in which several participants began to identify themselves as scientific thinkers and doers, both in and out of the science classroom.

Sci-YAR Constraining Science-Related Identity Work

While participating in Sci-YAR did facilitate several participants in shifting their views of science and themselves in relationship to science, for some, Sci-YAR constrained this type of science-related identity work. Sci-YAR constrained youth in viewing science as a tool and a context in which to take action and constrained youth's views of themselves as scientific thinkers and doers, particularly in cases where participants did not select a research topic that was connected to their lives in a meaningful way. For example, Cameron's case highlights a youth whose identity work was constrained by Sci-YAR, resulting in his unchanging perceptions of science and of himself in relationship to science.

When Cameron spoke of how he chose his research topic of household chemicals, he indicated that a major factor influencing his decision was to work in a group with his friends, rather than because of his passion for the topic. From the beginning of the curriculum, Cameron admitted that this was "a bad idea," saying, "Well, I kind of wish we could go back [and choose our topics again] because I probably would have picked a different topic." Although Cameron was somewhat interested in the potential to create chemical reactions with household chemicals, this interest was not connected to his life in a meaningful way; rather, it was a superficial interest of seeing something exciting, such as an explosion. Cameron recognized early on in the process that selecting a topic based on a fleeting interest was a challenge to research because it did not have deeper meaningful connections to his personal experiences or his everyday ways of thinking and doing. This caused him to speak repeatedly about his confusion over what his group could do to research their topic of household chemicals, what research questions they should investigate, and how they might actively test out their ideas. Cameron described the discomfort he felt when dealing with the uncertainty of not knowing in which direction to take the research:

> Researcher: So do you feel like you're invested in the topic [of household chemicals], or are you excited about it, or [not]?
>
> Cameron: At some points I am [excited], but other points I'm like, "Uh, what do I write about this?"
>
> Researcher: Okay. You just feel like you need some deeper --
>
> Cameron: Yeah, thoughts on it…..Yeah, I'm not sure what we're going to do [for our research] actually. We started recording videos [for our self-documentation], but nothing [else] big.
>
> Researcher: Okay. How do you feel about that uncertainty?
>
> Cameron: Not good….Just because I don't know a lot about the topic….It's just [that] other [topics] are easy to talk about. Like erosion, that would be easier to talk about than chemical engineering because erosion happens every day, like in the Grand Canyon. So that'd just be easy to talk about.

Cameron found conducting his research daunting in large part because he did not have a lot of background knowledge or experience regarding his topic. He attributed his wavering interest in the topic to the fact that he needed some "deeper thoughts" on it to conduct meaningful research. In the end, Cameron did not change his perspective on his topic, and when asked if he would consider following up on his research in the future in any way, he said with certainty that his research did not generate any new questions for him, and he would definitely not continue to investigate this topic in the future.

Cameron's primary focus throughout the Sci-YAR curriculum was his low level of interest in his research topic and his consistent concerns with the feasibility of testing out the group's ideas. Dealing with this mental discomfort prevented him from confronting, examining, and shifting his perceptions of science or of himself in relationship to science. When it came to his perceptions of science, Cameron gave descriptions consisting of isolated concepts typically associated with stereotypical perceptions of science and scientists:

> When I think of scientific [things], I think of chemicals or any type of element. I don't think of other things like…football like how [sports involve] velocity and stuff. I don't really think of that. I think of chemicals and microscopes and all that.

Although Cameron had been encouraged in class to see science in his everyday activities, he did not accommodate his schema of science to include activities like football, even though they involved scientific concepts. Instead he kept his everyday activities, like athletics, in a schema separate from science. Cameron maintained equilibrium in his perceptions of science, holding firm to the images of "chemicals and microscopes". This was further reinforced when he chose a research topic that involved household chemicals, creating little cognitive dissonance and reinforcing the idea that science involves working with particular materials, such as chemicals. Cameron maintained his perception of science over the course of his research, recognizing these images as stereotypical, but choosing to retain them regardless:

> When I think of science, I just think of stereotypes, which is being in a lab [and] doing experiments. That's what I think when I think of science, so it just hasn't changed.

To accompany his stereotypical images of science, he described scientists as “old men in lab coats”. Cameron consistently distanced himself from this perception of a scientist, saying that he was unable to identify qualities he might have in common with scientists or ways he might use scientific thinking or skills in his own life:

> I can't really think of anything [I have in common with scientists]. I know that there are some [qualities] that I could think of if I kept thinking about it, but like, right off the top of my head, I would not know.

When asked questions related to seeing himself as a scientific thinker or doer, Cameron consistently gave similar responses, which could be attributed to his lack of a meaningful connection to his research and possibly wanting to avoid any further mental discomfort. Keeping his schemas of “science” and practices in his everyday life, such as “athletics” separate, Cameron did not have to deal with the dissonance in making sense of how these schemas might overlap or be related in some way. This allowed him to continue to identify as an athlete, and he did not have to make sense of also seeing himself as a scientific thinker/doer. Cameron described how it was not applicable to bring his strengths, such as his athleticism, into conducting his research, indicating his separation of science and athletics and his choice to identify himself as an athlete, rather than a scientific thinker/doer:

> Researcher: Do you feel like, while you were doing the [research] project, were you able to be yourself? Like be all of these things [you described about yourself] and bring them into the project?
>
> Cameron: Not really. Like, I don't know what being athletic has to do with any of the science. I don't think you have to be athletic to do experiments or anything, so I don't think this would [help with science]….I don't think that's a big factor.

Cameron saw his qualities as an athlete and his experiences playing sports as unrelated to his participation in science, and he did not see himself drawing on ways of thinking or doing in his everyday life to help him conduct his own scientific research. In this way, Sci-YAR constrained Cameron's identity work in service of critical science agency; the structure of the curriculum allowed him the autonomy to select a topic that would not facilitate disequilibrium in his thinking about science and his life.

In addition, Sci-YAR's reflective components did not facilitate Cameron in accommodating his existing schema and achieving a deeper understanding of science and himself. While he did recount some positive experiences working with his friends during Sci-YAR, learning some new things about his topic when reflecting through self-documentation, and having pride in his work while presenting it at the research symposium, Sci-YAR did not significantly shift Cameron's perceptions of science towards a way of knowing and taking action, nor did he see himself as scientific thinker and doer as a result of conducting his own research.

Science as Action for Personal and Social Transformation

A final key element of critical science agency involves youth taking action through their practices of science to bring about personal and social transformation. Sci-YAR both enabled and constrained participants in taking action through their research to positively impact their lives and the lives of others in their communities. Sci-YAR's most significant constraint on participants' action was the nature of it being a required curriculum operating within the context of a school, which carried with it youth's existing perceptions, expectations, and understanding of what it means to engage in school-related activities.

Sci-YAR constraining action through science. Sci-YAR's stance as a required, school-based curriculum impacted participants' perceptions of its purpose. Although the explicit messages sent by the teachers of the Sci-YAR curriculum emphasized that youth were conducting their own research to better themselves and their community, it was difficult for many participants to put aside their existing perceptions of the purpose of schooling. Several participants spoke of their Sci-YAR research, not as something they were doing to promote their growth or benefit their community, but rather as work to be completed in order to get a grade.

Several of the participants described their past and current experiences in school as negative, in the sense that they were often inactive and bored with what they were learning in their classes. They described little interaction between the teachers and the students, as the teachers usually lectured to students who acted as passive recipients of information or as teachers gave the students independent work to keep them silently occupied for the class period. Enacting Sci-YAR within a school climate where youth viewed schooling as something involving inaction constrained participants in seeing Sci-YAR as a venue in which they could take action through their practices of science. When asked throughout the curriculum whether participants saw evidence of any personal transformation as a result of conducting their own research, they often responded by calling their experience just another school project:

> I haven't really seen a change [in myself], really. [Sci-YAR] just feels like a regular project that we do. I know I changed what I know on the subject [of our research] basically, but not really my personality or anything like that. (Dan)

Participants described learning more about the topic they were researching, but they did not see a "regular" school project influencing them as people. Even when participants reported enjoying some of the various activities involved in conducting their own research, they still referred to it as unpleasant work that had to be completed in order to get a good grade:

> I didn't mind [doing the Sci-YAR research], but I didn't enjoy it. I never really -- I don't think a lot of people enjoy -- I might be wrong, but I don't think a lot of people would enjoy doing all this work or anything. I understand what it's all about, but, for me, it was kind of just like, "Okay. I got to get a good grade in this class. Let's get this done and get through it." (Cameron)

Certain participants were consistent in their messages about schooling as work that not "a lot of people would enjoy," but something they persevered through in order to reach their goal of getting a good grade. Getting an A on the project and in the class often times drove the decision-making of youth in their research. For example, some participants selected their research topic and group based, not on issues that were deeply connected to their lives and communities, but instead on what topic and group they thought might help them get an A on the research project, justifying their decision-making by saying, "I'd do anything to get a [good] grade" (Robert).

Several participants also reported that they did not think conducting their Sci-YAR research would help them have a positive impact on their community in any way. These participants attributed the lack of impact they could have on the community to the fact that they were kids who would not be taken seriously by adult community members:

> I don't really know [if our research will have an impact] because most kids don't make an impact until they're much older because some people don't really listen to kids that much, even though kids mostly know what to do. (Robert)

Being placed in roles at the symposium where they actively conveyed their expertise on a topic and instructed more knowledgeable adults was not always effective in instilling a sense of agency in participants. Even when they received positive feedback from their adult audience members who described how youth's research impacted their thinking, some participants were still skeptical as to whether the adults were sincere in their comments, and whether their research would really positively impact people's lives:

> A lot of people [at the symposium] said they thought about [our findings on household chemicals]. They're like, “Huh, that's very interesting. I'm going to have to tighten my caps [on bottles of chemicals] and stuff,” but I honestly don't think they're going to go back [home] and just remember all this [information]. They're probably just going to be like, “Whatever, just throw [the chemicals] in there.” (Cameron)

Sci-YAR being enacted within the context of a school constrained youth’s identity work in service of critical science agency, as participants ascribed meaning to their work in ways that aligned with their existing perceptions of school. Several participants were clear that their research was simply work they were doing to receive a grade. This gave their ways of knowing and doing science through Sci-YAR less personal meaning, which caused participants to report that Sci-YAR had not been a transformative experience for them, nor, something that spurred them into taking positive action. Also, because some participants did not see their practices of science as different from schoolwork, they did not acknowledge the potential power it might have to influence their community. Participants who primarily viewed Sci-YAR as required schoolwork clung to their preconceptions that what they did in school could not positively impact their lives and that their ideas did not matter to adults, and therefore could not have an impact on the surrounding community or world.

Sci-YAR enabling action through science. While several participants were constrained by the school-based nature of the Sci-YAR curriculum, participants who selected topics meaningfully connected to their own lives began to see their research as more than just a school project, which also enabled them in seeing science a way to take action in their own lives. After engaging in the research process for several months, multiple participants began to describe how Sci-YAR was distinct from other school-based assignments:

George: The research we're going through and the thinking we're using- I don't know how to explain it but, you could feel that it's different and it's not like, "Oh let's do this research [ho hum voice]." When we come into class it's not, "Let's do this research project." It's, "Ok, we've got science to do."

Researcher: Okay. Are you trying to say that [Sci-YAR's] not like work you do for every other class? It's different?

George: [It] depends kind of. Because in speech [class], we have to do research, in geography [class] we have to do research, but in science you have to experiment and you have to do other stuff too, other than just, "Here is your project, do it."

Researcher: Got it. So it's more than just directions. Here are the directions of the project, follow the directions.

George: Yeah pretty much, because for other classes I wouldn't go try and do stuff to figure out [the] reasoning behind [something]. I would do [research] for [the class] and I wouldn't go be like, "Oh, let me go try this." I would just say, "Okay." Where in science I would be like, "Oh let me go try this and see if it actually works."

George's description of what made Sci-YAR different from other research projects he had done in school represents the views that several participants developed through their participation in the curriculum. Rather than seeing their research as following directions and looking up required information that they would not think about or question, these youth saw science as allowing them to take action to figure out the reasoning behind a phenomenon by asking investigable questions and testing out their ideas. This shows that although the school-based nature of Sci-YAR did constrain some youth in taking action through science, others were able to make distinctions between doing science in their Sci-YAR research and doing other school-based assignments, enabling them to then take action through science.

