HOW URBAN YOUTH EXPRESS CRITICAL AGENCY IN A 9TH GRADE CONCEPTUAL PHYSICS CLASSROOM

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An array of data suggests that American students do not have a deep comprehension of physics and remain disenfranchised from a physics education. Drawing upon critical feminism, funds of knowledge and Freire, I developed the idea of critical physics agency to describe instances in which students expressed rigorous knowledge and skills in physics but also used physics to pursue goals for personal and community transformation. The research questions explored in this study include:

1. What do five urban youth, enrolled in a 9th grade conceptual physics course, articulate as their critical goals -- their goals for participation in physics, for participation in relationships, and for personal and community transformation?

2. In what ways do students work towards their goals in their physics classroom? Specifically:

   - What mechanisms do youth use to pursue their critical goals?

   - How do youth transform curriculum to shape the figured world of their classroom?
3. What are the relationships among critical goals, youth identity, utilization of resources and how youth use physics as a context and tool for agency?

The research is qualitative and took place in an under-resourced public school in New York. Data collected included interviews of five students and their families and teachers, student work, classroom observations, field notes and reflection on my role in the study as a teacher-researcher. I analyzed data using principles of grounded theory.

Students articulated critical goals related to: learning, finding opportunities for voice, altering participation in relationships and participating in the world, as activists. Youth, using physics as both a context and a tool, relied on three mechanisms to progress towards their critical goals: a) pursuit of physics related careers, b) engaging in and creating opportunities to learn physics content and skills, and c) taking on the role of a scientist. Youth also expressed agency by envisioning and enacting lesson plans for their physics classroom. How youth revealed agency was linked to their identity and funds of knowledge. Choice, inquiry-based curriculum, opportunities to cultivate specialized epistemic authority, and the process of engaging in action research were key resources that students drew upon.
# Table of Contents

Table of Contents........................................................................................................................... i  
List of Tables .............................................................................................................................. vii  
List of Figures ............................................................................................................................ viii  
Acknowledgements..................................................................................................................... ix  
1. Introduction ................................................................................................................................1  
2. Literature Review ...................................................................................................................... 6  
   The Challenges of Physics Education in the United States: Poor Performance and Exclusion........ 6  
   Historical Explanations for Declines in Physics Education Quality and Enrollment........ 8  
   Defining Physics Literacy: Conceptual Understanding and the Nature of Science......... 9  
      Rationale for Scientific Literacy......................................................................................... 9  
      Defining Scientific Literacy ............................................................................................ 10  
      Rationale for Physics Literacy .......................................................................................... 12  
   What Does It Mean to Be "Physics Literate? ................................................................. 13  
      Physics as a foundation for exploring the structure and principles that govern the universe............................................................................................................................ 14  
      Physics as a foundation for enhancing and developing new technologies ............. 15  
   "Incremental" versus “Fundamental” Change ..................................................................... 16  
   "Incremental" Changes for Cultivating Engagement and Rigor in Physics Education ...... 17  
      Changes in School Organization ....................................................................................... 17  
      Training, supporting and compensating teachers ....................................................... 18  
      Cultivating teacher leadership, independence and empowerment .............................. 20  
      The systematic effects of standards on physics course offering ............................ 22  
      Small schools: documented advantages and organizational questions ............... 22  
   How Can Physics Educators Encourage a Broad Range of Students to Participate?  
      Possibilities within the Category of Incremental Change ............................................. 25  
         Encouraging women ....................................................................................................... 25  
         Encouraging minorities and English-language learners ............................................ 28  
         Encouraging students with disabilities ........................................................................ 29  
         Encouraging students from low-income backgrounds ........................................... 31  
   When Should Physics Be Taught? ................................................................................... 32  
      Project 2061 ..................................................................................................................... 32  
      Physics 1st ......................................................................................................................... 33  
   How Should Physics Be Taught? Possibilities within the Category of Incremental Change .... 36  
      Less is more. ..................................................................................................................... 36  
      The importance of collaboration: physics curriculum designed around the philosophy that science is socially-influenced ............................................................ 37  
      Math integration and rigor ............................................................................................ 38  
      Technology ....................................................................................................................... 40  
      Incorporating advances in science into the physics curriculum ............................... 42  
      Incorporating parents in student learning .................................................................... 44  
   Incremental Change in Assessment ................................................................................. 44  
      Assessing conceptual change .......................................................................................... 45
4. Being an Activist by Increasing One’s Participation in the World ........................................ 186
Summary .................................................................................................................................. 188
Cross-Cutting Themes ............................................................................................................. 193
How Critical Goals Connected to Youth Building a “Physics Presence” .......................... 193
How Critical Goals Were Shaped By and Shaped Students’ Figured Worlds ............... 197
6. Mechanisms through Which Students Pursued Their Critical Goals ............................ 199
The Process of Agency: Mechanisms Students Used to Pursue Their Critical Goals 200
Mechanism 1: Students, by pursuing physics-related careers, sought to transform their identities ................................................................. 200
How Grant, Linda and Nicholas used their pursuit of physics-related careers to advance their critical goals ........................................................................................................ 200
Resources that Grant, Linda and Nicholas drew upon in linking physics-related careers with critical goals ........................................................................................................ 208
The role of physics as context or tool in linking physics-related careers with critical goals ..................................................................................................................... 211
Mechanism 2: Students, by engaging in and creating opportunities to learn about the universe and materials in it, sought to transform their identities ................................................................................................................................. 215
How engaging in and creating opportunities for understanding the universe helped Darlene, Linda and Kanisha pursue their critical goals ................................................................................ 215
Resources that Darlene, Linda and Kanisha drew upon in linking opportunities to learn about the universe with critical goals ................................................................................ 217
The role of physics as context or tool in linking opportunities to learn about the universe with critical goals ..................................................................................................................... 218
Mechanism 3: Students, by taking on the role of a scientist, sought to transform their identities ................................................................................................................................. 221
How taking on the role of scientist and helped students pursue their critical goals. .................. 221
Resources student drew upon in taking on the role of scientist with critical goals. .................. 222
The role of physics as context or tool in “taking on the role of a scientist” with critical goals ................................................................................................................................. 223
Cross-Cutting Themes ............................................................................................................. 225
The Relationship among Mechanisms, Critical Goals and Resources for Agency 225
7. Critical Physics Agency Expressed Through the Transformation of Physics Curriculum .... 225
Introduction .................................................................................................................................. 230
How Case Study Youth Envisioned and Enacted the Transformation of Physics Curriculum ................................................................. 231
Darlene ..................................................................................................................................... 231
Darlene’s envisioned curriculum ............................................................................................. 232
Decisions to enact the lesson plan ............................................................................................. 233
Relationships between Darlene’s authority and the design and enactment of curriculum ................................................................................................................................. 235
Grant: ...................................................................................................................................... 235
Grant’s envisioned curriculum ................................................................................................. 236
Decisions to enact the lesson plan ............................................................................................. 237
List of Tables

Table 1: Elements of Critical Physics Agency ................................................................. 141
Table 2: Critical Goals of Case Study Youth .................................................................... 191
Table 3: Youth Progressed towards their Critical Goals by Pursuing-Physics-related Careers ........................................................................................................ 214
Table 4: Youth Progressed towards their Critical Goals by Engaging in and Creating Opportunities to Learn about the Universe and Materials within It ........................................ 220
Table 5: Youth Progressed towards their Critical Goals by Taking on the Role of a Scientist ............................................................................................................. 224
Table 6: Envisioning and Enacting Lesson Plans, Connections with Epistemic and Positional Authority ......................................................................................... 248
List of Figures

Figure 1: Sample Concept Map by Student Prior to Unit on Newton’s Law ..................... 46  
Figure 2: Sample Concept Map by Student after Unit on Newton’s Law ........................... 46  
Figure 3: Processes that Contribute to and Culminate in Student Agency ..................... 60  
Figure 4: Exploring Identity: Foundational to and Shaped by Reflection on Agency ...... 60  
Figure 5: Settings Goals: Connecting Identity to Agency and Refined by Reflection on Agency ................................................................................................................................. 62  
Figure 6: Enhancing One’s Repertoire to Make Acts of Agency More Effective............ 64  
Figure 7: Model for Critical Physics Agency ..................................................................... 92  
Figure 8: Model for Agency Based on Data Regarding Critical Goals ...................... 193  
Figure 9: Revised Model for Agency Including Mechanisms for Progressing Towards Critical Goals ......................................................................................................................... 229  
Figure 10: Revised Model Based on Data Regarding Transformation of Curriculum ... 250  
Figure 11: Revised Model of Agency Including Resources for Curricular Transformation ............................................................................................................................................. 254  
Figure 12: Summative Model Showing Curricular Transformation as An Example of Critical Physics Agency ............................................................................................................... 259  
Figure 13: Final Model for Critical Physics Agency ............................................................. 271
Acknowledgements

I feel strongly that all young people, of all backgrounds, should have access to an excellent science education that is simultaneously rigorous and engaging. The purpose of my research was to explore ways in which these dual goals could be accomplished.

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Chapter 1

Introduction

John Glenn (2000), in the report *Before It's Too Late*, writes that "mathematics and science will...supply the core forms of knowledge that the next generation of innovators, producers and workers...will need if they are to solve the unforeseen problems and dream the dreams that will define America's future" (p. 4).

Knowledge of physics is essential for a person to be an informed, intelligent participant in society. Physics research often catalyzes technological and economic progress. Gadgets -- computers, radios, telephones, X-rays, MRIs -- that increase our efficiency and the quality of our lives are the result of physics research. World-wide conflicts are centered around the products of physics -- World War II, the recent American intervention in Iraq and many regional conflicts such as that between India and Pakistan involve the threat of nuclear weapons. Private companies and the federal government spend billions of dollars on physics research and development\(^1\). Physics has allowed us to investigate renewable forms of energy -- for example, solar panels, nuclear power plants and fuel cells. Through physics, we increasingly understand the universe in which we reside. Given the ubiquitous impact of physics in our lives, successfully including all types of people in physics, as scientists or informed, activist citizens, is essential for a society that hopes to be innovative, ethical, and dynamic.
Despite the fact that learning physics is imperative for informed citizenship and opens possibilities for affecting the direction of one's community, nation and world, statistics predict that the low-income, minority students whom I teach in Sunnyside Park are unlikely to have access to a quality physics education.

The neighborhood in New York City, where I teach, is a place of rich cultural diversity, growing home ownership and community activism. The students who attend public schools in this area are almost entirely black, of Caribbean-American origin. The school is located in a poor district, has a history of racial tensions, and one of the highest incidences by neighborhood of HIV infections in New York City. Not many students from this neighborhood are likely to enroll in high-school physics. The few who do will probably not develop the engagement and skills to pursue physics in college, investigate physics as a career, or participate in the resolution of social issues that require an understanding of physics.

The disenfranchisement that one might expect for my students is an extrapolation from the overall state of physics education in the United States. Only a small percentage of students in the United States enroll in physics. This small number of students does not reflect the diversity of race, geographic origin, income, gender and disability evident in the larger student population. Students who do take physics in the United States do not achieve as highly on international comparisons as do physics students in other countries. The problems listed above result largely from how physics is taught and learned in the United States. Christian and Belloni (2001) write that

Physicists are consistently among the most creative and inventive of all scientists. ...But as teachers, we tend to be among the most conservative, repeating the content and methods that we had received from our teachers and that they had from theirs. For the coming generation of students, that's not going to be good enough. We are going to have to understand their ways of
thinking and their learning styles. We are going to have to find new ways of holding their interest and keep them excited about learning physics (p. xv).