Youth who saw a distinction between Sci-YAR and other school-based curricula also recognized science as a way to promote their own personal growth. A positive change several participants described in themselves was developing ways of scientific thinking that helped them critically examine relevant issues in their lives. For example, James saw his practices of science in Sci-YAR, not just as a way to gain more scientific knowledge on his research topic of household chemicals, but as a way to facilitate personal growth. James reported that he no longer took for granted his everyday experiences, but instead asked "How?" and "Why?" when experiencing phenomena. Discussed earlier was his group's attempts to recreate a chemical reaction with toilet bowl cleaner and aluminum foil that youth in his neighborhood commonly videoed and posted on YouTube. James talked about how through Sci-YAR, he began to think more deeply about what he was seeing in these videos:

> We felt that toilet cleaners [were] a big [common] household chemical….and then we thought, "Well, we've seen it on videos where kids will blow it up." But then we kind of wanted to know, well, kids blow it up, they just put [the toilet cleaner and the aluminum foil] in [the bottle], and they don't say anything about it. But we wanted to know why it did that. And like how it did that. So then, as we looked into it, we saw…what causes the reaction to actually happen.

Through conducting his research, James went from viewing this chemical reaction as simply something that creates a cool explosion, to questioning why and how it works the way it does, and then considering the implications for creating this reaction without being aware of what is actually happening on a scientific level.

Participants also reported beginning to see issues from other points of view as a significant aspect of personal growth. Dan, an athlete who had experienced a serious injury the year prior, discussed how his research on bodily injuries helped him better understand why athletes might deal differently with recovering from injuries, allowing him to consider experiences outside of his own. Dan described this personal change as he reflected on why one of his favorite basketball players, Derrick Rose, had not returned to play after suffering a torn ACL, even when doctors had cleared him to play:

> Dan: I see how people like -- Derrick Rose [make decisions]. I always thought if you're injured, you could [recover quickly]. I came back [from my injury] really fast because I actually worked hard and did everything the doctor said. I just didn't get why [Rose didn't come back because] he should have been ready in

> nine months or something like that. Like was he trying not to work hard? Did he want to come back? That's the question I was trying to find out.
>
> Researcher: And so did doing this [research] project help you understand that better?
>
> Dan: Yes, more like [how others are] mentally and stuff. Not everyone thinks like me and, you know, wants to go back [right away].

When Dan spoke of his growth in Sci-YAR, he described how he gained more scientific knowledge on how injuries occur and affect the body, as well as increased skills in conducting research; however, this was not what he saw as the most significant aspect of his learning. Instead, Dan described his most significant growth as gaining the ability to make sense of other people's perspectives and their actions. Before engaging in Sci-YAR, Dan could not understand why a great athlete like Derrick Rose would take more time than required to recover from his injury and return to playing basketball, especially since this decision was different from Dan's own experience recovering from an injury quickly and returning to athletics as soon as possible. Engaging in relevant practices of science by investigating this meaningful issue and reflecting extensively about how others might experience the world differently from himself enabled Dan's growth in seeing an issue from multiple viewpoints. Just as Dan spoke about better understanding perspectives outside of his own, other participants who conducted interviews with experts on their topics and surveyed class members about their experiences as part of their research described similar benefits of taking into account a variety of viewpoints and perspectives, recognizing this as a key way they grew during their participation in Sci-YAR.

Participants who studied personally meaningful topics also reported viewing science as another venue in which they could work toward and achieve personal goals. When beginning their research, many participants described themselves as goal-oriented, and they identified conducting their own research as a way they could be "achieving [their] goals through thick and thin" (James). Participants described setting and reaching a variety of personal goals within Sci-YAR, but Aaron is a salient example of a youth who used his practices of science in Sci-YAR to reach his goals. Because Aaron selected a research topic (muscle growth) that coincided with an existing personal goal—to become stronger and more muscular—he was able to use his research to learn more about science and to actively work on improving himself and his quality of life. Aaron described how he was unable to see progress in his goal before he began his research:

> Yeah, [I set my goal to become more muscular] after football [season]. I started working out more. But once I actually [starting researching it] -- after our [Sci-YAR] project started, [then] I was putting on more weight and stuff because [I was lifting] more weight and [gaining] more strength. So that's probably why I [chose my topic] at first because I really wasn't getting the results yet. But then I started really getting into [working out] because I had to [research] it for school. So I really got into it, and that's when I started improving.

For Aaron, participating in relevant practices of science by systematically examining his practice as a weightlifter had a positive impact on his life, as he ate healthier, was more thoughtful in designing and executing his workouts, and was able to reach a personal goal of being stronger and more muscular. Aaron acknowledged the difference between just going through the motions of working out and systematically gathering data on his practice by recording his protein intake and workout routines (including weight lifted, reps, and muscle groups worked), and then analyzing and reflecting on this data in order to adjust his workouts accordingly. Early on in his research, Aaron said he was unsure if collecting and recording data was “truly a scientific thing” and was unsure if it would be helpful in his practice as a weightlifter. After his experience in Sci-YAR, Aaron identified collecting data as a key part of science, and he reported that the systematic collection and analysis of data is something he would continue to use in the future to keep his workouts as effective as possible. Participants who chose a research topic that required them to systematically examine and improve a practice important to their lives saw their participation in science as a way to act in their lives in order to bring about personal transformation.

Participants also described using the scientific skills they developed in Sci-YAR as a way to address personal problems they were experiencing in their lives. For example, during James’ research, the school’s administration accused him of cheating in another class. James viewed himself as a good student and an honest person, so he was greatly troubled by this accusation, and he worried about the implications for his future college plans. While dealing with this personal problem somewhat detracted from his participation in his research, as he relied heavily on his group to generate their findings and put their display board together, James later described how he was using the scientific skills he had developed in Sci-YAR to address the cheating accusation:

> James: [Doing my own research helped me in] deciding what to do [and] reflecting on what actually happened. And then when it actually came down to it, truthfully, gathering information, to prove to them that I didn't [cheat]. And then, if that didn't [work], working through failure because things like [cheating] can stay with you forever [on your record], [affecting] college and everything like that. So what I had to do was just work through failure, I guess.
>
> Researcher: Yeah. I wouldn't have thought about that, but you were gathering information, trying to construct your own argument.
>
> James: [I had an argument in] a four-page paper [which stopped it from getting] any bigger….[Before Sci-YAR] I didn't even know what to do.
>
> Researcher: So [your research] did help you, the way you approached [this problem].
>
> James: Yes.

James worked through personal adversity by applying the scientific skills he had developed in his research to address his cheating accusations. This included reflecting on the nature of the problem and possible courses of action, making decisions about how to address the problem, and constructing an argument for his innocence using evidence to support his claims. James exemplifies how engaging in Sci-YAR can influence a youth's ability to take action through his practices of science in order to address and resolve an immediate problem in his life, where before this experience, he would not have known how to act.

While some participants questioned their ability to influence adults, and so did not see their Sci-YAR research as having any positive impact on the larger community, others did see their practices of science as a way to take action in order to benefit others. As part of their research, youth created tentative action plans to help them envision how they could use their research to benefit others besides themselves. Due to time constraints, youth were not given time as part of the curriculum to put these plans into action, which certainly constrained them in taking future action through their practices of science. However, many participants saw the opportunity to publically present their research at the symposium as a way to take action and have a positive impact on their school community, including both their peers and their families. These participants felt that sharing information they learned through their research at the symposium would potentially benefit those audience members, as they could learn from youth's findings and apply it to their own lives in the future. Because participants saw their topics—such as injuries, nutrition and food safety, and household chemicals—as being applicable to others' lives besides their own, they felt that they could inform the public about what they found, so those people could take action in their own lives. Participants described how their information might benefit others:

> Maybe [hearing about our research] helped [the audience members] out. So it would just give them [information], so that they won't be wasting their time

> [trying to figure out a problem]. They could just jump right in and get into [fixing the problem] and know the correct ways to do it. (Aaron)

Participants felt that sharing information from their research could help people if they encountered problems related to their topics. For example, some participants felt that sharing how student athletes cope with, recover from, and prevent injuries would help other athletes deal with related scenarios; or that teaching about proper food safety practices would prevent cross contamination of foods in others' kitchens; or that informing people about the nutrition content of different foods might help guide them in having healthier diets.

While participants did not connect their research to larger global issues or report that their research would have a broader impact outside of the school community, they recognized what they were doing as science and they saw the smaller-scale impact of their practices of science on others, which was meaningful to them:

> Science can be anything if you look into [an issue] hard enough. So that was my main goal to achieve [in doing my research]…to prove to people that just the littlest thing could affect you, or affect your family, or your house, or maybe even the world you live in today. (James)

For participants, bringing about social transformation through their practices of science did not mean having a large-scale impact. Instead, informing people in their community about how everyday issues impact their lives and helping their community be more informed when making day-to-day decisions was meaningful for participants and helped them feel like they affected positive change by conducting their own research in Sci-YAR.

Discussion

Youth participants' experiences in Sci-YAR were varied, as they found a multitude of components meaningful and engaged in identity work in unique ways. This study aimed to examine how participants made sense of these experiences, in order to better understand how school curricula, like Sci-YAR, might promote and hinder youth's identity work in service of critical science agency. Findings of previous studies point to the importance of youth's development of critical science agency by giving them opportunities to critically analyze their surroundings, and then use those analyses to take action that positively benefits theirs and others' lives (Basu, 2008a; Basu, 2008b; Mallya et al., 2012). The findings of this study suggest that Sci-YAR presents youth just such opportunities; however, the findings also highlight the power that youth have to decide whether or not they will acknowledge, accept, and capitalize on these opportunities. These findings support Elemsky and Tobin's (2005) view that identity work is a "dialectic interplay" (p. 817) between the individual and their context. By taking a deeper look at how youth exercised their individual autonomy through their identity work while engaging in Sci-YAR, one can see how Sci-YAR's key features were both effective and ineffective in providing a context that encouraged youth to connect science to their lives in personally meaningful ways.

Youth's autonomy to initiate the design and execution of their own research, as well as take on the primary decision-making responsibilities in the curriculum, was an essential factor intended to promote relevance and youth's agency in the science classroom. The autonomy youth had in Sci-YAR emphasized the idea that outcomes for youth's understanding and their development of agency can never truly be predetermined (Aikenhead, 2006), as participants engage in identity work in unique ways to construct understandings of themselves in relationship to science. Consequently, Sci-YAR's promotion of youth autonomy was a key factor empowering youth to engage in identity work in ways that connected their intellectual and social identities with identities reflecting critical science agency (Basu et al., 2009); however, this autonomy also created conditions that hindered youth's identity work in service of critical science agency, as it gave youth the freedom to disengage from doing identity work related to science and to retain stable images of themselves as disconnected from science.

Participants' identity work towards being scientific thinkers and doers was prompted through Sci-YAR's ability to provide a context in which youth had the autonomy to position themselves in particular ways. Shifting youth's positioning in school science and allowing them to take on a variety of roles in the science classroom has been shown to promote critical science agency (Basu et al., 2009). However, examining youth's identity work through the additional lens of constructivism highlighted how this positioning created disequilibrium in youth regarding what science entails and ways they themselves engaged in scientific thinking and practices in their everyday lives. By using lenses to emphasize both social and individual aspects of identity work, this study aimed to illuminate stronger connections between youth's identity work and critical science agency, which has been identified as an essential area for research to address (Mallya et al., 2012).

Youth who exercised their autonomy by selecting topics deeply connected to their own lives, interests, and personal goals also actively addressed the disequilibrium they experienced as they engaged in the reflective components of the curriculum and tried to make sense of how science could be enacted in multiple contexts, such as a classroom, a gym, a sports field, the school cafeteria, or even one's home, as well as how it could be used as a tool to address problems or investigate relevant issues encountered in those settings. Those who selected research topics of deep personal meaning or interest also engaged in more meaningful reflection on how they were acting as scientists, both in their research, and in the everyday contexts they were studying. For instance, Aaron's case was provided as an example of a youth for whom Sci-YAR created disequilibrium, prompting him to re-examine how he might be a scientific thinker and doer in various aspects of his life. Aaron reported repeatedly that studying his topic of muscle growth was of great importance to him, which pushed him to address the disequilibrium he encountered in his perceptions of science and of himself as a scientific thinker and doer. However, there were multiple cases of youth, like Cameron, who maintained equilibrium in their views of science and themselves in relationship to science while engaging in Sci-YAR. These youth were also those who exercised their autonomy by selecting research topics that were not meaningfully rooted in some practice or experience related to their lives, but rather to achieve other goals, such as receiving a good grade.

While youth's autonomy to select their own research topics and drive their own learning is paramount, consistent efforts should be made to facilitate youth in exercising personal agency through their practices of science by encouraging them to focus on problems and questions in their immediate surroundings (Basu, 2008b), and particularly those that might help them address pressing problems they are experiencing, or reach personal goals in other areas of their lives. This requires more than simply tying the curriculum to youth's interests, and it involves educators finding ways to balance an emphasis on youth's autonomy with pushing them to consider more deeply how they might use science as a tool and a context for thinking about and acting on relevant personal and social issues (Buxton, 2010). While curricula like Mallya and colleagues' (2012) *C3* curriculum have been shown to aid youth in expanding their science learning beyond the classroom by critically analyzing their local conditions and taking positive action to transform those conditions, studying food environments and activity choices may not be meaningful or relevant for all youth. What is needed to ensure the design and implementation of relevant science curricula are core curricular principles that can be infused into any locally relevant topic that youth deem important to their lives. Sci-YAR's design—consisting of core principles that are manifested in its key features used to guide instruction—allows educators their own autonomy in striking this balance for youth and tailoring the curriculum to meet the needs of their particular contexts and the lives of the particular youth in their classrooms.

For youth to connect their school science experiences to their own lives in personally meaningful ways, curricula cannot only emphasize youth's development of science content knowledge and process skills, hoping that youth will apply them in their lives (Coleman, n.d.). Curricula must also facilitate students in using their school science opportunities to critically analyze their surroundings and apply their knowledge and skills to transform themselves and their conditions (Mallya et al., 2012). The findings from this study emphasize the idea that promoting this agency involves not just youth taking action, but thinking and reflecting in-action, on-action, and for-action (Basu et al., 2009; Killion & Todnem, 1991; Mallya et al., 2012; Schön, 1983). Participants' experiences highlighted the key role that purposeful and extensive reflection played in promoting their identity work in service of critical science agency, suggesting that methods such as metalogues (Basu et al., 2009) or self-documentation should be an integral part of promoting youth's identity work in school science curricula. Overall, these findings support and complement those in past studies suggesting that school curricula can facilitate youth in powerfully connecting science to their own lives; however, additional research needs to be conducted to fully understand the impact of Sci-YAR as a science curriculum.

While participants' experiences engaging in Sci-YAR indicate its potential to influence youth's identity work in service of critical science agency, Sci-YAR's continued impact on participants' identity work, their development of critical science agency, and the future action they may take is unsure. Participants described how they thought they might use the scientific knowledge, thinking, and skills they learned through Sci-YAR to continue to take positive action to benefit their lives and their communities. They saw the potential for their Sci-YAR experiences to help them work with others to figure out answers to questions, make more informed life decisions, and address problems they encountered in the future. Continued longitudinal studies are necessary in order to determine whether youth's experiences in Sci-YAR do provide them future benefits such as these. These types of studies can better identify and describe the lasting impact that Sci-YAR and similar school curricula might have on youth's perceptions of themselves in relationship to science.

In addition, more research is needed to determine specific ways in which school science curricula like Sci-YAR facilitate and hinder youth in leveraging categorical roles and attributes associated with their existing identities to support specific identity work in service of critical science agency. Building off of Basu and colleagues' (2009) work, additional studies are needed to more clearly link youth's leveraging of other intellectual and social identities to their development of critical science agency.

Conclusion

Ultimately, addressing youth's disconnection with science requires educators to critically evaluate school curricula that present science as a specific set of content knowledge to be learned and skills to be developed. Furthermore, educators must continue to find ways to infuse relevance and agency into science curricula if they are to engage all youth in meaningful learning and prepare them to act as responsible democratic citizens who can take positive action through science. This study suggests that curricula like Sci-YAR have the ability to promote youth's identity work in service of critical science agency, thereby helping to achieve this goal. While this study demonstrates the potential of a purposefully designed curriculum to facilitate youth's identity work as scientific thinkers and doers, it also suggests that Sci-YAR's key features are essential elements that can be brought into existing curricula to promote youth's critical science agency and combat their disconnection with school science. The urban youth in this study identified curriculum features related to collaboration, autonomy, and reflection as promoting a meaningful shift in how they perceived themselves in relationship to science and the world. The benefits voiced by these youth serve as a reminder of the power science education can have when it is authentically connected to youth's lives.

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ARTICLE III: MAKING SCIENCE LEARNING RELEVANT THROUGH PRINCIPLES OF A STUDENT-DRIVEN CURRICULUM

Abstract

In this article, I provide guidance to teachers in implementing student-driven curriculum and instruction, so they might promote relevance in their students' science learning. I offer Science Youth Action Research (Sci-YAR) as an example of a curriculum embodying principles designed to further student relevance and agency in the science classroom. After introducing Sci-YAR and its structure, I detail five key features that can be used as guiding principles for designing a student-driven science curriculum. I include students' descriptions of their experiences engaging in each feature to highlight some of the benefits and challenges of implementing this type of curriculum. In addition, I provide examples for how teachers might promote each feature with their own students, and I detail major lessons learned as a teacher from implementing and studying the curriculum. Finally, I give specific recommendations for incorporating Sci-YAR's key features in any existing science curriculum. In this article, I emphasize Sci-YAR's key features as a flexible guide teachers can use to adapt their curriculum and instruction, so that it meets the needs of their particular students and school contexts, while promoting student agency and relevance in school science.

As a science teacher, I recall numerous instances where I excitedly planned what I thought was "the perfect" science lesson or unit, only to watch my plan fail to ignite a passion for learning, or to see my students react with disinterest in the topic. My experience, I am sure, is one shared by both novice and experienced teachers alike. We as science teachers thoughtfully prepare objectives, align them to standards, develop assessments and activities to help our students better understand science concepts and get them excited about learning. We gather and prepare materials to give students visual and kinesthetic ways to engage in learning content and in developing their skills as inquirers. We put management and safety procedures in place to ensure smooth implementation. It is rewarding when these efforts result in successful science teaching and learning experiences, but what happens when we take all of these steps, only to see our students disengaged or unable to display signs of meaningful learning? A high school science teacher colleague and I noticed similar issues arising in our classrooms, where our lessons failed to engage all students or to result in lasting learning. We, like many teachers, were confident in our abilities to design rigorous science learning experiences for our students, and we were excited to help students see themselves as scientific thinkers and doers. So why did well-planned lessons fail to excite students, and why did many of our students quickly forget science concepts we had studied extensively in class?

In complex classrooms, there is rarely a simple answer to questions like these, but after reading research, consulting with other experienced teachers, curriculum developers, and researchers, and studying our own practice, my colleague and I realized our commitment to making science learning relevant and empowering for our students required that we relinquish some control in the classroom (Coleman & Leider, 2013). We became aware that we were not alone in our quest to get students more interested and actively involved in their own science learning, and we thought making our curriculum and instruction more student-driven was the place to start overcoming these challenges.

Challenges of Science Teaching and Learning

Researchers in science education have studied and written about how many youth feel disconnected from science, because they do not see it as something relevant to their lives. School science classes reinforce this problem when they present students with a narrow view of science. Intentional or not, when teachers limit the topics considered scientific that can be studied in a science course, and when they only emphasize certain skills and ways of thinking that scientists use, they are controlling what is considered scientific and preventing youth from having a voice in defining science (Calabrese Barton, Ermer, Burkett & Osborne, 2003; Elemsky & Tobin, 2009; Roth, 2009; Roth & Calabrese Barton, 2004). For example, qualities like being precise and logical when designing experimental trials and controlling for variables tend to be emphasized more in science classrooms, while qualities like creativity and curiosity, as well as practices like argumentation, tend to be emphasized less, even though scientists may rely heavily on any of these, depending on their area of work (Anderson, 2003). Promoting a narrow view of what it means to participate in science limits the number of students who see themselves as scientists and see what they do in their everyday lives as fitting into the discipline of science. For students to perceive themselves as scientific thinkers and doers, we need to help them recognize that engaging in science includes a variety of practices. In addition, we must show students how scientific ways of thinking and doing connect to ways they think and act in their own lives.

Relevance through Student-Driven Science Learning

Educators have tried different ways to make science student-relevant, often by connecting students' learning in the classroom with issues related to their lives or communities. Helping students connect science learning to issues they directly experience facilitates learning content and developing scientific practices and thinking, and it promotes the *use* of science as a tool to solve problems and make sense of everyday life (Basu, Calabrese Barton, Clairmont, & Locke, 2009; Mallya, Mensah, Contento, Koch, & Calabrese Barton, 2012). Getting students to connect science to their everyday lives and then take action on that knowledge requires science curriculum and instruction that promotes student agency. Students exercise agency in science when they use their knowledge and skills to "giv[e] significance to the world in purposeful ways, with the aim of creating, impacting and/or transforming themselves and/or the conditions of their lives" (Calabrese Barton & Vora, 2006, p. 209). Promoting science agency requires teachers to relinquish some control and provide students opportunities to drive their own learning and take action to positively impact their lives and their communities through science.

An example of a student-driven curriculum promoting agency involved a high school agricultural management course, described by Brydon-Miller, Kral, Maguire, Noffke, and Sabhlok (2011). Frustrated by the lack of unauthentic scientific problems being study by her students, the teacher in this study sought a new way of teaching science that would require directly connecting science to the students' lives. When one of her students showed an interest in addressing the problem of the school lunches having low-nutritional value, she encouraged that student to generate a possible solution. The student suggested the idea of starting a school garden in which fresh produce could be grown to enhance the nutrition of the lunches served. Together with other interested students, the teacher developed an agricultural management elective course where students worked with the support of community members to plan, build, and operate a school greenhouse and garden. This example shows the potential teachers have to authentically connect students' science learning to real issues and to help them take positive action through science.

While research studies can include clear examples of curriculum that promote relevance and student agency in science classes, they do not to provide guidance to teachers about developing their own curriculum to achieve these goals. Simply assuming that these examples will easily transfer to other settings fails to recognize the institutional constraints, barriers, and unique needs of students that exist within each school or classroom context. For example, the curriculum described above came out of the unique context of the school and the particular interests of the students in that school. Packaging a curriculum that replicates what Brydon-Miller and colleagues did might not be helpful to all teachers, as it may not be feasible to implement in any setting. Instead, teachers need to understand the principles that underlie an example of a student-driven, action-based curriculum, so they can use them in their existing science curriculum to make it more relevant. This way, teachers can develop a curriculum that fits their own unique contexts and institutional requirements, as well as students' interests and needs. Next, I offer an example of a science curriculum with several key features that can be used as guiding principles when modifying any science curriculum and instruction to be more student-driven and more relevant to students' lives.

Science Youth Action Research

We, my high school science teacher colleague and I, developed the Science Youth Action Research (Sci-YAR) curriculum to encourage our students to take action through their science learning. We have implemented this curriculum in her ninth-grade environmental science and biology courses over the past four years. The Sci-YAR curriculum promotes student relevance and agency by asking students to work in groups to identify issues in their lives or communities related to science concepts they have been learning in their course. Students then pose questions to investigate and conduct action research projects to better understand the issues and propose possible solutions. Students use a variety of data collection methods in their research that are not limited to controlled experimental trials. For example, in the past students have made both quantitative and qualitative observations of wildlife found in their schoolyard, interviewed the school cafeteria staff on the food safety practices used when preparing school lunches, as well as surveyed school and community members about recovering from injuries they sustained playing sports.

To promote relevant and personal connections to science, during the Sci-YAR curriculum students engage in *self-documentation* (Reeve & Bell, 2009) of their experiences, where they record, analyze, and reflect upon their personal growth and their practices as scientific researchers. Students can use any medium they choose for their self-documentation, such as photography, film-making, blogs, or other social media. For example, one past group filmed their process of examining the hazards of household chemicals, and another kept a collective journal with photographs and writing as they studied the best ways to increase their muscle mass.

At the conclusion of the curriculum, students further exercise their agency by developing an action plan based on their research findings that could be used to address the issue or problem they studied. For example, past groups gave recommendations for proper food handling, preventing sports injuries, and using household chemicals with care. Students then have the opportunity to share the results of their research with the school community at a research symposium. Youth share the findings of their research, their proposed action plans, as well as the self-documentation showing their growth as scientific thinkers and doers.