Project 2061 and the idea of Physics 1st (physics for all students in the ninth grade) are strong proposals that emphasize engagement, conceptual understanding and rigor. They are movement in the direction to which Christian and Belloni (2001) aspire. But these curricula are insufficient for remodeling the elitism, conservatism and underperformance that characterize the field of physics education. To a large degree, Project 2061 and Physics 1st are positivist programs – they specify the content and process to be learned without incorporating the context and beliefs of learners into curriculum.

In contrast, critical, feminist theory suggests that for marginalized and resistant students to be successful, science curriculum should be structured with the needs, beliefs and interests of students in mind. Education must be connected deeply to and shaped from students’ life experiences – their “funds of knowledge” (Gonzales & Moll, 2002). Freire proposes that for education to be more than the perpetuation of oppressive power structures, students must critically reflect upon these systems and then use their analysis to transform their world with the goal of improving equity.

Turner (2003) combines an emphasis on engagement and excellence with critical and Freirian theories, in her exploration of mathematics education. She develops the idea of critical mathematical agency – “a student’s capacity to (a) view the world with a critical mind set and imagine how the world might become a more socially just, equitable place, and (b) identify themselves as powerful mathematical thinkers who construct rigorous mathematical understandings” (Turner, 2003, iv).

Freire suggests that this meeting of scholastic excellence and social activism is essential in an educational setting. He writes, “Teaching, by its very nature, involves
rigorous intellectual pursuits" (Freire, 1998, 4). Salinas and Reyes (2004) write that educators interested in advocacy must have high expectations of their students. In short, a commitment to social justice and student-centered science can occur alongside an emphasis on intellectually-exacting curriculum. In fact, one can strengthen the other.

I choose the term critical physics agency for the learning that take place when physics education is based on pedagogical strategies that cultivate engagement, excellence, on youth directing their action towards their personal goals, on students’ “funds of knowledge,” and on Freire’s notion of personal and social transformation. My research questions are as follows:

1. What do five urban youth, enrolled in a 9th grade conceptual physics course, articulate as their critical goals -- their goals for participation in physics, for participation in relationships, and for personal and community transformation?

2. In what ways do students work towards their goals in their physics classroom? Specifically:
   - What mechanisms do youth use to pursue their critical goals?
   - How do youth transform curriculum to shape the figured world of their classroom?

3. What are the relationships among critical goals, youth identity, utilization of resources and how youth use physics as a context and tool for agency?

However, teaching and learning towards any agenda do not stand apart from external influences; they function within the context of a school and school system. Several authors discuss the effects of school organization on teaching and learning. For example, Borko, Wolf and Simone (2003) document the significant impact of “principal
leadership; professional community; program coherence; technical resources...and learning opportunities for teachers” (p. 171 and 174) on student proficiency. Glasser (1990) emphasizes how an administrator’s philosophy and practice greatly affect school success. Given the importance of school structure in determining student experience, I have explored how school mission, organization and community influence the development of critical physics agency at my research site.

It is my hope that as a result of our participation in this research, my students and I have acquired a better sense of critical physics agency. We have observed and reflected upon the power structures that govern our society, and tried to take small steps in transforming situations of oppression to those of freedom. I hope that the research we have engaged in together will have an impact beyond my classroom and students. My goal is to contribute to the body of literature that explores how to make physics education inclusive, engaging, rigorous, empowering and transforming. In this way, I imagine that my work might contribute to improvements in physics education that directly impact students and, therefore, our society.
Chapter 2

Literature Review

The Challenges of Physics Education in the United States: Poor Performance and Exclusion

According to the report *Before It's Too Late*, American fourth-graders taking the Third International Mathematics and Science study “scored above the international average in math and science” (p. 10). However, advanced math and physics students scored poorly on this test – no other country of the forty-one total “scored significantly lower than the United States in advanced mathematics, and only one scored lower in physics” (p. 10). As students spend time in school in the United States, their performance in physics, relative to their peers around the world, declines.

Other sources of data suggest that physics education in the United States is unsuccessful. Only a small fraction of the overall population is pursuing physics. In 1998, only 29% of high-school students took a first-year of physics (US Department of Education, National Center for Educational Statistics\(^4\)). In 2001, the number of foreign graduate students in physics surpassed the number of American students (AIP Report, 2003, Figure 4). The raw number of physics bachelor’s degrees awarded declined between 1970 and 2000; physics degrees now constitute 0.33% of total bachelor’s degrees awarded (AIP Report, 2003, Figure 1). Redish and Steinberg (1999) write that
"More than 95% of students in introductory [college] physics will never take another physics class (p. 24).

Students who do enroll in physics do not represent the diversity of the general American population. Women and minority groups are vastly under-represented in the number of bachelor’s, master’s and Ph.D.s awarded (AIP Report, 2003, Table 8). Gollub and Spital (2002) state:

Inner-city and rural schools, and especially those with high percentages of under-represented students, are less likely to offer advanced courses [in physics]. Private school students are more likely than public-school students to enroll in physics (AIP Report, 2003, Figure 1). Many schools in low-income communities are poorly equipped to provide advanced study because they lack qualified teachers or sufficient laboratories, equipment and other curricular materials...students with low socioeconomic status are still much less likely to enroll in AP courses even when they are available (p. 49).

The American Institute of Physics argues that physics enrollment is increasing and that racial and gender gaps are improving. Nevertheless, the following still hold: (1) Not many students are studying physics at any level. (2) Those who pursue physics do not compete well with students from around the world. (3) The enrolled physics population does not reflect the diversity of the American population.
Historical Explanations for Declines in Physics Education Quality and Enrollment

In 1893, the Committee of Ten, and later, the Committee on College Entrance Requirements, supported the decision that physics be taught before chemistry. At the turn of the 20th century, more students were taking physics before chemistry than vice versa. However, physics enrollment has been in decline since the 1920s (Sheppard and Robbins, 2003). Multiple historical factors explain this decline.

First, groups such as the Committee on the Reorganization of Science in Secondary Schools recommended the placement of biology before physics and chemistry (Sheppard and Robbins, 2003). So, by 1948, 80% of physics classes were offered to students during their senior year of high-school (Sheppard and Robbins, 2003). Meanwhile, the Committee on College Entrance Requirements (CCER) made a crucial recommendation that would shape the future of secondary science education. The report of the CCER “in 1899 led to the establishment of the ‘credit system’ for subjects, and they recommended that only one science credit be required for college admission. This decision would effectively make both physics and chemistry [into] elective subjects, because as biology started to appear as a distinct subject it was almost always placed before chemistry and physics in the sequence” (Sheppard and Robbins, 2003, p. 422).

The credit system resulted in high-school science subjects being offered as one-year courses and delayed offering of physics in a high-school student’s course sequence. This combined with the implication that the subject was an elective resulted in a precipitous decline in the percentage of students enrolled in physics. Also, students and
teachers often complained that physics was overwhelmingly abstract and mathematical. Sheppard and Robbins (2003) argue that these issues arose as high-school physics evolved into a selective course – a class that only an elite group of students pursued and that increasingly resembled a mathematically-driven college physics course.

**Defining Physics Literacy: Conceptual Understanding and the Nature of Science**

Before inquiring into how one might improve the poor physics education available to most students in the United States, it seems essential to define what a rigorous, meaningful education in science and physics might include. So, in the following sections, I propose definitions of science and physics literacy, based on existing research.

**Rationale for Scientific Literacy**

Knowledge of science and of scientific inquiry is essential to be an informed, intelligent participant in society. Inquiry in science, in part, determines what tools our society uses for resolving domestic and foreign conflicts, meeting health care needs, constructing homes and businesses, traveling by air, train or road, and providing entertainment. If people are simply consumers, if they do not understand the design of products and the process by which products are created, they are likely to struggle with the complexity of ethical issues that arise with scientific progress. For example, a scientifically-informed individual might:
• pro-actively ask about the side effects of the therapies recommended by her doctor and explore the possibility of clinical trials for new drugs

• avoid dangerous illegal substances and risky sexual practices because he understands the effects of such behavior on his brain and body.

• contest the placement of waste dumps in her neighborhood until her city has investigated the potential of increased health risks to her community

• purchase new generations of software only after estimating the costs and benefits of upgrading his computer system

• ask the government for public information about the range, firepower, deployment capability, destructive potential and diplomatic implications of lethal weapons before voting for or against increased military spending

• develop new theories or discover new information for understanding, modeling and predicting aspect of the universe

In my opinion, a scientifically-informed individual understands current scientific models and the process by which scientific knowledge is accumulated. Without scientific literacy, people concede their ability to exercise choice and voice in the future of their country and world.

*Defining Scientific Literacy*

O’Neill and Polman (2004) ask: “What kind of scientific literacy is necessary or desirable for life in a technological society?” (p. 235). They argue that preparing a broad
range of students to be “little scientists” – individuals who can practice science – is a more important goal for science education than emphasis on the communication of content knowledge. First, supporting “little scientists” may “encourage students to study [science] at the university level. This is usually thought of as the best way to ensure a steady supply of young scientists, and an economically prosperous future” (p. 236). Second, the authors believe that teaching a vast range of topics contributes to weakness in conceptual understanding. Third, citizens could “participate in the conversations of experts [if they] gained an understanding of research design, techniques of data analysis, and wider aspects of persuasion crucial to the practice of scientific inquiry in the empirical-analytic tradition” (p. 238).

O’Neill and Polman argue that science education should prepare citizens to “participate in discussions about and [conduct] critical evaluations of ongoing research within the traditions of Western science” (p. 239). They also propose that exploring unanswered and open-ended questions through scientific methods is preferable to replicating and memorizing existing knowledge -- “struggling (and even failing) to formulate and carry out empirical investigations in science may teach students more meaningful lessons about how science is accomplished than flawlessly executing cookbook labs or solving carefully formulated problems” (p. 261).

O’Neill and Pollman (2004) present the case of an earth science teacher who focused his entire curriculum on investigation-based projects. By the end of the school year, students had acquired general earth science knowledge and depth of knowledge in one specific area of earth science. Also, they improved their abilities in understanding the nature of science; they could: “formulate empirically investigable questions” (p. 241),
“create evidentiary links between data and knowledge claims (p. 244), “recognize threats to validity and thinking about implications,” (p. 245), “understand the role of dialogue and debate in science” (p. 246), and debate their positions and arguments, in written form, with on-line mentors. This research suggests that investigation- and project-based curricula develop students’ ability to practice science and analyze the quality of scientific arguments.

**Rationale for Physics Literacy**

Progress in physics has been the foundation for our current understanding of the structure of the universe, the weapons that affect global politics, the development of the digital age and the technology we use regularly in our homes and businesses. Billions of dollars of federal research money are allocated for research in physics and associated fields -- approximately $5 billion per year for engineering and $4 billion for physical sciences in 1999 (National Research Council, 2001, p. 24-25).