Sci-YAR Curriculum Structure

While Sci-YAR has evolved each year we have implemented it, I will share the structure used during the 2012-2013 school year: the year I studied the curriculum for my dissertation, as it was being implemented in an all-boys Catholic high school on the south side of Chicago. The ninth-grade biology class had about 30 students total, and they participated in Sci-YAR during the second semester, from January to June. The Sci-YAR curriculum was broken down into four units, which included connections to the Scientific and Engineering Practices in the Next Generation Science Standards (http://www.nextgenscience.org/), key objectives and activities related to designing and conducting research, as well as formative and summative assessments (see Table 1 for an overview of the curriculum structure). During Unit 1 and Unit 2, the curriculum was only taught one to two days per week, as it was gradually integrated with the school's required course of study. As students' research progressed in Unit 3, they participated in Sci-YAR three to four days per week. During Unit 4, leading up to the research symposium, students worked on their Sci-YAR research in class five days a week.

Key Features

Sci-YAR has five key features that can be brought into any school science curriculum (Coleman, n.d.a). These key features are: (1) collaborating through collective research, (2) conducing research that is student-generated and student-led, (3) participating in relevant science through action research, (4) engaging in extensive personal reflection, and (5) using science as a way of knowing and taking action. Because the curriculum structure described above may not fit the needs of all teachers and students, I offer these key features as guiding principles that could be emphasized in any science curriculum. Next, I will discuss each feature's role in the Sci-YAR curriculum, what students said about their science learning experiences with regards to that feature, and the lessons I learned from implementing and studying each feature. I will then provide suggestions for how teachers might promote each feature with their own students, as well as recommendations for teachers looking to implement these features in their own science curriculum.

Table 1

Sci-YAR Curriculum Structure

Unit	Timeframe	NGSS Scientific and Engineering Practices (Grades 9-12)	Key Objectives	Summative Assessments
Unit 1: Selecting a Research Topic	6 class sessions over 3 weeks	8. Obtaining, evaluating, and communicating information • Recognize the major features of scientific writing and speaking and be able to produce written and illustrated text or oral presentations that communicate their own ideas and accomplishments.	During this unit, students: • Select an issue of concern in their lives, school, city, communities, and/or neighborhoods, explain how the proposed topic relates to an area of science, and then begin to analyze this issue in light of the cultural, social, and political context. • Engage in the beginning stages of the research process by creating a research proposal for their topic.	Preliminary Topic Proposal & Concept Map In groups, students create a written preliminary topic proposal, describing the proposed issue or problem to be investigated and indicating why their topic is appropriate to research. Students also create a visual concept map, representing the connections they have made between their research topic, science, and their own lives.
Unit 2: Developing a Research Plan	10 class sessions over 4 weeks	1. Asking questions • Ask questions about the natural and human-built worlds. • Formulate and refine questions that can be answered empirically in a science classroom and use them to design an inquiry or construct a pragmatic solution. 3. Planning and carrying out	During this unit, students: • Generate research questions that require taking action to address, are connected to the problem or issue they are investigating, will potentially help them develop a deeper understanding of the problem, and are of value in	Written Research Plan & Presentation In groups, students create a written research plan, which includes: a) overall goals, b) relevant background research on the topic, c) research questions, d) a data collection plan, e) support,

		investigations • Decide what data are to be gathered, what tools are needed to do the gathering, and how measurements will be recorded.	that they might bring about possible solutions to that problem. • Select data collection methods to address their research questions. • Create a written research plan to guide their project. • Share their written research plans with the class and provide other groups feedback on their work.	materials, and/or resources that are needed to complete the project, and f) any questions or concerns the group has for the teachers. Students also create a PowerPoint presentation with this information to share with the class and receive feedback.
Unit 3: Collecting and Analyzing Data	14 class sessions over 4 weeks	3. Planning and carrying out investigations • Plan experimental or field-research procedures, identifying relevant independent and dependent variables and, when appropriate, the need for controls. 4. Analyzing and interpreting data • Analyze data systematically, either to look for salient patterns or to test whether the data are consistent with an initial hypothesis. • Recognize when the data are in conflict with expectations and consider what revisions in the initial model are needed.	During this unit, students: • Carry out their data collection plans in a timely manner, communicating clearly and professionally with the teacher and other adults involved, and generating at least three forms of data from different sources. • Consistently review and organize their data as they conduct ongoing analyses, using methods that are most appropriate given their data and research questions. • Share their progress made on data collection and their preliminary findings with the class, incorporating the	Data Collection & Reflection Students complete a series of written self-assessments on their contributions to the project and their ability to effectively manage time and communicate with others. They also complete similar peer assessments for the other members of their group. Using these formative assessments, students then compose a summative data collection reflection in which they discuss: a) how effective they think their data collection methods and

			feedback they receive as they move forward in their research. • Reflect on their own and others' contributions to the project through written self- and peer assessments.	sources were in generating useful information, b) successes and challenges they encountered during this process, c) how collecting their data influenced their understanding of their topic, and d) how they might generate and communicate scientific knowledge for the benefit of others through their research.
Unit 4: Formulating Findings, Sharing Results, and Taking Future Action	14 class sessions over 3 weeks	7. Engaging in argument from evidence • Construct a scientific argument showing how the data support the claim. • Identify flaws in their own arguments and modify and improve them in response to criticism. 8. Obtaining, evaluation, and communicating information • Use words, tables, diagrams, and graphs (whether in hard copy or electronic), as well as mathematical expressions, to communicate their understanding. • Recognize the major features of scientific writing and speaking	During this unit, students: • Use their data to generate findings in the form of claims supported by multiple pieces of evidence from multiple sources. • Develop written action plans based on their findings that outline possible future actions to address problems related to their topics. • Share their research and findings at a school-wide research symposium, where they listen to others' points of view and use others' critiques to think about how they might take action in the future to improve and/or continue their investigation.	Research Symposium Presentation & Action Plan Students create visual presentations to share with peers, faculty, administration, and families at the research symposium. Students explain to their audience the process they went through in conducting their research and share their findings. They also share their action plans and elements of their self-documentation. Students select the visual aids to use when presenting their work (examples include making a tri-fold backboard, an

		and be able to produce written and illustrated text or oral presentations that communicate their own ideas and accomplishments.	• Reflect on how they used science as a tool to help them address a problem and how they might use science in the future to take action to make the world a better place.	electronic slide show, or a video).
Ongoing throughout the entire curriculum			During the entire curriculum, students: • Identify, compare, and critique various definitions of science as they develop and revise their own written definitions of science. • Document the development of their practices of science and their personal growth through the use of various media, such as writing, art, photography, film-making, blogs, or other social media. • Consider, discuss, and write personal reflections on how their participation in research has influenced them. • Review all data collected through self-documentation and reflections, and generate claims/new realizations about how participation in research has influenced	As the overarching summative assessment, students: • Generate a final written reflection on the entire process of engaging in Sci-YAR, including new definitions of science based on their experiences. Students also discuss how they used science as a tool to address an issue and how they might use science in the future to take positive action. Finally, students discuss what they learned from their research and any limitations, including how the research could be improved in the future. • Conduct both final self-

			them as persons, as well as how participation in research has influenced their scientific practices. • Share these realizations brought about through their research, with the intention of positively influencing others by showing the benefits of conducting scientific research.	and peer assessments of theirs and others’ work throughout the project. • Complete an evaluation of the teachers’ roles in facilitating the research process and provide suggestions for future implementation.

Sci-YAR's Key Features in Action

Feature 1: Collaborating Through Collective Research

Students collaborated with their peers during the Sci-YAR curriculum mainly by conducting their research in groups, sharing ideas and making decisions together, and providing feedback to other groups on their research. This feature was designed to promote student agency by encouraging students to guide one another through the research process, rather than have their learning directed only by us, the teachers.

Students liked working with their peers to conduct research, especially since this made their science learning a social process. Students shared and were exposed to many different points of view, which helped them generate ideas for their research, feel more confident in their ideas, and see science as a team effort (Coleman, n.d.b). Collaborating with their peers was also important because they could spend time with their friends and meet their needs for social interaction at the same time they worked to achieve their academic goals. Students talked a lot about the importance of being able to enjoy themselves with their friends while they worked hard to achieve good grades:

> Well, I mean, getting a good grade is [important], but also having a lot of fun is. I mean, if I get a B+, but I have a lot of fun in [the Sci-YAR project], I'm not going to be that upset about it. But I feel that if we work hard enough, [my group] should get a good grade in the end. (James[2])

Students talked about getting good grades on the research project and in the course as important personal goals; however, they also had to gain some enjoyment from their

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[2]Names of all students are pseudonyms.

learning. For some, this enjoyment was necessary to be academically productive and successful. For example, one student described how a social learning environment that included humor and joking around with others was essential to his success in school:

> Well, [learning's] a lot better when people have a sense of humor when they're working together because if everything is always so serious, I can't work like that. I definitely cannot work like that. (George)

George reported that in many of his classes, he was asked to be completely serious at all times, which made it more difficult for him to be engaged or to focus on his work. Many of the students, like George, enjoyed working with their peers during Sci-YAR because it allowed them to both develop their social relationships and achieve their academic goals.

Students said balancing their academic work with fun was also important, so they could maintain their motivation to work hard through the four-month curriculum. Many students said they found this balance by working with their friends on research tasks that were challenging. For example, Cameron said working with his friends was especially important since doing their background research on household chemicals and chemical reactions was not as exciting as other parts of the project:

> It was fun hanging out with [my friends]….[My group] got to hang out too and talk, but like when we had to do [background] research on [chemical reactions], it was just like, "Okay, I'll get this done now."

Students liked spending time with their friends and socializing while doing their research and it helped them complete less exciting parts of their research like looking up information. Many students said they maintained their motivation to learn because they worked on their research in groups with their peers.

Students also liked learning personal things about one another while working in groups. Working with their classmates throughout the semester allowed them “to get to know each other more” (Dan) because they interacted more frequently and shared more personal experiences in class than they had previously. Students liked getting to know the members within their project group, saying that “being with the same people for a long time, [I] got comfortable [working] with them” (Wasalu). This comfort level helped students develop deeper personal relationships with one another, which created a stronger classroom community for their science learning.

Overall, students found their science learning in Sci-YAR enjoyable because it was collaborative and social:

> [Sci-YAR is] probably the best thing I've done in science so far. Yeah, because we get to think of [ideas] as a group and it's more like just hanging out basically because [we] come up with [ideas] about a pretty cool topic, [and share] what happens to all of us [related to that topic]. (Dan)

Students liked Sci-YAR because they could collaborate on their research and socially interact with their peers. Most students did not see learning science as unpleasant work; instead they said it felt like spending time with friends and talking about meaningful things, just as they would do in social circles.

Lesson learned: Collaborating with others was essential to students' science learning. Working with their peers helped students share ideas and make decisions about their research. It also motivated students by helping them see their science learning as something fun and enjoyable. This was especially important to keep them engaged in a long-term curriculum that spanned an entire semester. Students showed that they could be focused on academics, while still being social with their group members. Designing and conducting research with their peers was also important because it made students' science learning more closely resemble their everyday interactions. Students could talk about their lives, laugh and joke, yet also exchange and debate important ideas about science. Making science learning social in Sci-YAR built a stronger classroom community, and it also helped students see science as an enjoyable part of their lives.

Feature 2: Conducting Research That is Student-Generated and Student-Led and Feature 3: Participating in Relevant Science through Action Research

Features 2 and 3 are discussed here together because giving students the freedom to design and lead the execution of their own research in Sci-YAR (Feature 2) encouraged them to participate in relevant practices of science (Feature 3). Students selected their own topics, generated their own research questions, collected and analyzed their own data, and presented their own original findings. This made students the primary decision-makers in the science classroom who had control over their own learning. The classroom teacher and I encouraged students to use this control to make their science learning relevant. We advised students to select topics that were personally meaningful, would address pressing issues in their lives or communities, and would bring about positive action.

Students enjoyed Sci-YAR because they could drive their own learning by making important decisions in their research. Students liked having the freedom to make a variety of decisions, such as selecting their own data collection methods, managing their time as they saw fit, and deciding how to divide tasks among group members. One of the most important decisions students said they made was choosing their own topics to research. Aaron is an example of a student who chose a meaningful topic and had a positive experience in Sci-YAR. His group wanted to become stronger and more muscular, and so they chose to study their own muscle growth. Aaron spoke repeatedly about how selecting his topic made the project interesting:

> [We picked our topic] because we all really just wanted to get in shape. And [working out is] not like writing stuff, so it's not really miserable. We're all like, "Alright, we could get this done." So we all got [the project] done [thinking], "No, this is actually not bad."

Students who picked topics related to their lives found their research meaningful, and they were more willing to take action to investigate those topics (Coleman, n.d.b). In Aaron's case, the research process was more enjoyable because he could collect data on something he really enjoyed, such as lifting weights, and he could reach a personal goal. Students like Aaron valued the freedom they had to make decisions, especially choosing their own topics of interest.

Picking their own topics not only gave students control over their decision-making; it was also an important way that students made their science learning relevant. Because they were able to drive their own learning by selecting issues that related to their lives and interests, many students said this science learning experience was more meaningful and enjoyable than those in the past. For example, Aaron talked about how being able to drive his own research made Sci-YAR different from other open inquiry experiences, like science fair, since teachers and other adults were facilitators of learning, rather than directors:

> [For] science fair, I have my mom help me a lot. It's like, I don't really do that much of [the project]. Now, [the responsibility] it's all on us and [the research is] something I like doing. So [now], I actually like this stuff. I kind of get more into it. I don't really remember too much [about] science fairs. They just seem really boring.

While Aaron selected his own topics in prior science fair experiences, his teachers had not encouraged him to pick issues important to his everyday life. Aaron did not see studying his weightlifting and muscle growth as scientific, and so he picked science fair project ideas that had already been done by others. As a result, he let adults (like his mom) take the lead in making sure the project was completed. In Sci-YAR, selecting his own topic with encouragement from his teachers helped Aaron make his science learning relevant and helped him take charge of his own learning.

Although driving their own learning was an important part of Sci-YAR, students still valued having teachers as facilitators who provided them guidance and support throughout the process. Students recognized how important it was to have guidance from their teachers, and they realized they could not design and conduct research on their own:

> We knew that [our group] couldn't just do this project [alone]. If you were like, "Alright you're [researching] household chemicals. I want a project due in two months or three months," we would not know where to start, even with…. [writing] research questions or getting the [necessary materials] or even [deciding] what we were going to do with the chemical reactions. (James)

Students saw teacher support as important, and they liked teachers helping them select meaningful topics, giving mini-lessons on skills like writing research questions, sharing useful information like particular websites, as well as providing access to resources like needed supplies or experts to interview.

Students liked having teacher support when making important decisions about their research, and it helped calm their fears about conducting their own research. For example, Cameron said that receiving supplies from me lessened his fears about the project and helped him decide what his group would do to collect data on their topic of household chemicals:

> Cameron: I feel like [the project's] going to turn out better now because you helped us get more [ideas for] experiments. It's easier now to see why the [household] chemicals [might] react and stuff, so I think [my feelings have] got[ten] better.

Teacher: Okay. When did you- what was the point that you started to feel better about it? You stopped having those fears and was like, "Oh, okay, this is going to be alright."

Cameron: When you emailed us.

Teacher: About the chemistry kit and those supplies [I bought for you]?

Cameron: Yeah. That's when I felt [better] about [the project] because I was like, "Alright, now we've got some stuff that we can actually look at." And it would be easier then [to design our tests].

Cameron valued guidance from teachers because having complete freedom left him unsure about how to make decisions, such as how to design tests and collect data. Students recognized that being able to drive their own learning with teacher support was the best way to do research successfully.

Even though students knew they needed assistance when conducting their own research, it did not detract from their sense of control to direct their own learning. Students appreciated the increased control they had over their own learning, rather than just being told what to do by the teachers. According to George, "I wouldn't say we have complete freedom, but we have more freedom than some of the other classes I have, so that's what I like about [Sci-YAR]."

Lesson learned: A student-driven curriculum made science relevant to students and gave them ownership over their practices of science. Giving students the freedom to make their own decisions about their research was difficult at times. It was hard for the classroom teacher and I to give up control and allow students to make mistakes or decide on courses of action that were unproductive. It was also hard for some students to accept this responsibility, as it left them feeling uncertain about how they should proceed and how their research would turn out. However, working through this discomfort had a positive outcome because it ultimately made the students more interested and invested in their research. Picking meaningful topics especially increased student engagement and made science more relevant to their lives. Even when given the freedom to choose their research topics, though, not all students selected meaningful issues to investigate, and those students did not see science as more relevant or useful in their lives. The classroom teacher and I realized that we are still trying to find the proper balance between giving students control and facilitating them in choosing topics that will lead to meaningful learning. There were times we did not achieve this balance, which resulted in students that were confused or unsure about how to move their research forward. This is a challenging lesson we are still learning.

Feature 4: Engaging in Extensive Personal Reflection

Students engaged in extensive personal reflection throughout Sci-YAR by documenting and reflecting on their research experiences and personal growth. They also reflected through activities like journaling and self-assessment. This feature was designed to promote student agency by helping students personally connect with their science learning as they reflected before, during, and after taking action through science.

Students reflecting through self-documentation. Students liked reflecting on their science work by doing self-documentation, where they represented themselves and their experiences through media such as photography, video, or art. Before students did self-documentation independently, they tried different forms, modeled by their teachers in class. For example, during one class session, students brought in artifacts related to their interests, photographed them and shared them with their research groups, and then wrote reflections in their journals about how the artifacts represented them. Students enjoyed this opportunity to share information about themselves, like Dan who said, "[Self-documentation's] fun. It's fun just bringing stuff in that represents you."

For self-documentation, students also created "picture frames" to represent themselves. Students either brought photographs into class or drew pictures that represented themselves in some way. They then wrote four statements to create a border along each edge of the picture, framing it with a description of how their personal qualities might help them conduct their own scientific research. Students wrote about: (a) what object or action was in the picture and why they selected that picture; (b) what the picture showed about them, (c) what skill(s) they had related to the picture, and (d) how they could use those skills as they conducted their research. Appendix B contains the student directions for the *Picture Frame* activity, and Figure 1 shows an example of a student picture frame created during Sci-YAR. These self-documentation experiences prompted students to think about who they were and how their qualities might help them be scientific thinkers and doers as they conducted their own research. For example, Cameron, who brought in photographs of himself playing various sports over his elementary, middle school, and high school career said, "I enjoy [self-documentation] because I could think about old things [from my past] and stuff I like." He reflected on how his passion and resilience as an athlete over the years helped him to stay positive as he conducted his own research, even when Sci-YAR was challenging and he was unsure of his success.

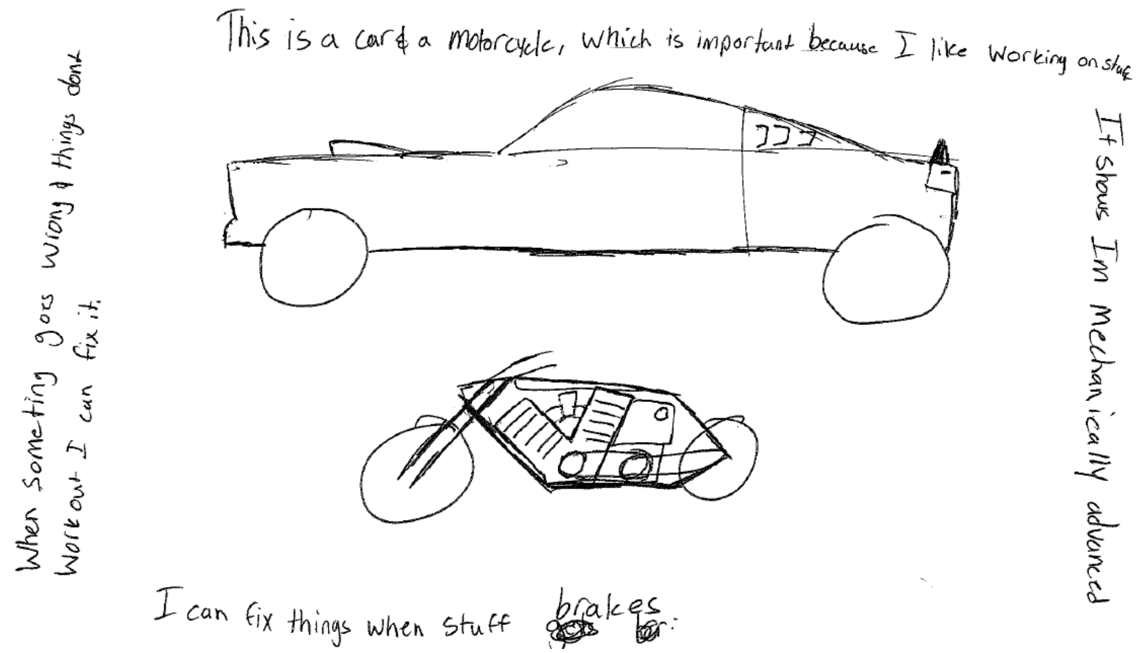

Figure 1. A “picture frame” created by a student during the Sci-YAR curriculum as part of his self-documentation

Teacher benefits of self-documentation. While the classroom teacher and I designed the self-documentation to help students reflect on their strengths and how they could be used in science, an unanticipated benefit for us was making more personal connections with the students. This happened when we shared examples of our own self-documentation we created to model the process for students. The day we introduced the *Picture Frame* activity, I shared an example with the students, based on my experience as a captain of the women’s boxing team in college. Many students were excited to discover I was a boxer, as they did not think that boxing could be an expertise of a science teacher. Students said they were excited to learn personal information about a teacher, and that this experience changed the way they viewed me:

> I still think of you as a teacher because you are, but I think you're more like a cooler teacher because you like actually [box]….When kids like me think of teachers we think that's all they- they just teach and whatever. We don't think of their outside lives, like boxing. (Cameron)

Learning details about my life and experiences outside of the classroom helped Cameron see me as more than just a science teacher, which gave me a higher status in his eyes. I was a “cooler teacher” who shared similar outside interests, like athletics. Students were excited to share personal details about their own lives through self-documentation, and they were also excited to learn personal details about their teachers’ lives.

This experience of mutually sharing self-documentation was unique because many students had not experienced personal connections with their teachers before:

> All the other teachers, all they do is talk about school. They don't really give you any information about themselves. I think once you give some information about yourself, you build a strong relationship. I really thought it was cool to hear about [your boxing]. I still do. (Aaron)

The students saw sharing personal information as a way to build stronger relationships. By sharing personal information through my self-documentation, I positioned myself in a more accessible way to students, which helped me build stronger relationships with them. When designing the self-documentation component of Sci-YAR, the classroom teacher and I thought it would help us learn more about our students, so we might help them connect their own interests and life experiences with their practices of science. However, we did not anticipate that sharing information about ourselves would be meaningful to students and would help us form deeper personal connections with them.

Independent self-documentation. In addition to the structured self-documentation activities done in class, students also chose their own method to document themselves and their research. Many students chose to make videos to represent themselves and their thinking, preferring to reflect and communicate through this medium:

> I think it's easier just to talk than write everything [about my thoughts] down. Maybe visuals would help, but if you're videoing [what you're doing], you could just show the pictures in the video and everything that you have with [your research]. So I think that it's easier [to video]. (Cameron)

Students also thought videoing was a more seamless way to create documentation, store it, and access it when necessary, especially if it was on a smart phone, which was a part of many students' everyday lives:

> I thought filming would be the easiest [way to document our research]. Then that way, all you have to do is -- because with our modern technology, of course, you hit one button and you can just get what everyone says and keep it, and the picture. So it's kind of the best of both worlds. And then that way, it would be easier to keep too, because it

> would be on my phone, and I bring my phone everywhere with me. (James)

By videoing their research for their self-documentation, students expressed themselves more freely and documented the process more seamlessly. Some students also used their videos to review and critique their data collection procedures and reflect on how their understandings of science concepts developed over time, which was an additional benefit of video self-documentation (Coleman, n.d.b).