Given the influence of physics in our lives and the resources devoted to this discipline, individuals should be knowledgeable about the content and processes of physics. Science is often a domain considered inaccessible by the general public, dominated by the claims of “experts” (O’Neill and Pollman, 2004). An emphasis on physics literacy in the United States would result in broader inclusion of the population in evaluating and conducting the types of physics research that are pursued. This expanded involvement in physics would result in a more representative segment of the American
population deciding how physics should be conducted, for what purpose, at what cost, and to whose benefit.

**What Does It Mean to Be "Physics Literate?**

What physics content should a graduating high-school student know to achieve the social goals described above? What should she understand about the processes by which physics knowledge is accumulated? What information should she be able to analyze and interpret? In the section below, I begin to address these questions by developing a definition of "physics literacy."

Project 2061 proposes that physics include the study of two main ideas—exploration of the structure and principles that govern the universe and examination of methods to develop new technology (*Benchmarks for Scientific Literacy*, 1993). A physics-literate person must be able to understand the nature of science -- to evaluate and enact scientific processes such as inquiry and invention (O’Neill & Pollman, 2004; Kaelin & Hubner, 2003, *Benchmarks for Scientific Literacy*, 1993). Students should be exposed to the tentative nature of scientific ideas and learn to “identify bias for themselves, encouraging them to take a critical stance towards claims of neutrality, a lack of bias and claims to offer a balanced view” (Oulton, Dillon & Grade, 2004, p. 420). In light of the work of these authors, I include investigation of the nature of science in my definition of physics literacy.
Physics literacy does not only include the acquisition of content knowledge in and investigation of the nature of science (National Research Council, 1996). Wiggins (1998) emphasizes the importance of youth developing conceptual understanding, as opposed to simply acquiring content knowledge.

In the next section, I have organized my discussion of physics literacy around the two topics I identified above – 1) physics as a foundation for exploring the structure and principles that govern the universe, and 2) physics as a foundation for enhancing and developing new technologies. Within these areas, I discuss the types of conceptual understanding and nature of science investigations that, according to the literature and in my opinion, constitute physics literacy.

**Physics as a foundation for exploring the structure and principles that govern the universe.**

When considering physics as a foundation for exploring the structure and principles that govern the universe, students might rely upon historic, cross-cultural and current scientific models to investigate the following questions, which are modified from Benchmarks for Scientific Literacy (1993):

- Where do humans fit into the context of the universe?
- Where do scientists think the universe and its components come from?
- What principles do scientists think govern nature, from the workings of our body to extreme environments such as black holes?
- What are predicted fates of the solar system, our galaxy and the universe?
• How are mathematical models and computer simulations used to model the universe?

Project 2061 also expects twelfth grade students to understand a variety of concepts about the structure of matter, energy transformation, and forces in nature, all of which are related to the structure and workings of the universe.

In the context of learning cosmology, students might participate in designing and enacting experiments and analyzing quantitative and qualitative data. But replicating historical experiments to learn about existing physical principles is insufficient; instead, students should be inquiring about current questions and observations. For example, students could analyze and interpret simplified data from existing telescopes, satellites, probes, detectors, and human space exploration.

*Physics as a foundation for enhancing and developing new technologies.*

Physics is a discipline through which students can explore the source and quality of new technologies that result in the creation of everyday gadgets but also products of global impact. To be informed about the common-place devices, students should be able to answer the following questions:

• How are everyday devices (computers, microscopes, hair dryers, cars, and music players) designed and built? With this knowledge, youth become more than consumers; they can develop an understanding of the design and function of products they purchase. Also, they can acquire the foundational knowledge necessary for becoming creators of these products and technologies

• How does physical science impact the world in which students live? For example, how are weapons of mass destruction crafted and launched? What is the physical
impact of military devices such as nuclear weapons, missile shields, and precision bombs?

Project 2061, in the section of *Benchmarks for Scientific Literacy* (1993) titled "The Designed World," lists an array of standards connected to the questions above, concerning what students should know and understand about technological systems.

In the context of learning about everyday devices and technology, students should, of course, pursue experiments and data analysis. But again, students should be exploring questions relevant to their lives and futures. For example, students could collect and/or analyze data about the strength, stability, longevity, and energy efficiency of everyday devices. With this knowledge, students might devise earthquake and fire safe buildings or implement strategies to make their communities more energy-efficient. They might explore facilities and technologies that rely on renewable forms of energy. They might model, using model rockets and basic electronics, the effects of nuclear warfare.

"Incremental" versus "Fundamental" Change

Cuban (2001), distinguishes between two types of change, incremental and fundamental. The former term he reserves for change related to smaller problems, for which the solutions fit into the existing educational systems and frameworks. He describes fundamental change as processes that fundamentally question, alter, significantly enhance or demolish larger systems in a school. Kuhn (1962) describes
revolutions in science as paradigm shifts in how scientists think about the organizing principles of the universe; his lens on science can be applied to education.

I consider changes to be incremental in physics education if they involve strategic shifts in how physics is taught, learned and organized rather in contrast with paradigm shifts in how educators view physics education. In the section below, I discuss incremental shifts in physics education; I reserve a discussion of paradigm shifts in physics education – fundamental changes – for the conceptual framework section of the dissertation.

"Incremental" Changes for Cultivating Engagement and Rigor in Physics Education

Changes in School Organization

Creating positive change in physics education requires more than mandated improvements in curriculum and pedagogical strategies. Wilson Farmer and Farmer (2000) state that “The school is a social organization serving the public and producing not a visible but an abstract product – relationship, attitudes, understandings and intelligence. ...Many attempts to implement reform take little account of the social contexts in which teaching and learning take place. The price of ignoring the context of teaching is failed idealism, guilt and frustration at not being able to meet the standards; criticisms of teachers who fail to make the changes; and erratic leaping from one bandwagon to the
other” (p. 63). The research of Wilson Farmer and Farmer (2000) suggests that changes in school organization are essential for physics education reform to occur. Candidate areas for changes in school organization are described below.

Training, supporting and compensating teachers.

Though the “Percent of Teachers Describing Themselves as Specialists in Physics Teaching” and having a physics major or minor is increasing (AIP Report, 2003, Figures 6 and 7), Deng (2001) argues that “a college degree in science is insufficient to teach high school science” (p. 275). Candidates for teaching positions with just this background may not have “a sound understanding of concepts and principles,” connect abstractions to the “experiential world of students” and “communicate physics through concrete examples and meaningful questions” (p. 275). These authors suggest that content courses in college are not sufficient for producing high-quality physics teachers. Therefore, teacher education programs must help pre- and in-service physics teachers expand their content knowledge into effective pedagogical strategies.

In addition, university physics departments must collaborate with and support teacher programs. Gollub and Spital (2002) observe that the “The Physics Teacher Education Coalition (PhysTEC) is a collaborative venture of the American Physical Society, AIP, and the American Association of Physics Teachers,” but only “involv[es] physics departments and science education programs at a few selected universities” (p. 49). Such ventures should be expanded, so education departments have access to scientists with content and experimental expertise, and physics departments have opportunities to reflect upon and improve their pedagogical strategies.
Teachers must be compensated at higher levels if the profession is to attract high-quality educators. "On average, teachers earn 29% less than other workers with a baccalaureate degree... Given that the national average starting salary for teachers is $25,735, the teaching profession is nowhere near being a financially competitive option for most young people who leave college with backgrounds in math and science" (The National Commission on Mathematics and Science Teaching, Before It's Too Late, 2000, p. 36). According to the AIP report (2003, Figure 15), graduates with a bachelor's degree in physics make, on average, $10K less as a starting salary in education than their peers in government and industry.

As long as teaching is viewed as a profession that scientists and mathematicians pursue as a charitable act towards society, the cadre of highly-qualified professionals necessary to turn-around science and math education in the United States simply will not exist. To bring about reform in physics education, teacher salaries simply must go up, perhaps disproportionately for science and math educators given the opportunity costs for foregoing jobs in industry.

Along with salary raises, the federal government should fund and require career-long teacher education programs, so educators can be reflective practitioners who stay abreast of progress in science and in pedagogy. Currently, the majority of physics teachers do not participate in a professional organization and, therefore, do not have access to enriching activities and collaboration that such groups allow. Many also do not use the various innovative curricula designed to enhance physics learning (AIP Report, 2003, Figure 11 and Table 13.)
Simultaneously, the federal government should administer tests that evaluate teacher competency. These tests might be ongoing -- motivated teachers could progress from being simply certified to being master teachers and district leaders and coaches. Teacher salary should be based not just on experience, but also on performance evaluation centered on student learning and engagement. The structure for this performance evaluation should be carefully designed because districts might face incentives to eliminate high-performing, and, therefore, highly-paid teachers, during economic downturns.

*Cultivating teacher leadership, independence and empowerment.*

For schools, and particularly for physics education, to improve, teachers must have power to make change. Wilson Farmer and Farmer (2000) write that “A widespread conceptual shift from thinking that school reform can be mandated and manipulated from the ‘outside-in’ to the ‘inside-out,’...is needed if reform is to be successfully implemented. If policy makers, researchers, and the general public continue to seek reforms independent of teachers’ input..., reform efforts will continue to fail or be short-lived” (p. 61). Reisner, Rubenstein, Johnson and Fabiano (2003) argue that “shared decision-making among the teachers and principal within a school is a consistent feature of instructional environments that promote teachers’ professional satisfaction and effectiveness” (p. 67). These authors also found that making sure that teachers are content, challenged and respected is “a consistent feature of schools characterized by high levels of student satisfaction” (p. 67).

*Conceptual Physics* by Hewitt and *Physics* by Giancoli are rated most-highly for quality, by physics teachers (AIP Report, 2003, Table 4) and, therefore, preferred for use
in physics classrooms. But Moje (2001) writes that teachers should be able to choose textbooks from a range of choices, based on the needs and interests of their students. They should also vary the textbooks they use, within the course of one year, depending on the quality of a source's coverage of a particular topic. In addition, curricula should include material from sources accessible and interesting to students — for example, Moje in her talk to the Teachers College Science Education Department (2/23/04) supported incorporating media such as magazines and on-line chat rooms in which students already participate, into mainstream science curricula. But for teachers to have the power and confidence to flexibly choose appropriate material for various portions and segments of their classrooms, they must feel a sense of leadership, independence and empowerment.

Multiple authors argue that teachers are pivotal actors in school reform (Howe and Stubbs, 2003; Borko, Wolf, Simone & Uchiyama, 2003). For example, Howe and Stubbs (2003) write, “Teacher leaders work with colleagues within their schools, school districts, and professional organizations to introduce new ideas, support the growth of others, and lead the way toward reform” (p. 284).

How does one create a climate for teacher leadership, knowing that it is essential for school reform to occur? In their study of science teachers, Howe and Stubbs (2003) found that for this type of leadership to occur, several elements are essential:

- mutual respect between teachers and scientists,
- challenging problems to solve,
- a supportive learning community in which to practice leadership skills,
- opportunities for leadership in the teacher's school setting.
In short, teachers must have training and ongoing support to become leaders and agents of reform in their community. For this to occur, leadership at a school must be shared, and teachers must have the authority and opportunity to make decisions and affect change. For reform to succeed, teachers should be able to affect the overall vision and practices of the school (Borko, Wolf, Simone & Uchiyama, 2003).