Challenges to self-documentation. While many students liked the self-documentation part of their research, some did not because they did not see its connection to their science learning. For example, George was a student who was confused about the self-documentation and what purpose it served in his research:

> It's kind of -- it's different [doing self-documentation in science]. Because [in] English [class] you're thinking [about] biographies and different books. And then [in] science [class], you're not really thinking about any scientists that [do the science]….because when you hear somebody say "self-documentation", you automatically think [of] a book. And then when I heard it in science [class], I'm like, "What the heck?" And then that's how I got confused [about what to do]….[You] don't put [self-documentation and science] together really.

Students like George thought sharing information about themselves was something they would do in an autobiographical book, not in a science research project. These students had a difficult time seeing how documenting and sharing personal information and experiences were relevant to developing their scientific understandings and skills. These students did not do any independent self-documentation or use it to reflect as they conducted their research.

Lesson learned: Extensive reflection helped students see themselves as scientific thinkers and doers. Finding new ways to promote student reflection, such as the different types of self-documentation, helped students feel more connected to science. Students regularly wrote in reflection journals, but many liked to communicate in ways other than writing, and so it was important to let students use a variety of media to express themselves. When they shared personal information and reflected on how their strengths helped them conduct research, students were encouraged to see themselves as scientific thinkers and doers. It also created a classroom community where everyone's skills and qualities were acknowledged and valued. The classroom teacher and I needed to be a part of this process and share personal information about ourselves to build stronger relationships with students. Extensively reflecting throughout their research motivated many students and made them excited about their science learning. However, the purpose was confusing for some students, and so not all of them enjoyed it or found it useful. The classroom teacher and I continue to develop ways to help all students understand the purpose of self-documentation in science.

Feature 5: Using Science as a way of Knowing and Taking Action

In Sci-YAR, the classroom teacher and I encouraged students to see science as more than just facts to be learned. To help students see science as a way of knowing and taking action, we asked students to write and continuously revise their own definitions of science as they gained new perspectives from conducting their research. We also encouraged students to take action by developing future action plans and by presenting their findings to the school community at the research symposium. This feature was designed to promote student agency by positing students as experts who could have a say in defining science and who could teach others using their scientific knowledge.

Many students enjoyed presenting their research to the school community at the research symposium because they could actively share their science learning with others. Students said this opportunity motivated them to take their research seriously and work hard to make it rigorous:

> [After being told about the symposium, our group] got a lot more accomplished than we did any other days. I think a big thing had to do with it since we were going to be presenting these [projects], so we knew that we actually had to do this [research] seriously, and we had to get actual evidence [to back up our claims] and stuff like that. (James)

For many students, the symposium was a motivator to persevere and continue with their long-term research until the end, so they would be prepared to share it with an audience.

Students liked presenting their research to others, and they saw it as a unique chance to explain their own original work, rather than recreate an experiment others had done before. For example, several students admitted that while they had presented and explained science projects in the past—mostly when participating in grade-school science fairs—the process had never been pleasant before. Aaron, in particular, enjoyed presenting at the symposium because he could talk about a project related to his own life, which made interacting with audience members more interesting and more comfortable:

> Aaron: Not once [at the symposium did] I really feel embarrassed or uncomfortable.
>
> Teacher: Why do you think that is?
>
> Aaron: Maybe just because I knew so much more about [my topic] than [before]. Usually when I'm presenting in class in like grammar school at science fairs, I'm like, "Uh, uh. I don't know." Yeah, but because we've been doing so much of [the research] in class, I felt more comfortable saying [stuff about] it….
>
> Teacher: That makes sense. Yeah, so what was that like? What was it like interacting with all of those different people and talking with them and sharing this research with them?
>
> Aaron: It was pretty good because everyone was really nice. So it's like nothing was weird or I was never nervous. So I actually enjoyed it. It wasn't bad. I thought it was better than going to class because it's like, "Hey, I get to talk for an hour and a half instead of sleep and be bored." So I was pretty happy about it.

Many students thought presenting at the symposium was the best part of Sci-YAR because it was interesting and exciting to talk with others about their meaningful topics. They also felt like experts because they shared new information with adults, and they could actively teach others, rather than just passively receive information in class.

Actively sharing their knowledge at the symposium helped students feel positively about their research. This was important because during the final few weeks of the curriculum, many students found it difficult to stay focused, work productively with their groups, and follow through on the final tasks that needed to be completed. These students described the symposium as a positive experience because they could put aside their difficulties and take on a more active role as science experts. For example Cameron, whose group struggled to finish their data collection and put their display board together, found the symposium meaningful because it gave him the opportunity to see his group members be actively involved in the project:

> I think [the symposium] was really good, actually, because [our group] all came together and- I'm not going to lie- Andy [a group member] came out of nowhere, [and] he started talking [about chemicals and chemical reactions]. I was like, "What? Are you the real Andy?" But [the project] actually -- it came out a lot better than I thought, because we were all frustrated. I could tell. We were all getting mad at each other for stupid things. And then when the day [of the symposium] came, we did [a] really good [job presenting] and I felt like that was the best point because we were all together and explaining everything. And then towards when [the symposium] was over, it's like, "We did really good on this [project]". We were happy about it, so it was good.

The symposium helped Cameron feel like his research was successful, despite the challenges his group encountered. The symposium was also an opportunity for Cameron to see his group members in a different light. For example, he mentioned Andy, a quiet group member who did not often share his ideas or make decisions with the group. Throughout the research process, Cameron was frustrated with Andy for being passive and allowing others to take the lead on tasks. When Cameron saw Andy step up at the symposium and take an active role, expertly explaining many of the tests they had done and giving scientific explanations, Cameron started to view their research as more successful. The symposium eased tensions that had been building within groups like these, and group members were able to come together to present their research successfully to an audience. Students set aside their frustrations at the symposium, leaving them with a sense of accomplishment at the end of the Sci-YAR curriculum.

Lesson learned: Sharing their work publically encouraged students to start taking action through science. The research symposium was essential to students' science learning because it was an opportunity to share their expert knowledge with the community and to feel successful in conducting their own research. This was a logical first step to encourage students to take action through science. Because they were able to teach others about their topics, the students felt a sense of accomplishment. They hoped that teaching others about issues like proper nutrition and food safety, preventing injuries, or storing and using household chemicals safely would help others in their daily lives. This small way of taking action was meaningful to students, and it made them feel important and connected to their science work.

Moving Forward with Sci-YAR's Key Features

Sci-YAR's five key features made the curriculum more relevant to students and promoted their agency while participating in science. However, it is important to note that teachers do not necessarily need to integrate all five features into curriculum to encourage student agency and make science learning more relevant. Teachers can select features most appropriate for their contexts, their teaching styles, and their students. Table 2 provides some flexible examples of how teachers can promote each key feature with students in a science classroom.

Recommendations for Creating a Student-Driven Science Curriculum

To ensure a student-driven science curriculum, teachers do not necessarily have to replicate Sci-YAR exactly as it was implemented in the classroom described. Using Sci-YAR's key features as guiding principles for curriculum design can help teachers create a student-driven curriculum with the potential to make students' science learning more relevant. I offer the following recommendations to help teachers begin this work.

Recommendation 1: Pick one key feature of Sci-YAR and plan to bring it into an existing curriculum. Each year the classroom teacher and I have used the Sci-YAR curriculum, we have gradually brought in each of the five key features, which has taken extended time for us to integrate into practice. Teachers can select at least one key feature to bring into an existing curriculum, based on students' needs and what teachers feel would best enhance their science teaching. For example, teachers can give students more opportunities to collaborate in groups or share their work with the community.

Table 2

Promoting Sci-YAR's Key Features

Key Feature	How to Promote the Feature with Students
Feature 1: Collaborating through collective research	• Give students opportunities to discuss science topics with one another and how those topics are related to their lives. • Allow students to form research teams to investigate topics of common interest. • Encourage student collaboration as they develop and execute their research plan as a team. • Give student teams multiple opportunities to present their research plans and progress, so they can receive feedback and suggestions from the class, which teams can use as they move forward with their research.
Feature 2: Conducting research that is student-generated and student-led	• Allow students to select their own research topics and generate their own research questions. • Encourage students to develop their own data collection plans, selecting from a variety of methods, such as interviews, surveys, and controlled tests. • Encourage students take the lead in seeking out sources and developing tools for data collection. For example, ask them to design their own interview questions and find participants to interview, develop and distribute their own surveys, and design their own controlled tests.
Feature 3: Participating in relevant science through action research	• Introduce students to the idea of taking action through their research. Explore and discuss ways they can use scientific inquiry to take action in their lives or communities. • Ask students to reflect on how they already use scientific thinking and skills in their own lives and discuss how they might use these to conduct research that benefits others. • Allow students to select and research topics related to their own lived experiences.
Feature 4: Engaging in extensive personal reflection	• Introduce students to self-documentation. Allow students to choose ways to document themselves, such as through writing, art, photography, film-making, blogs, or other social media. • Have students keep a reflection journal where they write about science, their lives, and

	their experiences conducting their own research. Provide them with meaningful prompts that encourage students to make connections between science, their lives, and their experiences as researchers. • Ask students to analyze the data from these reflective activities to make assertions about their personal growth and their growth as scientific thinkers. Encourage students to share these publically with their research findings.
Feature 5: Using science as a way of knowing and taking action	• Discuss with students what science entails and what scientists' work involves. Ask students to write and reflect on their own definitions of science. • Discuss with students how they might do scientific work to answer questions and solve problems that could benefit others. • Following their research, have students develop a plan for future action based on their findings. • Give students the opportunity to share their work with the school and surrounding community in a venue such as a research symposium.

They can have students reflect more extensively on their science learning through regular reflection journals or self-documentation. Teachers can also look for opportunities to hand over some decision making to students. For example, instead of giving them structured lab procedures to follow, teachers can ask students to share their ideas and develop lab procedures together. Or teachers can modify an existing science fair structure to encourage students to investigate more authentic scientific topics related to their lives, using more than just controlled experimental trials. Teachers should pick key features they think would best enhance students' learning and that would help them grow as professionals. As teachers become comfortable with one feature, they can add in additional features or increase the extensiveness of the feature, such as allowing students to make increasingly more decisions regarding their learning.

Recommendation 2: Seek out a colleague to support curriculum changes. In our implementation of Sci-YAR, the classroom teacher and I found the support of one another essential to making this curriculum change. Teachers can share Sci-YAR's key features and their goals for adapting a curriculum with another colleague to receive some feedback. Together, they can discuss how to integrate these features into a curriculum, as well as generate and refine ideas for changes that can be made in the classroom. Teachers can invite a colleague to observe their teaching and provide feedback on how the features are or are not enhancing students' learning. If possible, teachers should find a colleague who would also be willing to bring some key features into his/her own curriculum, so all can work together on making curriculum more student-driven and support one another through this process. Further recommendations for collaborating with colleagues to facilitate the curriculum are described later when I address management issues.

Recommendation 3: Take a step back and release more responsibility to students. Releasing our control over decision-making was a significant challenge for the classroom teacher and me. Teachers should start to envision their roles as facilitators, rather than directors of students' learning. Teachers can begin by talking openly with students about the new level of responsibility they will be asked to take on, emphasizing that they will be trusted to monitor themselves and make important decisions regarding their own learning. Teachers can then follow through by giving students opportunities to select their own partners or groups to work with, and by allowing students to decide how to organize their group work and divide tasks among their group members. Teachers should be prepared to allow students to struggle at times or make poor decisions, recognizing that these struggles are a part of the learning process, which will not always be neat and smooth. Rather than directing and telling students what to do, teachers should encourage them to monitor their own work and to recognize when it is necessary to ask for help. Before jumping in to direct students, teachers should carefully observe their interactions, allow them to support one another, and learn to recognize when teacher intervention is necessary to keep them motivated and moving forward in their learning.

Recommendation 4: Encourage reflection and open dialogue with students. Making the science classroom a space for continuous personal reflection and open dialogue helped the classroom teacher and me connect with our students. Teachers can give students opportunities to share personal information and interests with the class, and should be sure to take part in this process as well, so they can form personal connections with students. Teachers can build a strong classroom community by allowing students to reflect on their science learning and honestly share their views on science, particular topics under study, and the classroom activities in which they are engaged. Whenever possible, teachers should permit students to communicate in a variety of ways (not only writing), allowing them flexible ways to express themselves. Teachers can use these opportunities for reflection and open dialogue to help them find additional ways to connect students' science learning to their lives.