The systematic effects of standards on physics course offering.

Trends in physics education in New York City demonstrate that if schools are penalized for low scores on physics Regents exams in NYC, they may respond by not offering physics to students at all (Strachan, 2003). As a result, large groups of students may be disenfranchised from receiving an education in physics.

How might the system be restructured so that the vast majority of students in New York City can take physics? First, schools should not be penalized for students struggling with an advanced Regents exam. This change would encourage schools and students to engage in physics courses and prepare for the associated tests. Also, schools might consider offering conceptual physics as a first-year physics course to high-school students so that students have a strong grasp of physics ideas before facing challenging math-based physics problems.

Small schools: documented advantages and organizational questions.

In recent years, the US government and non-profits such as the Bill and Melinda Gates Foundation have channeled substantial amounts of money into restructuring large public high schools into smaller institutions (Ilg and Massucci, 2003, p. 74). Their actions are largely in response to research-based and anecdotal evidence, which suggests that
large, public schools do not provide urban youth with a quality education. For example, Ilg and Massucci (2003) write, “Though these large institutions “may offer wider curricular choices and more diverse experiences” (p. 69), “there is a consensus among reformers that comprehensive, urban high schools are unsuited to meet the needs of poor and minority children. Because educators in these schools tend to be rigid and inflexible, there is little collaboration, and the curriculum tends to be fragmented and superficial. Big-city, comprehensive high schools are worlds unto themselves that maintain few meaningful links with outsiders” (p. 64).

Research suggests the advantageous aspects of smaller, restructured secondary schools, despite the challenges to students of long periods, shared space with other schools, and a small community (Lee and Smith, 1995; McMullan, Sipe, and Wolf, 1995; Pittman and Haughwout, 1987; Stiefel, 1998; Reisner, Rubenstein, Johnson and Fabiano 2003; VanderArk, 2002). At small schools, “students learn better, but they also behave better, are more likely to be involved in extra-curricular activities, have lower dropout rates, and graduate at higher rates” (Ilg and Massucci, 2003, p. 70). Jackson (2003) describes small schools as potential “intellectual hothouses...with a distinctive scholarly image and a sheltered environment in which intense teacher/student relationships can be built around a shared academic focus” (p. 583). He argues that this type of environment results in “unusual student engagement and high academic achievement. [The schools] are staffed by committed teachers with an infectious enthusiasm for their subject matter who communicate a caring concern for their students as individuals, combined with a conviction that they can accomplish more than the students themselves believe possible” (p. 583).
Reisner, Rubenstein, Johnson and Fabiano (2003), in their study of the small schools opened in New York City, found that “Students had very high educational aspirations, with almost two-thirds (65 percent) stating that at the very least they wanted to continue their education through college” (p. 24). This, despite the fact that they found the teaching staff at small schools to be inexperienced in comparison with the average New York City teacher.

Reisner, Rubenstein, Johnson and Fabiano (2003) also described staff at these schools as infrequently reporting “student absenteeism, cutting class, or dropping out as serious or moderate problems” (p. 24). Fights that occurred tended to results from interactions between students at the small schools and youth at the larger comprehensive schools in which the small schools were situated. Students felt “known” in these small schools, documented positive relationships with peers, understood the expectations of the school, and saw these expectations as “high standards for academic performance” and “consistent…from classroom to classroom” (p. 49).

Although it has been documented that “in schools with enrollments under 1,000, economic status plays a significantly smaller role in determining who succeeds and who fails” (Crocco and Thornton, 2002), little research has been done to examine how other organizational factors contribute to what is actually happening in the classroom. My study goes into significant depth in examining the implementation of effective physics instruction in restructured secondary schools, beyond the surface strategy of simply making schools and classes smaller. An exploration of the effects of organization on small school outcomes is essential to their success because “without key shifts in the emphasis and disposition of leadership, the new small schools…run the risk of winding
up simply as smaller versions of their former giant selves” (Copland and Boatright, 2004, p.763).

Reisner, Rubenstein, Johnson and Fabiano (2003) report that teachers at small schools “tend to use traditional instructional strategies and address fairly low-level skills” (p. 41). Additional research into small school organization is necessary to identify how school structure can contribute to high-level instructional goals rather than simply the memorization of facts, formulas and figures.

How Can Physics Educators Encourage a Broad Range of Students to Participate? Possibilities within the Category of Incremental Change

Given that equity and access are significant issues in physics education, a key question to be addressed in this discipline is how a broad range of individuals might participate and successfully acquire strong knowledge and skills in physics, while feeling deeply engaged and meaningfully challenged by the subject. The sections below describe issues of inequity, in detail, and summarize a range of strategies to cultivate a thriving community of diverse students.

Encouraging women.

Since 1970, the number of women receiving bachelor’s degrees in science has increased by a multiple of four (Eisenhart and Finkel, 1998). However, women still receive only 21% of bachelor’s degrees, 22% of exiting master’s degrees, and 13% of the
Ph.D.s awarded in Physics (AIP Enrollment and Degree Report, 2003, Table 7). While approximately 31% of male students take physics in high school; only 21% of female students do the same; a gender gap exists in advanced high-school physics and math courses as well (US Dept of Education, National Center for Educational Statistics, 2000). Women are participating less than men in learning physics, and discrepancy between the genders increases with level of physics education.

Female physicists also perceive a gap in career progress, in comparison with their male peers. An AIP (2003) survey of women physicists reports: “About one-third of the women who responded felt that they had progressed more slowly in their careers than their colleagues had” (p. 3). Having children particularly seems to slow women’s career progress. “Another barrier was discriminatory attitudes, usually expressed in the form of assumptions that women cannot do physics” (p. 3). So female physicists, according to this report, feel that they are facing barriers because of gender and as a result of the decision to raise children.

One strategy for increasing the participation of girls in physics may be to offer students the option of single-sex classrooms. Evidence points to the benefits that accrue to girls in math and science, as a result of gender-separated educational settings. At one school studied by Sanford and Blair (2002), girls experienced significant success in math and science competitions in comparison with their peers in other settings. At a second school studied by Sanford and Blair (2002), teachers felt that the girls’ single-sex classrooms were successful because the teachers established strong relationships with the girls, and girls who would not attempt problem-solving in other contexts did so in this one.
So is gender segregation the solution for improving gender equity in physics? One source of opposition to single-sex education is that the effects of this strategy may be negative for boys. For example, Campbell and Sanders (2002) suggest that boys are harassed more in single-sex classrooms than in co-educational classrooms. Also, conclusions on the benefits of single-sex education are controversial because the methodology of studies advocating single-sex education is in question (Campbell and Sanders, 2002). Also, though some media sources and politicians portray single-sex education as a silver bullet, research literature suggests that an all-girls’ school cannot assume that its work on gender issues is complete because it has separated students (Herr and Arms, 2002). Instead, for gender equity to occur, a discussion of gender must continually inform faculty, staff and student experiences at the school. For example, conversations on gender equity must be part of all courses and a portion of professional education (Datnow and Hubbard, 2002).

To improve gender equity in physics, educators should also support the organization of women’s support groups – Davis (2001) writes that a women’s science support group she observed helped women “speak out, share their experiences and make changes in their everyday environment” (p. 409).

Finally, physics programs should include female teachers and professors – Sadler and Tai (2001) found that “Women achieved 3.16 points better with female rather than male professors. Quite possibly, women might see their female professors as role models, feeling less out-of-place in a classroom dominated by males” (p.129). Given that women are not an equal fraction of physics teachers in the United States (AIP Report, 2003,
Table 7), particular effort must be made to encourage women to successfully teach physics.

Jones, Howe and Rua (2000) suggest that strategies to support girls in learning and embracing science should take effect early in their schooling. They write that by "middle school, girls' attitudes towards science tend to decline and this decline may persist through high school" (Jones, Howe and Rua, 2000, p.181). Introductory physical science and physics courses are ideal middle- and high-school settings in which girls can become comfortable and skilled with physics material. As a result, they may be more likely to pursue higher education and careers in physics.

Encouraging minorities and English-language learners.

With the exception of Asian-Americans in high-school, minority students are less likely in high-school, college and graduate school to pursue physics (AIP Enrollment and Degree Report, 2003; US Department of Education, National Center for Education Statistics). Of the students who do pursue college physics, "white and Asian students receive higher grades in college physics than blacks and Hispanics" (Sadler and Tai, 2001, p.127).

Non-English Language Background (NELB) students are "the majority in many urban centers and a part of every state and most school districts" (Lee and Fradd, 1998, 14). Though limited information is available about the achievement of these learners because they are often exempted from standardized assessments, Lee and Fradd (1998) cite evidence that NELB students are often marginalized and perform poorly in the field of science.
So how might one encourage students of minority backgrounds, some of whom are non-English speakers, to feel engaged in physics? Several curriculum guides acknowledge the presence of traditional physics concepts such as mechanics and waves in the practices of cultures from around the world. For example, the guide *Math and Science Across Cultures*, published by the *Exploratorium Teacher Institute* uses a study of the music-making *cuica* from Brazil to an examination of sound waves (p. 17-24). A later section in the guide encourages students to build and predict the motion of rockets and arrows after they examine similar practices in the native cultures of North and South America and in early Chinese civilization (p. 131-144).

These pre-designed lesson plans incorporate the ethnic backgrounds of a diversity of students into physics curriculum, which is likely to make some marginalized students feel that physics is for and about them. But each student and each learning environment is different, regardless of the shared heritage and backgrounds of participants in that setting. For example, in discussing research, Delgado-Gaitan (1994) writes, “Sharing the same ethnic background as the participants does not necessarily make the researcher more knowledgeable about the meanings of participants’ feelings, values and practices. Researchers often hold misperceptions...based on influences such as assumed cultural knowledge” (p. 390). The assumption that a curriculum that matches a student’s country of origin or his/her ethnicity might engage a student’s interest may not always be valid.

*Encouraging students with disabilities.*

An extensive literature exists around practices for including students with disabilities in mainstream education (Nickerson & Brosof, 2003; Rief and Heimburge, 1996; Salend, 2001). This literature suggests the importance of cooperative learning,
multiple forms of assessment, teaching to varied levels of abstraction and to multiple intelligences (Gardner, 1983), when including a diversity of students in one classroom.

Science is often used to understand and categorize disability. In contrast, hardly any literature examines how disabled students perform in science courses and what specific strategies might improve their success in this discipline. The minimal research that does exist does not reflect positively on the science community’s integration of disabled students. For example, Alston, Bell and Hampton (2002) suggest that parents do not believe that science teachers generally make appropriate accommodations for students with disabilities.

To include students in physics education, researchers must, first and foremost, document the participation and performance of students with learning and physical disabilities in physics courses. Are students with disabilities absent and neglected in advanced science classes and in the physics education literature because researchers, educators and administrators assume that disabled students cannot learn challenging science? How are different types of disabled students performing in science, particularly in physics, and why?

For more disabled students to succeed in physics, science teachers must also be trained in best practices in inclusion, asked to regularly reflect upon on their success in engaging and retaining students with disabilities, and receive support in making inclusion possible. In summary, significant work needs to happen with regard to students with disabilities gaining access to physics education.
Encouraging students from low-income backgrounds.