Recommendation 5: Give students opportunities to share their work and use their science learning to take positive action. When provided opportunities to share their work with others, students increased their levels of engagement and became more motivated to learn science. Teachers can seek out opportunities for students to share what they are doing in the science classroom. It might begin with groups sharing and debating different ideas with other groups in the same classroom, and then extend outside of the classroom to share their work with other students and teachers in the school. Teachers can host a "science day" or symposium where students share their learning with other students, teachers, families, and community members. Rather than make these presentations something evaluative (like science fair projects), instead teachers should emphasize them as times for the students to be experts and take positive action by teaching others about their work. Whenever possible, teachers should encourage students to take further action related to their learning. For example, if studying the nutrition of the school cafeteria food, students can petition the school administration to provide healthier food options or start a poster campaign in the school to encourage students to make healthy food choices. Letting students generate and execute these actions is a way to further develop a student-driven curriculum.

Recommendation 6: Have a strong management plan in place. When implementing Sci-YAR, the classroom teacher and I faced significant management challenges, which required us to act as co-facilitators of student learning. While managing multiple student research projects may initially seem overwhelming, by developing tools to keep us organized during each unit, we found it was possible to address these management demands, even working in schools with few human and material resources. Breaking down the tasks involved in each unit and developing a management plan for each stage of the research process is essential to keep both teachers and students on track. Table 3 contains some tips for managing student-directed research (for teachers who are implementing the Sci-YAR curriculum structure in its entirety), as well as specific recommendations for finding a co-facilitator to support teachers in this work. In addition, Appendices B through F contain specific examples of management tools used in prior implementations of Sci-YAR.

Table 3

Management Tips for Sci-YAR

Unit	Management Tips
Unit 1: Selecting a Research Topic	• Have a structured process for group and topic selection. See Appendix C for an example.
Unit 2: Developing a Research Plan	• Keep a running list of all research groups, their topics, and their data collection needs, including resources and supplies needed from the teacher.
Unit 3: Collecting and Analyzing Data	• Create a large classroom calendar for groups to record their daily plans for data collection and analysis. • Be aware of safety concerns for each group project, and ensure that groups have proper safety equipment and supervision for their data collection procedures. • Schedule regular check-ins with groups to provide updates on their progress. See Appendix D for an example of a group check-in form.
Unit 4: Formulating Findings, Sharing Results, and Taking Future Action	• Give students graphic organizers to help them organize their data, formulate findings, and develop action plans. See Appendix E for an example. • Provide criteria for groups to self-assess their findings. Visitors at the symposium can also use these criteria to provide groups feedback on their work. See Appendix F for example criteria.
Ongoing throughout the entire curriculum	• Find at least one colleague to be a co-facilitator. For example, partner with another science teacher at the school and use free periods to visit one another's classes and help groups work on their research. • Publicize to administrators and other faculty that students are conducting their own research. Reach out to them and community members to support students' research. • Look for areas where students are struggling and provide mini-lessons on those skills. Examples might include mini-lessons on writing research questions, writing claims using a claim-evidence-reasoning framework, organizing data into charts and graphs, or analyzing interview data. • Regularly administer self- and peer assessments to ensure that all group members are contributing. These can also help determine if students are participating in a limited range of tasks, so they can be encouraged to take on new roles in their groups if necessary. See Appendix G for example self- and peer assessment forms.

Conclusion

Getting students to meaningfully connect their science learning to their lives requires more than a solid curriculum design that includes learning science content and developing scientific skills. Implementing and studying the Sci-YAR curriculum, I have found that allowing students to actively drive their own learning is a way to make science relevant and useful to their lives. I recommend integrating Sci-YAR's key features into any existing science curriculum, so teachers can enhance student agency and create more relevant science learning experiences for students. While teachers may need to take on new roles and develop plans to manage new challenges, allowing students to drive their own learning ultimately gives them a voice in how science is carried out in classrooms. By encouraging all students to exercise this voice and make decisions about their science learning, teachers can help students develop broader, more relevant views of science and provide more opportunities to act as scientific thinkers and doers.

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CONCLUSION

Synthesizing a Three-Article Dissertation

The three articles comprising my dissertation build upon one another to create a comprehensive view of Science Youth Action Research (Sci-YAR) as a curricular framework and instructional approach. By defining Sci-YAR and situating it within the literature, Article 1 prompts educational leaders to think critically about the goals of science education and to envision new approaches to curriculum and instruction that value relevance and youth agency. It encourages educators, researchers, and curriculum designers to embody critical science agency themselves by questioning limited definitions of science generated and promoted by those few given a voice in science education, such as political leaders and elite academics. Instead of adopting views of science that value only certain knowledge, skills, and habits of mind as "scientific", all are encouraged to critique these narrow views and allow everyday people, such as youth, a voice in defining science to include systematic practices in their own everyday lives. If we as education advocates want schooling to serve the purpose of building critically-minded citizens who participate actively, fully, and productively in a democratic society, the curricular and instructional approaches we use in school science must foster youth's identity work in service of critical science agency.

Article 2 demonstrates curricula's potential—and Sci-YAR's potential in particular—to facilitate youth's identity work in service of critical science agency. It offers researchers and other leaders in the field of science education a comprehensive view of youth's identity work by examining it through various lenses that highlight both the individual and social aspects of this process. Rather than holistically examining a structured curriculum's ability to facilitate youth's identity work in service of critical science agency, this piece highlights specific key features of Sci-YAR and analyzes how those features both enabled and constrained youth's identity work in particular cases. The nature of the Sci-YAR curriculum—being designed around principles manifested in its key features—and the analysis of its impact on youth's identity work using multiple lenses intends to develop more complex understandings of how youth might engage in identity work in service of critical science agency as they participate in school science.

Article 3 brings together the theoretical knowledge used to conceptualize Sci-YAR and the empirical findings from studying its enactment in a school science course to inform teachers' practices in their own classrooms. The arguments made in the first two articles regarding Sci-YAR's ability to facilitate youth's identity work in service of critical science agency—and therefore develop their critical science literacy and their use of science to enhance their participation as democratic citizens—cannot be substantiated without bringing this knowledge to practitioners who work directly with youth in the science classroom. Article 3 also reflects the basic tenets of Sci-YAR, as it acknowledges and values the importance of both teacher agency and making science curricula and research relevant to practitioners. This article promotes practitioner relevance by valuing their own agency as educators to make curricular and instructional decisions that best fit their contexts and the needs of their students. Emphasizing Sci-

YAR's key features as principles that can be infused into any existing curriculum and encouraging practitioners to select and implement the features most meaningful to them and their own students, rather than presenting Sci-YAR as a packaged curriculum, aims to enhance practitioners' own critical science agency.

My dissertation would not be complete without these three complementary viewpoints that highlight unique perspectives on challenges and opportunities present in science education, yet all critically evaluate what science curriculum and instruction should entail. All three articles aim to make the discipline of science a relevant set of contexts and tools that real people can use to take positive action to affect change in their lives and in the world.

Personal Reflections on the Dissertation Process

This process of developing a curriculum, designing and conducting research to study that curriculum, and then writing this three-article dissertation has been a six-year journey that has facilitated my own identity work in service of critical science agency. When I first entered my doctoral program, I did not know what would be the focus my research, but I certainly knew it would not have anything to do with science! Like many of the elementary teachers with whom I now work, I had experienced science in very narrow and limiting ways throughout my own schooling, and I failed to see it as something relevant to my life or something that could enhance my agency and my impact on the world. Despite taking honors science courses in high school and receiving A's in those classes, I did not think I had a "mind" for science, and so I initially shied away from teaching it to my own elementary students. As I individually constructed images and understandings of myself as being disconnected with science, others also influenced this identity work in specific ways. I constantly heard messages about teachers not having enough science content knowledge, and I always feared I was inadequate in this area. Even my own family shaped my identity work, as they told me that science was just not my strength. (Imagine their surprise when they discovered I was focusing my dissertation research on science!) I can greatly identify with the youth I write about in this dissertation. Initially, I was an outsider when it came to science, and I had formed an identity that included images and understandings of myself as an intelligent woman and passionate educator, yet someone who was not competent enough to do or teach science, resulting in my own disconnection and disengagement with this discipline.

This situation began to change once I was introduced to the critical frameworks used to question dominant views regarding science education. I intimately connected with authors like Angela Calabrese Barton, Chris Emdin, and Michael Wolff-Roth who wrote about others' attempts to exclude them, and the youth with whom they worked, from science. I was inspired by their efforts to speak back to those attempting to keep science an elite discipline accessible to only a few, and I was invigorated by their calls for action. In addition, reading critical literature in other areas and learning about initiatives, such as Youth Participatory Action Research, helped me broaden my views of what practices of science could entail, and it showed me the power science could have to facilitate personal and social transformation. These ideas prompted me to redesign my own (almost non-existent) elementary science curriculum, which began a radical transformation of my own identity towards embodying critical science agency.

During the 2009-2010 school year I started *really* teaching science. No more textbooks, wrote memorization, “scientific method”, or feeling inadequate about my own knowledge. Instead, my fifth-grade students and I actively explored questions of interest together. We designed and conducted important tests that would help us learn about the world around us. For example, studying the effects of pollution on a model ecosystem in a 2-liter bottle prompted us to think about ways we might be hurting our own environment, such as by contributing to air pollution or over-salting our sidewalks. We engaged in engineering design challenges and applied principles of physical science to make ideal products with a purpose. We studied the interaction of land and water, and we learned how to model large-scale processes, such as erosion, to see what effect this might have on our earth and our lives. We reflected on how having an abundance of clean water is a blessing, and to show our appreciation, we raised money to build water wells for small towns in Haiti. I did not realize it until now, but these experiences were significant ways I engaged in identity work in service of critical science agency. I was transformed from the teacher who never taught science, to being known as “the science teacher” in my school. When I left the elementary classroom at the end of that school year, my gift from my class was a lab coat signed by all of my students with the words “Mrs. Coleman, Science in Session” embroidered on the front. That year, for the first time, my students developed a passion for learning science, and they were powerful influences in promoting my own identity work as a scientific thinker, doer, and teacher.

Changes in my life continued to enable and constrain my identity work in particular ways. As I transitioned into being a science teacher educator at Loyola, I once again began to doubt the extent of my knowledge and skills. Initially, I had difficulty connecting with many of the teacher candidates in my classes the way I had with my elementary students, and I wondered if I really ever knew that much about science or science teaching. However, when the opportunity arose to design and implement the Sci-YAR curriculum with Megan, this experience shaped my identity work in significant ways. We designed a curriculum that was relevant to our experiences learning about research as doctoral students, and we exercised our agency by teaching science in a very different way than either of us (or anyone else in the school) had done before. Despite the challenges and struggles we experienced this first year of implementation, going through this process and conducting a self-study on our transformation as educators enabled my identity work in service of critical science agency.

Each year we implemented Sci-YAR, I saw more students undergo personal transformation and work to bring about social transformation. Witnessing the ways these youth used their practices of science to improve their lives and influence their schools and their communities strengthened my sense of critical science agency as a practitioner, as this is when I became fully conscious of science learning being a context and a tool for youth to take action. Being exposed to the range of issues youth considered to be scientific, as well as articulating my own beliefs and values about science education through my teaching, continued to broaden my definition of science. In addition, when I saw students who underwent extensive personal transformation during their participation in Sci-YAR, my efficacy as a science educator was renewed, and I was convinced that this curriculum's implementation needed to be studied, in order to document youth's experiences.

Moving this work forward by designing and conducting the research for my dissertation continued to influenced my identity work, specifically as a science education researcher. Having had limited experience collecting and analyzing data in order to formulate original findings, when I began my research, I was often afraid of "messing up" when interviewing students, coding and analyzing data to generate themes, or asserting my ideas when constructing and presenting arguments. As a teacher, I emphasized broad definitions of science with youth, but as a researcher, I was still stuck in the mindset that my own practices of science had to be done in a particular, correct way (defined by other experts, of course) in order to produce any legitimate knowledge. Through countless in-depth conversations with Dave and constant dialogue through my writing and his comments on my work, I began to develop a stronger sense of agency as a researcher. Having previously relied on heavily quoting others and over-citing their ideas, Dave encouraged me to step out from behind these scholars and stand *with* them in articulating my views of the purpose of science education, defining my own curriculum, and arguing for how educators can best serve youth in science classrooms. A small artifact from Dave—a Post-it note hanging above my desk that reads, "Your ideas are as legitimate as others."—has served as a reminder that what I teach youth about science applies to me as well. Although I admittedly still have fears about the inadequacy of my work at times—indicating to me that this process of identity work is never complete—

through my research, I have actively worked to construct images and understandings of myself as a science education researcher embodying critical science agency.