Sadler and Tai (2001) found that, on average, students from affluent communities earned higher grades in physics than those from less affluent communities. Other authors support Sadler and Tai’s findings on the effect of socio-economic status on participation and performance in physics. Neuschatz (1999) found that students of low-income backgrounds were less likely to enroll in high-school physics, had fewer physics courses offered in their schools, and often did not have access to qualified science teachers. In short, low-income students are disenfranchised from a high-quality physics education.

How can educators make physics education more equitable for low-income students? First, given an overall shortage, the education system needs to attract a larger number of qualified physics teachers by increasing physics teacher salaries (AIP Report, 2003, Figure 15). But to specifically improve physics teaching in under-served neighborhoods, incentives such as additional pay and loan deferment or reduction must exist to attract physics teachers to low-income schools. New York City, through the New York Teaching Fellows program, encourages young professionals to work in high-needs locations by supporting candidates financially in their pursuit of master’s degrees in education. This program emphasizes the need for capable science teachers. Opportunities such as these must be replicated and expanded if low-income, urban, minority students are to have better access to high-quality physics teachers. These new teachers must also have opportunity to receive substantive training in pedagogy.
When Should Physics Be Taught?

Physics researchers and educators, at all levels, are trying to reform physics education; the reasoning for and implications of many of these reforms are interspersed throughout this paper. However, two movements are especially worth mentioning, especially in the context of the sequencing of physics topics. Project 2061 is an ambitious attempt to design the scope and sequence of science curriculum for grades K-12. Physics 1st proposes a sequence through which high-school science might be taught.

Project 2061.

The goal of Project 2061 is to identify what American students should learn in science, math and technology, before they graduate from high school. Project 2061 developers have chosen concepts, topics and skills they believe are essential for a scientifically-literate adult to know, such as being able to “describe, explain, and predict real-world phenomena, consider alternative positions on issues, and solve practical problems” (Stern, 2003, p. 829). Project 2061 also proposes that “the knowledge science literate people possess is richly interconnected” (Stern, 2003, p. 829) rather than linear and straightforward. Project 2061 views the transition to a coherent, interconnected science curriculum as requiring many years of gradual change.

The Atlas for Scientific Literacy, a publication of Project 2061, still under development, uses “strand maps” to show what aspects of different science, math and technology concepts should be taught from grades K-12. “Rather than using names of theories or other scientific terms, such as ‘Newton’s laws’ or ‘genetic drift,’” the
developers of Project 2061 have “specified the actual ideas represented by those phrases” (Stern, 2003, p. 832). Such specificity emphasizes that the purpose of science curriculum is not simply to introduce vocabulary to students but to build conceptual understanding and analytic skills.

Project 2061 emphasizes teaching physics from early elementary school forward. For example, Project 2061 recommends that students in grades K-2 study celestial objects and the representation of physical objects with figures and also gain experience with gravity, forces, motion and magnifiers (The Atlas for Scientific Literacy, p. 42-65). By grades 9-12, Project 2061 recommends the teaching of physics concepts as one might traditionally expect in a physics course – gravity as proportional to mass and inversely-related to distance, motion as relative to a reference frame, and electromagnetic energy as dispersed across a spectrum. But, unlike traditional physics courses, Project 2061 builds these “traditional concepts” from K-8 experiences and experiments with physical objects, so that knowledge of the physical world is based on experience and intuition, not just memorization, theory and calculation.

*Physics 1st.*

The Physics 1st movement, supported by the American Association of Physics Teachers (AAPT) and Nobel Prize winning scientist Leon Lederman, proposes that physics be taught before chemistry and biology as a foundational subject in high-school. The AIP Report (2003) states, “The ‘Physics First’ movement is a strong and growing campaign that sees physics as the most basic of sciences, and argues that it should be taught as the foundation for introductory chemistry, which in turn should provide the underpinnings for high school level biology.” An implication of the Physics 1st
movement is that chemistry be taught before or concurrent with biology because an understanding of modern biology depends on familiarity with chemistry and because studying chemistry alongside biology provides an application and context for the former.

According to the AIP Report (2003, Figure 17), 43% of physics teachers strongly support that schools experiment with the idea of Physics 1st. Two school districts, San Diego, California and Cambridge, Massachusetts, are attempting Physics 1st (AIP Report, 2003) – the results of their experience will significantly affect whether the Physics 1st movement catches fire nation-wide.

The benefits of Physics 1st are as follows:

(1) Teachers can introduce concepts fundamental to how macro- and microscopic objects interact (matter, energy, forces, waves) before studying the interplay of atoms, molecules and larger systems in chemistry and biology.

(3) Placing chemistry before biology allows teachers to include, in biology, a detailed discussion of DNA and biochemistry, areas of current research.

(4) Physics 1st connects easily with introductory math that students cover at the beginning of high school, such as variables, equations, and graphing, making math more relevant and giving students multiple opportunities and perspectives from which to understand this math. Physics also provides students a foundation from which to approach topics in geometry and trigonometry.

(6) The Physics 1st movement increases the likelihood that many students will enroll in at least one year of each of the basic sciences, because most students will progress through physics and chemistry towards an advanced course in biology.

(7) All students have the opportunity, through Physics 1st, to understand physics principles primarily conceptually and then can return to these ideas from a more rigorous mathematical perspective, if they pursue a second year of high-school or introductory college physics.

The concerns surrounding Physics 1st are as follows:

(1) Far more physics teachers will be needed than exist now if schools emphasize that 9th graders across the country take physics. Sheppard and Robbins (2003) mention the importance of “recruit[ing] and educating]...a cadre of Physics First teachers” (p. 422).

(2) For a period of several years, schools moving physics from 11th/12th to 9th grade physics may be compelled to offer courses at both levels. Therefore, the transition from a traditional to Physics 1st sequence is complicated, requiring creative staffing and scheduling.

(3) Many educators and students believe that physics is an overwhelming subject-“Many do not see physics as foundational to understanding other sciences, but view it only as a subject for the mathematically sophisticated, to be taken by a perceived academic elite” (Sheppard and Robbins, 2003, p. 423). So some physics teachers are concerned that 9th graders will be unable to learn physics.

(4) Finally, opponents of Physics 1st argue that if students take physics early in high school, enrollment in advanced level physics courses may decrease.
Staffing issues should not prevent a transition to Physics 1st, if it is best for student learning. Similar to changes suggested in Project 2061, shifting to a Physics 1st sequence may require a generation during which intensive training of more physics teachers occurs and a math-integrated, hands-on, inquiry-based physics curriculum is developed that is appropriate to the cognitive level of ninth-graders (Sheppard and Robbins, 2003).

In contrast to fears of decreasing enrollment in advanced physics, involvement by all students in an engaging first-year physics course may increase diverse participation and success in advanced physics courses because more students may end up feeling that physics is relevant and accessible. If students pursue multiple physics (and math) courses in high-school, they are likely to be more competitive with their peers globally who often enroll in more secondary-school physics courses than the average American student (Neuschatz, 1999).

How Should Physics Be Taught? Possibilities within the Category of Incremental Change

Less is more.

Sadler and Tai (2001) observe “Students who had courses that spent more time on fewer topics, concepts, problems, and labs performed much better in college than those who raced through more content in a textbook-centered course” (p.111). Less is more! Covering vast amounts of material rapidly, without experiments and animations that ground abstraction in reality, does not prepare students adequately for college physics
courses and for careers in physics (Neuschatz, 1999). In their review of advanced physics
in high schools, Gollub and Spital (2002), emphasize conceptual understanding, the
formation of scientific habits of mind through logical problem-solving, and “depth of
understanding instead of exhaustive coverage of content” (p. 50). In fact, “Assigning a
large number of homework problems [is] negatively correlated with college grades”
(Sadler and Tai, 2001, p. 132).

Sadler and Tai, supported by Gollub and Spital (2002), recommend that labs also
cover fewer topics and that high-school physics courses focus on mechanics, rather than
this topic in combination with thermodynamics, electricity and magnetism, optics and
waves. Also, Gollub and Spital (2002) advocate the “omission of formal calculus” (p. 51)
from advanced high-school physics because many mechanics problems can be solved
without calculus and a shift away from calculus may increase students’ conceptual
understanding of physics.

The importance of collaboration: physics curriculum designed around the
philosophy that science is socially-influenced.

A positivist view of science assumes that science stands alone from community
and context. But many researchers argue that science is socially-influenced. For example,
separated from the ways the larger learning context is organized” (p. 88). Brickhouse and
Potter (2001) write of two students they observed who had the same “material resources
at home,” though one was more successful than the other in science (p. 980). “The
difference [between the students] was that Ruby’s engagement with computing was very
social...Ruby interacted with people different from herself to acquire computing competence” (p. 980).

Gutierrez, et. al., (1999) propose that “The goal, then, is to create rich zones of development in which all participants learn by jointly participating in activities in which they share material, sociocultural, linguistic and cognitive resources” (p. 88). For students to be successful in physics, curricula and teachers must ensure that students have the appropriate social capital to be successful. For example, are there peer study groups in which youth can work, in class and after-school? Is after-school assistance from teachers available to students? Can students have access to people who work in the fields of science and technology?

Math integration and rigor.

Many American students have poor skills in mathematics when compared to their peers around the world (Before It’s Too Late, 2000). On one hand, some researchers view the importance of mathematically-based physics as secondary to conceptual understanding (Gollub and Spital, 2002; Sadler and Tai, 2001). Their viewpoint suggests that the limited ability of American students in math is not of great consequence, as long as youth have a strong conceptual understanding of physics. However, Feynman (1965) writes that math “is a language plus [the] reasoning” (p. 34) of physics and is, therefore, fundamental to understanding physics. So, at some point, for students to pursue college-level coursework and careers in physics, they must become adept at mathematics.

How might American students’ mathematical abilities in physics increase simultaneous with their conceptual understanding? First, students need to be enrolled in math courses and successfully learn math throughout their school careers. For students to
be successful, they depend greatly on the ability of their teachers. However, in elementary school, when students are building a foundation in and developing their attitudes towards math, educators are often uncomfortable with mathematics materials. Elementary school teachers, therefore, need additional training to support their students (Spungin, 1996). Perhaps elementary school teachers should not be generalists; instead, elementary educators could be teaching science and math, based on specialized training.

Also, math educators should not be simply be teaching the memorization of rules, pattern recognition and the application of tricks to solve problems. Tuminaro and Redish (2003) write that students often know sufficient mathematics to solve physics problems but do not know how to apply this knowledge appropriately, partially because they have learned “rigid mathematical rules,...which can hinder their creativity during the problem-solving process” (p. 4). Teachers should, therefore, always be emphasizing creative, intelligent problem-solving in both math and physics.

Mathematical problems and conceptual understanding are not mutually exclusive. For example, Arons (1990) includes problems on a diversity of physics topics that require computation but also demand that students express their conceptual understanding. For example, in a chapter on “Rectilinear Kinematics,” Arons asks students to describe the motion information encoded in graphs with the words “speeding up, slowing down, reversing direction, standing still, moving at a uniform velocity,...and so on” (p. 43). But students also have to sketch velocity-time graphs corresponding to the position-time graphs in the question and calculate position, velocity and acceleration values using equations of motion.
In summary, given the poor performance of American students on international math evaluations and the limited training of many elementary school teachers in math, physics should be a discipline through which students can practice their mathematical skills and explore the contexts for which different mathematical techniques apply.

*Technology.*

Technology can greatly assist students as they try to envision ideal, tiny and unfamiliar worlds that are so much a part of physics theory. This technology includes the use of digital sensors for collecting data, simulation and animation software, video projects and just-in-time assessment technology.

Digital sensors are a popular addition to science classrooms. Sensors, such as those sold by *Pasco* and *Vernier*, free students from conducting observations only in their classrooms; instead, they can explore the larger world for data. For example, these sensors can be purchased to “capture data...at home, in a local ecosystem, at a playground or an amusement park, or wherever something interesting is happening (Albrecht and Firedrake, 1998, p. 38).” Plymate (1998) reports that both younger and older students can use these probes. Students using these tools are learning skills for real-life settings – scientists regularly use similar sensors to collect and report on data (Albrecht and Firedrake, 1998; Plymate, 1998).

Animations and simulations also help students develop a deep understanding of abstract physics ideas. For example, Christian and Belloni (2001) describe a series of animations titled *Physlets*, which help students “translate between representations (equations, graphs, diagrams), understand equations as physical relationships among
measurements,...build mental models of physical systems, and serve as a sketchpad on which students can communicate to each other” (p. xix).

A software program titled *Electricity and Magnetism: Exploring Physics* allowed students in my physics classes to model electric circuits before actually building them. Such simulations have two benefits. First, students must predict how to set-up a circuit for a particular outcome, instead of trying to connect circuit components at random. Then they must observe what happens in their simulated circuit and explain any errors that have led to an undesired outcome. Through this process, students must reflect upon their preconceptions of how electricity works. Second, simulations limit the destruction of lab resources because students test their circuits before connecting actual devices.

Introductory lessons on Newton’s First Law often require students to envision a world without friction. Simulation programs such as *Interactive Physics* permit students to experiment in worlds where friction and air resistance are absent. Students can repeat simulations multiple times, at their own pace, until they are comfortable with the material to be mastered.

Non-computer-based devices such as air tracks, hovercrafts and vacuum tubes similarly enhance students’ understanding of physical laws because they offer the possibility of exploring idealized environments. Once students grasp how physical laws work in an idealized world, the simulations allow them to gradually add in the features of the “real” world, such as air resistance and friction. Youth can therefore study the effects of the “real world,” one variable at a time.

The availability of digital video cameras and video editing software also offers technological support to physics curriculum. Students can create movies as assessments
of their understanding of a particular topic and/or to instruct other students. In these movies, students are able to express their identities, interests, values and personalities. As a result, they connect physics to their life experiences, raising the likelihood that they will be engaged in physics. Also, on videos, students can “freeze” motion, allowing them to more easily analyze the trajectory of moving objects.

JiTT6 (Just-in-time-teaching) helps teachers use assessment to construct their lessons around student needs. JiTT allows students to submit homework electronically a few hours before class. The software evaluates the student work, so lesson plans can be modified based on what students understand and must review from previous lessons.

The distribution of physics technology is not equitable. Low-income, minority students lack the opportunity to use cutting-edge curricular technology and learn skills in computing because these options are unavailable and/or under-emphasized in their schools and communities. Brickhouse and Potter (2001) emphasize the importance of creating educational programs that provide under-served youth with access to the resources available to middle-class communities.

_Incorporating advances in science into the physics curriculum._

20th century physics is barely discussed in many high-school and introductory college physics courses. But there are several benefits to incorporating this material, at least conceptually, into curriculum. First, the gadgets and technology upon which we rely -- X-rays, laser eye surgery, microwave ovens, computers, cell phones, nuclear energy -- were developed as a result of 20th century physics research. Second, a knowledge of cutting-edge topics in physics would suggest (accurately!) to students that physics is a
vibrant discipline that needs young people to answer a vast range of unsolved questions of social and intellectual significance.

Several web sites offer curricular materials for teaching modern-physics. *Physics 2000*\(^7\), sponsored by the University of Colorado at Boulder, introduces students to relativity, basic quantum mechanics and the implications of these topics for our lives today. *The Visual Quantum Mechanics*\(^8\) project at Kansas State University provides simulation, lab and written materials for a range of students with science and non-science career paths. *QuarkNet*, sponsored by the Stanford Linear Accelerator\(^9\) trains teachers in particle physics and helps them create related curricula for their classrooms. The Science Education Department at the *Harvard-Smithsonian Center for Astrophysics*\(^10\) offers curriculum to teach students about astronomical knowledge and research questions. *Gravity Probe B*\(^11\), an experiment at Stanford University, provides material for teaching students about Newton’s and Einstein’s descriptions of gravity.

Zollman, Rebello and Hogg (2002) describe several non-lecture-based strategies for introducing students to quantum mechanics and its applications. They propose the use of experiments and interactive computer activities to build appropriate mental models. In particular, they disagree with the ubiquitous use of the Bohr model as a representation of the atom, in early physics classes – they find that “students who studied and used the Bohr model intensively were very reluctant to embrace a quantum mechanical model in later instruction” (p. 254). These authors, therefore, question the common practice of teaching students antiquated models as the foundation for their exposure to more current ones. Is it possible that historic and current models could be taught simultaneously or that
a simpler model could be emphasized, while a more current one is mentioned or introduced?

_Incorporating parents in student learning._

Often parents are insecure about their own abilities in math and science and are, therefore, uncomfortable helping their children in these subjects. But, Crowley and Sieger (1999) emphasize that “When adults explain as they demonstrate new problem-solving strategies, children are better able to transfer strategies to novel problems” (p. 732). Such evidence emphasizes the important of parental participation in student learning. Unfortunately, Reisner, Rubenstein, Johnson and Fabiano (2003) report that parental participation in small schools is insufficient, according to staff and community partners to the new small schools.

Physics educators need to develop curricula that encourage families to discuss physics concepts and problems with students. One can imagine curriculum guides for physics similar to those of the *Equals Family Math* program, produced by the Lawrence Hall of Science. The bilingual *Equals* guides provide simple activities that families can pursue to improve a child’s mathematical skills.

_Incremental Change in Assessment_

Assessments are generally designed to monitor and document student progress. However, well-designed assessments can also be used to adjust instruction based on
student needs and help students develop meta-cognition about their own learning processes. If assessment is to contribute to the two latter goals, it must constitute more than students repeating their memorization of content knowledge. Assessment must address whether conceptual change has occurred for students, whether students have developed an improved understanding of the processes of science, and how students are improving their skills in collaboration. Assessments built with this type of in-depth exploration into student learning will allow teachers and students to understand and reflect upon what and how concepts have been learned, allowing both groups to respectively adjust their teaching and learning strategies.

Assessing conceptual change

How might physics educators assess conceptual change -- how mental models change as a result of lessons, activities and experiments? Gollub and Spital (2002) emphasize that advanced physics students should explain their reasoning to guarantee that shifts in conceptual understanding not just pattern recognition have been learned. The authors cite one example of what they consider to be high-quality assessment on the AP Physics B exam of 1998 -- in this problem, students did not need to calculate an answer but instead need to explain their conceptual understanding of the topic being examined. The authors do not oppose mathematical testing but feel that the purpose of high school physics is to gain a conceptual understanding of the discipline and that assessments should actively reflect this value system.

Similarly, to assess students' understanding of math problems, teacher might ask students to not only solve problems but also document their steps and explain their choices. When solving complex problems that require the synthesis of multiple
mathematics skills, teachers might require students to document what tactics they chose and why. For example, one might estimate the size of single oil molecule about which only two pieces of information are given – its volume and the assumption that, when it spreads over water, it has a thickness equal to the height of one molecule. Solving this problem requires a combination of geometry and algebra. At each step of the way, students would not just write their calculations. They would also explain their choice of strategies and formulas and make clear any assumptions upon which they are relying.

Gowin (1965) and Liu (2004) recommend that teachers encourage students, as part of assessment, to create ongoing concept maps that document conceptual change. For example, a student learning about forces might begin with the concept map shown in Figure 1, but after a unit on Newton’s Laws, create a concept map similar to Figure 2.

![Figure 1: Sample Concept Map by Student Prior to Unit on Newton’s Law](image1)

![Figure 2: Sample Concept Map by Student after Unit on Newton’s Law](image2)
Another tool in evaluating students’ conceptual change may be to vary the contexts in which students apply the knowledge they have learned (Marin, Gomez & Benarroch, 2004). For example, students might have learned about projectile motion from examples of launching objects short distances (pennies, darts) but an assessment might require students to extend their understanding of projectile motion to the analysis of satellites orbiting the earth.

To evaluate changes in student conceptions about the nature and processes of science, Sandoval and Reiser (2004) recommend that teachers use the following rubric in evaluating students’ explanations for phenomena in the world:

Thoroughness and clarity of explanations: This part of your score will be based on how clearly you state the causal chain in your explanation. 
Use of data: You will be graded on your rationale for how you link the data to support your explanations. 
Ruling out alternative explanations: You cannot be sure you have the best explanation if you haven’t considered alternative explanations and documented why those explanations should be rejected in favor of your best explanation. 
Documenting the limitations of your explanations: Any explanation, no matter how thorough it seems, will not be able to account for all available data (p. 362).

Licata (1999) emphasizes that students, in their lab reports, should answer the following questions: “What was I looking for? How did I look for it? What did I find? What did it mean?” In addition, Erekson (2004) advocates that student present orally to the class to defend their analyses and interpretations. During these presentations, teachers might encourage students in the audience to question the presenter’s conclusions and investigate the presenter’s consideration of alternate hypotheses and unresolved questions.

The assessment techniques, by Sandoval and Reiser (2004), Licata (1999) and Erekson (2004), emphasize an understanding of scientific processes as separate from
acquiring content knowledge, the first of which is an essential, but often ignored, component of physics literacy

Differentiated assessment.

Differentiated assessments ask students to demonstrate conceptual understanding, but, in this model, youth have the opportunity to communicate their ideas in several different ways – through writing, models, oral examinations, pictures, projects and more (Rief, 1996; Erekson, 2004). Differentiated assessment allows teacher to separate students’ conceptual understanding from their strengths and weaknesses at taking particular types of tests.

Marin, Gomez & Benarroch (2004) advocate that researchers supplement paper and pencil tests with interviews. One can imagine teachers extending on this practice by interviewing their students. Through interviews, teachers might develop a better sense of students’ conceptual frameworks, their grasp of scientific processes, especially if students struggle to communicate their ideas in a written form. Through interviews, assessment also becomes personalized, allowing teachers to more deeply understand the strengths and weaknesses of particular students.

For example, to assess a student’s comfort with designing and implementing experiments, a teacher might question a student about the design of her science experiment. From a weak written assessment, a teacher might conclude that a student has no grasp of scientific processes, but through an individualized discussion, a teacher may have a more subtle understanding of the student’s understanding.
Assessment of collaboration.

Collaborative work is central to the inquiry that constitutes scientific research. If physics literacy includes developing a skill set in the processes of science, students must cultivate their ability to work in groups.