My identity work as both a teacher and a researcher have not taken place in isolation, but rather, are intertwined and have occurred through extensive personal reflection and rich interactions with others. While simultaneously implementing Sci-YAR and designing my dissertation research, others helped me conceptualize all the experiences I was having in practice and translate them into particular frameworks I could use to approach this work as a researcher. Heidi introduced to me ideas related to identity work and critical science agency, which finally helped me to name the empowering and transformative experiences I had with regards to science, and what I was trying to bring to other youth through Sci-YAR. Dave constantly encouraged me to look at these concepts from multiple lenses, so I could enhance the perspectives heavily influenced by socio-cultural theory that had been used in so many studies about identity in science. Moreover, Dave, Heidi, and Ann Marie were all constant influences on my identity work in service of critical science agency, as they positioned me in ways to reinforce my competence as a science education scholar, researcher, and practitioner. They helped me gain the confidence necessary to develop and assert my own perspectives and my own original work, rather than simply rely on others as being the experts in the field.

In addition, using the three-article format for my dissertation emphasized the interconnectedness of the practitioner and researcher aspects of my identity, and it promoted my identity work as a researcher who can communicate for various purposes to multiple audiences. When writing the theoretical article, I developed my skills in translating the concrete experiences I had developing Sci-YAR into broader conceptual ideas, which allowed me to draw on my own practice to question dominant frameworks in science education and assert my views regarding the purposes of science education. Preparing for and writing the empirical article strengthened my skills in coding data, analyzing it to generate themes, and then constructing claims supported by robust evidence. Not only was it a challenge to navigate these processes, but I also struggled to maintain a scholarly tone in my writing, while still allowing the voices of my youth participants to be heard. Working through these difficulties helped me further assert myself as a researcher, while still honoring the experiences, perspectives, and voices of the youth with whom I worked. Finally, writing the application article strengthened my ability to communicate the ideas in my theoretical and empirical pieces to practitioners who work directly with youth in science classrooms. Being able to articulate what I had learned from my work conceptualizing Sci-YAR and studying its implementation, while still attending to practical concerns that arise in science classrooms and schools, helped me embody the idea that theory can directly inform practice. Furthermore, it solidified my stance as a researcher whose primary concern will never be achieving a long list of publications in top-tier journals, but rather ensuring my work applies directly to classrooms, so that it might benefit both teachers and youth.

My experiences as both a practitioner and a researcher over the past six years have helped me realize a vision of science as a way of knowing and taking action, rather than a discrete set of knowledge and skills to be learned or demonstrated. These experiences also strengthened my commitment to critically question narrow views of science and to give both youth and myself a voice in defining how science can be manifested in our own lives. Reflecting on this process, it is evident that every person I worked with on this dissertation has significantly influenced my thinking and my identity work in particular ways. Similar to my participants who found collaborating on research a significant learning experience, my collaboration with others such as Megan, Dave, Heidi, and Ann Marie made my research meaningful and enabled me to engage in my own identity work as I constructed positive images and understandings of myself in relationship to science. I now find that I exemplify someone who has gone through personal transformation to embody critical science agency, and that this identity work took place in relationship to the five key features of Sci-YAR. Completing this dissertation enabled my identity work in service of critical science agency because:

- I had opportunities to use science as a way of knowing and taking action.
- I engaged in relevant practices of science through my own research.
- I had opportunities to collaborate with others throughout this process.
- I had the autonomy to generate and lead my own research.
- I consistently incorporated extensive personal reflection into the research process.

Engaging in these key features helped me develop my conception of science as a tool and a context for me to take action. I also began to see myself as a scientific thinker, doer, teacher, and researcher as I engaged in designing, conducting, and disseminating my own research.

Furthermore, I see my dissertation research as a venue in which I used my practices of science to take positive action and bring about personal and social transformation. I was transformed through my research, and seeing the positive changes and growth in myself kept me going, even when the process was long, arduous, and involved significant sacrifice. Finally, I see my dissertation research as sparking social transformation, currently on the local scale, but hopefully on a broader scale in the future. When I think of the youth whose views of science and whose lives have been impacted by their participation in Sci-YAR, I am reinvigorated to continue this work and take it to new levels. My hope is that by disseminating my research to the larger science education community, and then continuing to bring Sci-YAR's key features to teachers and students on a broader scale, I might continue to enhance both my own sense of critical science agency and those of youth, teacher candidates, and teachers everywhere.

APPENDIX A

SCI-YAR CURRICULUM STRUCTURE AND KEY OBJECTIVES

Unit 1: Selecting a Research Topic

During this unit, youth collectively:

- Select an issue of concern in their lives, city, communities, and/or neighborhoods, explain how the proposed topic relates to an area of science, and then begin to analyze this issue in light of the cultural, social, and political context.
- Engage in the beginning stages of the research process by elaborating on their topic, using graphic organizers to make their thinking visible and written language to explain their topic in detail, providing support for the validity of researching their topic.

Unit 2: Developing a Research Plan

During this unit, youth collectively:

- Generate investigable research questions that require taking action to address, are connected to the problem or issue they are investigating, will potentially help them develop a deeper understanding of the problem, and are of value in that they might bring about possible solutions to that problem.
- Select data collection methods to inform their research questions and display the connections between their research questions and data collection methods in a matrix.
- Create a written research plan that provides overall goals for the project, some background information on their topic, multiple investigable research questions related to the topic, and data collection methods and potential sources that will help them gather data to inform those questions.
- Share their written research plans with the class and provide other groups feedback on their work through a written peer assessment.

Unit 3: Collecting and Analyzing Data

During this unit, youth collectively:

- Execute their data collection plans in a timely manner, communicating clearly and professionally with the teacher and other adults involved in the data collection process, and generating at least three forms of data from different sources that help them address one or more of their research questions.
- Consistently review and organize their data, as well as conduct ongoing analyses of the data as they collect it, using methods that are most appropriate given their data and research questions.
- Share their progress made on data collection and their preliminary findings with the class, incorporating the feedback they receive as they move forward in their research.
- Reflect on their own contributions to the project and their ability to effectively manage time and communicate with others through written self-assessments, as

well as provide other group members with feedback on their work and group contributions through written peer assessments.

Unit 4: Formulating Findings, Sharing Results, and Taking Future Action

During this unit, youth collectively:

- Use their own data to generate findings in the form of robust claims supported by multiple pieces of evidence from multiple sources.
- Develop written action plans based on their findings that outline possible future actions that could be taken to address problems in their own lives, city, communities, and/or neighborhoods, using the knowledge and skills gained from conducting their own research.
- Disseminate their research and findings at a school-wide research symposium, where they listen to others' points of view and use others' critiques to think about how they might take action in the future to improve and/or continue their investigation.
- Reflect, in writing, on how they used science as a tool to help them address a problem and how they might use science in the future to take action to make the world a better place.

Throughout the entire curriculum youth:

- Identify, compare, and critique various definitions of science as they develop and continuously revise their own written definitions of science.
- Document the development of their practices of science and their own personal growth through the use of various media, such as writing, art, photography, film-making, blogs, or other social media.
- Consider, discuss, and write personal reflections on how their participation in action research has influenced them as people and, specifically, how their participation in action research has influenced their scientific practices.
- Review all data collected through self-documentation and reflections, and generate claims/new realizations about how participation in action research has influenced them as persons, as well as how participation in action research has influenced their scientific practices.
- Share the realizations brought about through their action research at the research symposium, with the intention of positively influencing both themselves and others by showing the benefits of conducting action research.

APPENDIX B

PICTURE FRAME ACTIVITY STUDENT DIRECTIONS

Directions:

1. Tape/glue your photo representing yourself in the middle of a blank piece of paper. If you do not have a photo, you can draw a picture that represents you.
2. Create a "frame" for the picture by writing 4 statements or phrases as borders for the picture:

<u>Top</u>

What is in the picture (if it's an object) OR What you're doing in the picture (if it's an action)

Why you picked this photo or picture to represent you

<u>Right</u>

What this picture shows about you

What others will think about you when they see this picture

<u>Bottom</u>

Some skills you have related to this picture

<u>Left</u>

How you can use those skills as you do your research

APPENDIX C

GROUP AND TOPIC SELECTION PROCEDURES

1. Students brainstorm topic ideas and choose the top three they wish to investigate.
2. Record all students' top three topics on chart paper and post them around the room.
3. Discuss criteria for selecting a good research topic including: What has clear connections to the course? What is related to students' lives and most meaningful? What will be feasible given time, materials, students' skills, etc.? What might potentially benefit the school and/or surrounding community?
4. Students browse the room, looking at all the topic ideas, and stand by the topic of most interest.
5. The students gathered together discuss their interests in the topic and what issue they might investigate. If students are alone, they look to other topics and discuss with others how their topics might be related and if they might be able to form a single group.
6. Once preliminary groups have formed, students record group members' names and a short description of their proposed issue or problem, indicating why they joined together as a group and why their topic is appropriate to research.
7. Teachers review these proposals to determine whether groups have formed under appropriate circumstances and facilitate any changes if necessary.

APPENDIX D

DATA COLLECTION CHECK-IN FORM

1. What data has your group collected so far?

2. What data does your group still need to collect? List the dates and times when the data will be collected.

3. What help does your group still need from us? Is there anything else we should know?

APPENDIX E

RESEARCH QUESTION ORGANIZER

As you collect data for your group, write down information you've gathered that will help you address each of your research questions.

Research Question #1:
Relevant Information Collected:
Research Question #2:
Relevant Information Collected:
Research Question #3:
Relevant Information Collected:

APPENDIX F

CRITERIA FOR EVALUATING FINDINGS

Evaluate how strong your argument is by asking yourself:

1. Are the claims made here reasonable and clear?

2. Are they supported by multiple pieces of evidence from multiple sources?

3. Is the reasoning connecting the evidence to the claims clear and logical?

APPENDIX G

SELF-ASSESSMENT AND PEER ASSESSMENT FORMS

Self-Assessment

1. What positive things do you think you have done to contribute to the project? In other words, what have you done that you are most proud of so far?

2. What not-so-positive things have you done to prevent the group from making progress on the project? In other words, what areas could you work on to improve your performance in the group?

3. What role(s) have you played in your group (i.e. leader, follower, information finder, organizer, slacker, etc.)? How have these roles helped or hurt the group's efforts?

Peer Assessment

Name of group member: ____________________________________

An accomplishment and/or strength that this group member has contributed to the project:

An area in which this group member is encouraged to improve:

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VITA

Elizabeth Rimkus Coleman is the daughter of Charlie and Ann Rimkus. She was born in Poughkeepsie, New York on August 20, 1980. She grew up in Chantilly, Virginia with her three siblings, Kathleen, Laura, and Dan. She currently resides in Chicago, Illinois with her husband, Ed, and her quirky English bulldog, Polly Frances.

Elizabeth attended Catholic elementary and high schools in New York and Northern Virginia. She graduated from the University of Notre Dame in 2002 with a Bachelor of Arts in American Studies. In 2004, she earned a Master of Arts in Education from Seton Hall University.

Elizabeth has worked in the field of education for the past 12 years. She began her career as a Catholic elementary school teacher in Elizabeth, New Jersey. In 2005, she moved to Chicago and continued to work in elementary schools until 2010. She then accepted a one-year appointment as a Clinical Assistant Professor at Loyola University, where she began her career as a science teacher educator. She continues to work as an Adjunct Professor for the Teaching and Learning Affinity Group in the School of Education.

Elizabeth has been active in the Loyola community, working as a graduate assistant and faculty member for the past four years. She has served on the Teaching, Learning, and Leading with Schools and Communities (TLLSC) Program Redesign Steering Committee, where she has aided in the design, review, and implementation of new program courses. She has also worked to develop and sustain relationships with school and community partners in the city of Chicago, such as the Lincoln Park Zoo and the Peggy Notebaert Nature Museum. She has accepted a tenure-track faculty position as Assistant Professor in Elementary Science Education at the University of North Carolina Charlotte, where she will work in the Department of Reading and Elementary Education starting in the fall of 2014.

DISSERTATION COMMITTEE

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