Fusco and Calabrese Barton (2001) write:

Science classrooms are being transformed into scientific communities where students collectively muddle in ill-defined problem frames, such as engineering (Roth, 1998), technology (McShane & Yager, 1996), and ecological research (Eisenhart, Finkel, & Marion, 1996)... Individual contributions to a collective product are difficult to isolate. If communities of expert practice are to be replicated in the classroom, the assessment process will need to situate the learning process more closely in the development of the group... The documentation of our collective history captured the spiral nature of how knowledge emerged and reemerged, or was evident in many contexts. The assessment, like science, can be viewed as an ongoing, emergent process that serves to inform teachers and students of their individual and collective growth within their community (p. 351).

How might one design assessment that evaluates collaboration? First, for each group project completed by students, teachers should use one rubric to evaluate students’ conceptual change and a separate rubric to assess the success of the collaboration. Such a rubric might explore how students have organized their time and divided work, how they have resolved problems, and how they have shaped their individual work into a cohesive whole.

Conclusion

Though being educated in physics is essential for intelligent, informed citizenship, and intellectual and technological progress, physics education in the United States excludes many students. This section of my proposal synthesizes research on “incremental changes” that are likely to improve physics education. In summary:
• Teachers should receive enhanced training, support and compensation and be supported as leaders of school reform. To build a course around the interests and needs of her students, a physics teacher should be able to synthesize a broad range of resources to teach physics, instead of progressing sequentially through a particular textbook.
• Schools should be small and organized in ways that promote student success, so that youth are educated in personalized environments that honor youth diversity and emphasize high achievement.
• Standardized test pressures should not be structured as disincentives for schools offering academically-advanced courses to students.
• Educators should explore the value of single-sex settings for girls’ achievement in physics and embrace strategies that build women’s confidence and interest in physical science.
• Physics curriculum should reflect the backgrounds and interests of a diverse range of student ethnicities and address the needs of English Language Learners.
• Physics teachers and researchers must document the participation and performance of students with learning and physical disabilities in physics courses, and science teachers must also be trained in best practices in inclusion and asked to regularly reflect on their success in engaging and retaining students with disabilities.
• Physics teachers must be attracted to and retained in schools located in low-income neighborhoods.
• Physics concepts should be emphasized in the younger grades, and all ninth-graders should learn conceptual physics as a foundation for their high-school exposure to science.

• Physics curriculum should focus on fewer topics in greater depth.

• Collaborative learning should be built into physics education.

• More students should be taking more math during high-school. Physics curriculum should reinforce math concepts, conceptual understanding and vice versa. Elementary school teachers should receive the support they need to feel comfortable teaching conceptual understanding of mathematics concepts. Math and science specialization for elementary school teachers may be one way to progress towards the goal of improving the math/science instruction available to young students.

• Teachers should use technology to help students access microscopic or abstract worlds as they are learning basic or challenging physical principles.

• Physics teaching, even in a student’s first year of physics, should include exposure to modern physics, so students develop a sense of how they might affect physics research and how physics directly impacts their everyday lives.

• Physics curriculum and school organizational structures should encourage parents to be partners in a student’s learning.

• Assessment should emphasize conceptual understanding, the nature of science and collaboration skills.
"Fundamental" Changes in Envisioning Physics Education: Agency, “Funds of Knowledge” and Critical Reflection and Action

"Fundamental" Changes in Physics Education

In the section below, I explore the implications of viewing physics education from perspectives that question essentialist, content-focused models of education that reinforce existing power structures. In particular, I focus on student agency, curriculum shaped around student “funds of knowledge” and Freirian beliefs on education for the purpose of critical reflection and action. These changes suggest the need for paradigm rather than tactical shifts in how educators think about physics education; therefore, I have categorized these ideas as fundamental changes.
What Is Agency?

Jackson (2003) writes that educators, committed to school reform, should treat student agency as “the single most important ingredient in the educational brew” (p. 581). But developing this philosophy in schools is not easy – Jackson (2003) believes that a commitment to study agency requires that educators redesign the “entire social architecture” (p. 581) of schools.

What exactly is student agency? Why is it so important? How does a classroom that supports agency function? What strategies can a teacher use to cultivate student agency? Specifically, how does an emphasis on agency take shape in a physics classroom? In the sections below, I try to address these questions.

Research on Individual Agency

Blackburn (2004) identifies three students, who, in her view, engaged in acts of agency. She describes the first student as having “design[ed] an outreach to educate teachers so they [could] better help their sexual minority students” (p. 105). Blackburn (2004) records that this student also “confronted one of his teachers when she failed to intervene when a student used a homophobic epithet in class” (p. 105). A second student, relying upon social supports at his school for gay and queer youth, changed his trajectory from a student who originally chose not attend school to one who engaged in school in ways that allowed him to graduate. Agency around the issue of youth sexuality required
both of these students to explore their own orientation, choose the goals they hoped to achieve in his community (tolerance education and personal academic success), and enhance the repertoire of knowledge and skills they had to enact their goals.

Finally, Blackburn (2004) narrates the story of a young woman who chose to work in an alternative library setting to fulfill her academic work. She intended to avoid the harassment that she faced in urban public schools. This example, and that of the youth described above, suggests that the setting and enacting of goals can be personal. Agency is not exclusive to acting in pursuit of large social causes. Blackburn (2004) writes that acts of agency "may include simply being out at school, standing up for oneself to a teacher, or including oneself in class work... But they may also take the shape of staying in school, or even leaving school, and working in out-of-school contexts" (p. 109).

Danns (2002) provides a contrasting example of youth agency applied to large-scale social change. She describes the 1968 student movement in Chicago, in which the civil rights and black power community movements informed students' sense of identity, helped them identify youth-centered goals within the context of larger initiatives, and cultivated a feeling of youth empowerment. As a result, "students organized citywide boycotts demanding community control, Black administrators, more Black history courses, and various other school improvements" (Danns, 2002, p. 631). The Chicago student movement suggests the potential of youth to organize and enact positive, large-scale social change.

Butler (2004) writes of agency as a process of resisting social norms. Butler's (2004) definitions aligns with Freire's philosophy that power structures, though often presented in education as objective, are human constructions that can be changed.
Blackburn (2004) defines agency as the “ability to recover from and exert power against oppression” (p. 103). Once again, this definition of agency suggests critical reflection and action against systemic impositions.

Holland (1998) argues that pursuing agency does not guarantee a particular outcome but, instead, requires risk-taking, where one might expend energy but not achieve one’s goal. Holland (1998) describes agency, as a form of ‘semiotic mediation,’ “modifying one’s environment with the aim, but not the certainty, of affecting behavior” (p. 39). The uncertainty associated with agency further emphasizes that educators help students identify attainable goals, as they attempt to increase their agency. If students do meet with early success in their efforts to enact change, they are likely to develop increasing confidence in exerting their agency (Holland, 1998). This confidence, in turn, is likely to encourage youth to expand their goals to more ambitious ventures.

Dewey (1938), without using the term agency, describes the purpose of education as giving students the freedom to exert power over their own lives. He believed that this freedom resulted specifically in “the power to frame purposes, to judge wisely, to evaluate desires by the consequences which will result from acting upon them; and to select and order means to carry chosen ends into operation” (p. 64). His writing includes several elements of what current authors describe as parts of a pursuit of agency – identification of goals, reflection, development of the tools and skills necessary to pursue one’s goals, acting towards one’s purposes. In his discussion, Dewey distinguished agency from impulse – the former, in his opinion, required reflection and the use of past experiences and others’ shared experiences to evaluate the consequences of enacting a idea. The latter involved the immediate response to desire.
Sizer (1992) also connects education with agency. In his opinion, students are motivated to learn if their education empowers them to move towards realistic aspirations: “We learn when we are convinced that we eventually will have the power to act on that learning to take ourselves someplace we want that is in reality there” (p. 58). A school might prepare students to enact short- and long-term goals of consequence to them. For example, school-wide goals might be to develop structures by which youth can maintain their schools, travel in their school without passes and manage their food and sports teams. Their education might, therefore, empower youth to be involved in change within their own school. When students graduate, through the Exhibitions that he describes, Sizer (1992)suggests that an ideal school might have prepared youth in areas as broad as challenging the fairness of the tax code (p. 48), developing a plan for negotiating a trade deal with a foreign country (p. 107), assembling a wind instrument from pipes (p. 118), and designing and pursuing a year-long independent project (p. 81).

Individual v. Collective Agency

McCallister (2004) argues that social interactions between students in schools shape their identities: “The social perspective provides a way to understand how school situations offer the substance from which children develop a sense of self” (p. 425). She believes that identity creation, shaped by social dynamics, and learning take place simultaneously and inform each other. Zembylas (2004) describes the importance of social dynamics to how young children learn science in a classroom. He writes that the
social-constructionist theory of emotion...argue[s] that emotion is performative and the expression of emotion in the classroom has its basis in social relationships. Arising from these relationships is the emotional culture of the classroom that plays a key role in the development of classroom emotional rules as well as the legitimation of science knowledge... The dynamics of the negotiations of classroom emotional rules and science knowledge legitimation may dispose students to act positively or negatively toward science learning (p. 693).

I believe that Zembylas’ observations and the social-constructionist theory of emotion that he describes can be extended to older students. In addition to being an intellectual environment in which learning takes place, schools and classrooms are interactive places with particular cultures and explicit and implicit social rules (Sizer, 1992, 127). To view student learning as isolated from these social dynamics ignores factors that greatly influence how a classroom functions (McCallister, 2005). For this reason, I have documented, through ethnography (observations, interviews and field notes), the culture of my classroom. I believe that a record of social dynamics has helped me understand the difference between and overlap of individual and collective agency.

My Definition of Agency

I have drawn on the literature above to develop a definition of agency, upon which I rely on throughout this dissertation. In agreement with Butler, I believe that agency requires individuals to continually explore their identity and set particular goals towards which they want to direct their action. While agency, in my opinion, does not require conscious goal-setting, I do believe that increased self-awareness about personal beliefs and intentions allows a student to more successfully move towards the outcomes
she desires. So the practice of reflection upon and refinement of one’s goals are important components of developing agency.

Like Blackburn, I believe that agency can be personal, focused on improving oneself or one’s own circumstances. But, like Dann, I view youth agency as having the potential to influence large-scale social change. I agree with Holland’s position that students are likely to take on increasingly more challenging goals for personal and social change if they meet with success in smaller acts of agency. Unlike Butler, I do not believe that agency requires action against “oppression,” which, to me, suggests intentional coercion or persecution against an individual or group. But I do believe that, regardless of the scale of agency in which a youth participates, agency involves the questioning of personal and social paradigms that might at first seem objective, rigid and/or fixed.

I believe that there are two forms of agency -- *collective* and *individual* – that inform and influence each other. Collective pressures might alter an individual student’s goals or affect the strategies he uses to achieve these goals. Belonging in a collective may result in a student developing and enacting goals that she did not hold, recognize and/or articulate prior to her engagement in that particular group and might play out through the joint actions of the group rather than the individual.

In summary, I view agency the process of purposefully enacting change, based on one’s beliefs, whether or not these align with the goals of schooling and socialization.
Processes that Contribute to and Culminate in Student Agency

Noddings (1995) poses a series of questions a student might consider when actively developing her own agency: “Who am I? Who will I be? How hard should I work and toward what end? How am I doing and how can I tell? Can I make a difference in the world? Do I have any control over my own life?” (p. 153). Noddings’ questions cover a vast range of topics. I have, therefore, divided the questions into several processes that, I believe, together culminate in agency:

1) exploring one’s identity,

2) consciously and unconsciously setting goals based on this identity,

3) enhancing the repertoire of knowledge and skills one needs to achieve one’s goals,

4) engaging in ongoing reflection.

The diagram below summarizes my ideas on the interplay between these processes, which often occur simultaneously and inform each other. The following sections of my dissertation proposal are devoted to describing the relationships among these interconnected processes.
Figure 3: Processes that Contribute to and Culminate in Student Agency

Figure 4: Exploring Identity: Foundational to and Shaped by Reflection on Agency

Holland (1998) emphasizes the importance of students exploring their identity before they try to influence their world. She views a sense of identity as foundational to action, a “key means through which people care about and care for what is going on around them. They are important bases from which people create new activities, new worlds and new ways of being” (p. 5). According to Holland (1998), cultivating self-understanding “makes a least a modicum of self-direction possible. [Identities] are possibilities for mediating agency” (p. 4). Identity is how one imagines oneself acting in the world, the start of self-direction, of moving with purpose towards one’s goals.
What is the nature of identity, this foundation for agency? Is it fixed, or can it be changed through reflection and action? Brickhouse and Potter (2001) describe identity as "one’s understanding of herself in relation to both her past and potential future. Identity refers to ways in which one participates in the world and the ways in which others interpret that participation... Individuals have some control over identity yet are also constrained by structure and power relations that may limit the kinds of identities that are viable" (p. 966). This definition suggests that identity is malleable, dependent on one’s ever changing present context and aspirations for the future. Brickhouse and Potter (2001) also emphasize, in their definition, the influence of social constraints on defining identity. One can imagine the particularly far-reaching impact of social influences on school age students – education is designed to actively shape the beliefs and behaviors of students, and peer influence greatly impacts the types of identities and action that students choose for themselves.

Holland (1998) writes that despite being “based on past experience” (p. 4), identity draws upon “present discourses” (p. 4) and our images of how we envision and desire the future to be. Identity is fluid because it depends on our constantly developing view of how we can act in the world -- Holland (1998) writes, “Agency results in a transformation of identity” (p. 68). If a student reflects on how his actions affect his community and power structures around him, he is likely to see himself differently in the world. When students set and enact goals, they develop a more empowered, skilled, knowledgeable identity, which allows them to imagine increasingly large landscapes in which to exert their agency.
Many students believe that their identities do not match with the values that educators desire from students in school. However, the fluidity of identity imply that a student’s feelings of alienation from school are reversible. Jackson (2003) writes, “We know that as students move up through school..., the time and energy they devote to academics are increasingly functions of their willingness to take on and sustain what might be called an ‘academic identity,’ an understanding of self in which ‘intellectual’ activities both within and outside of school play a valued role” (p. 580). Finding an academic identity — a connection between one’s beliefs and values and those of one’s educational setting are essential for success in the latter. For students to engage in school, intellectual activities must connect to who they are, and they must know how to direct these experiences towards their goals. In light of this conclusion, Jackson (2003) emphasizes the need for “identity scaffolding” in school — allowing students to explore their own identities and develop, with guidance from teachers, one or more identities that include an emphasis on academic achievement.

![Diagram](Reflection)

_Holland (1998) proposes that exploring identity is foundational to agency. But how exactly does a sense of identity result in agency? Several authors suggest that goal-setting connects identity with agency. Jackson (2003) presents several meta-cognitive strategies — “planning, goal-setting, self-monitoring, social processing, and help-seeking” (p. 585) — in which students must engage if they are to pursue agency._
During the early stages of cultivating agency, youth may have amorphous, general, and contradictory goals. Youth may also set goals and direct their actions to fulfill stereotypical or simplified images of groups with which they identify (Pollock, 2004; Rolón-Dow, 2004). Holland (1998), however, proposes that an essential part of developing agency is recognizing and articulating one’s unconscious goals, defining conscious aspirations, resolving conflicts between competing beliefs, and acting in ways that align with one’s most valued intentions.

A student might have two strong school identities. One identity might include an explicit interest in succeeding in school, for example, to be the first in one’s family to acquire a diploma (Cammarota, 2004). But another identity might revolve around a questioning of or resistance against authority. For example, Cammarato (2004) found, in his study of Latino youth, that “many male participants spoke of how they were policed, contained, and treated as criminal threats in multiple locations, including their schools and neighborhoods. A common response to criminal treatment at school was to resist and cut class” (p. 54). So, in reaction to their experiences in school, students might act in ways that prevent them from meeting with academic success. A central part of students successfully developing their agency within school is that they explore and articulate their various identities, set goals for themselves, based on these identities and try to include these identities in their educational lives. In this way, students might simultaneously succeed in school and develop spaces in which to resist and question authority and established norms (Turner, 2003).

Reflection plays an essential role in the refinement of goals so they are attainable yet ambitious. Springer, Stanne & Donovan (1999) write that complex, successful
thinkers often “monitor their own understanding carefully, make note of when additional information [is] required for understanding, and whether new information was consistent with what they already know” (p. 26). Students reflecting on acts of agency can evaluate the strength of their goals, in the context of how they feel about what they achieved. For example, students might ask if their goals were sufficiently focused and articulate to develop a clear plan of action, whether their goals were overly- or insufficiently-ambitious, and how much unconscious or unacknowledged goals affected the outcomes youth hoped to achieve. Students might expand this introspection to identify general ways in which they can improve their goal-setting.

Figure 6: Enhancing One’s Repertoire to Make Acts of Agency More Effective

Self-awareness and articulated goals are necessary but not sufficient for developing agency. Upon setting or trying to achieve these goals, youth and their educators might discover that students need particular skills and knowledge to enact the changes and acquire the opportunities they desire.
For example, one can imagine a student who wants to increase voter turnout in his neighborhood. He might ask people who live on his block to vote but might be ignored or end up targeting community members who are already registered. Also, he may have no system for evaluating whether his efforts are successful. If he and an advisor, through reflection analyze his progress and arrive at these conclusions, he might choose to enhance his repertoire of knowledge and skills in several ways. First, he might, with other students, conduct a community assessment of who in his neighborhood is actually voting and why. In this initiative, he might build alliances with local non-profits and the school he attends, so people view his efforts as connected to larger institutions they respect and trust. He might research youth efforts to enact social change, particularly around voting trends and replicate the ideas he considers successful. He might create or use an existing system to document his progress, so that he can report back to his sponsoring bodies. This student, from a process of identity exploration, goal-setting and initial attempts at agency, has chosen to strategically enhance the "toolkit" that allows him to engage in acts of agency.

How Might Teachers Cultivate Student Agency in a Classroom?

Teachers play an essential role in helping students develop agency. Dewey (1938) writes, "guidance given by the teacher to the exercise of the pupils' intelligence is an aid to freedom, not a restriction upon it" (p. 71). What is important for teacher planning is
that a classroom and its practices be a “co-operative enterprise, not a dictation” (Dewey, 1938, p. 72)

I have used Holland’s (1998) discussion of “figured worlds” (p. 41) to articulate a vision of a classroom centered on youth agency:

(1) Youth themselves develop their classrooms through their “own work and through collaboration with others” (Holland, 1998, p. 41). Teachers and students together set goals and practices for classrooms, rather than a teacher, in isolation of his students, establishing classroom norms based on his own beliefs, experiences and the mandates of local, state and federal government.

(2) The opinions and voices of youth matter. Students’ goals are recognized as valid and built into the fabric of the classroom. Therefore, when youth exert agency, their actions, at least in part, fit into the goals and practices of the classroom. Students find that their identity can fit into and shape an intellectual / academic environment.

(3) External, supposedly objective standards are not the only influence on how education takes place; classrooms designed for developing study agency are shaped by “human voice and tone” (Holland, 1998, p. 41). This position suggests that “one-best system” does not suit all students, that classrooms should be shaped around who students are and around the aspirations of their families, teachers, and communities. Students cannot to be stamped with pre-set curriculum but, instead, should be part of the process of development and decision-making in a classroom.

Blackburn (2004) argues that supporting student agency requires educators to think beyond the traditional conventions for teacher-student interaction. For example, “This means recognizing that when a student challenges ideas, he or she is asserting
agency... However, withdrawing from school, whether that withdrawal is emotional or physical, is also a way of asserting agency... We need to recognize such moves as strategies that accomplish real and valuable work for the young person, not just as a failure to achieve in school” (Blackburn, 2004, p. 109).

Blackburn recognizes the strengths that youth express when they act in ways that are in opposition to the school establishment and teacher goals:

Even when these youth are asserting their agency in ways that are antithetical to our goals as educators, we come to know their potential to achieve their own goals. There is much hope in this potential. Our work, then, becomes not working against such youth but instead working with them to identify and work toward common goals. This means working with students to figure out what it is about school they are withdrawing from, resisting, and fighting. It means being receptive to students' interpretation of problems in the school, believing that those who are invested in the school can make it a better place for all students to learn, and being committed to engaging in this work with students. It means imagining and implementing school-sanctioned activities that provide youth with opportunities to be themselves” (Blackburn, 2004, p. 109).

An emphasis on helping students cultivate agency requires that teachers transfer authority to students, in particular, by allowing them to have voice and choice in how a course is designed and enacted. When students can express their voice and exert choice in a classroom, their goals and actions matter. As a result, they must choose their goals more thoughtfully, more independently identify the knowledge and skills they need to achieve their goals, and reflect on whether their beliefs, goals and choices have moved them in a positive direction. In this type of classroom, students are not just reflecting on or learning about agency, they are engaging in agency to direct their classrooms in ways that resonate with their identities. Educators, in this Freirian model, are guides and leaders, and students are primary contributors to the structure of their educational experience.
How does an educator develop opportunities for students to express their voice?

Kirman (2003), with reference to the philosophies of Dewey, Kropotkin and Freire, develops the idea of "transformative geography" in which student voice is "heard and recognized" (p. 95). But what exactly does it mean for student voice to be integral in shaping a classroom? If student voice is connected to developing experience in the processes of agency, student voice must imply more than students talking a lot of participating regularly in classroom discussion. Brooker and McDonald (1999) expand the idea of "authentic participation" as youth engaging in the "planning, implementing and evaluating of their own learning."

How might educators cultivate this authentic participation? Falk-Rafael, Chin, Anderson, Laschinger and Rubotzsky (2004) propose feminist pedagogy as a strategy for developing student voice. Feminist pedagogy, in their opinion, is focused on ensuring that all students' voices are heard, demystifying the processes involved in evaluation and grading, and creating a community of learners in which teachers and students share their talents. These authors find that feminist pedagogy "is effective in empowering students and that empowerment in the classroom may extend into students' personal and work lives" (p. 114).

The influence that Falk-Rafael, et. al. (2004) identify between classroom voice and students' personal lives is a re-articulation of the link I imagine between youth voice and agency. When students participate in designing the structure of their own education, they authentically engage in the processes of agency, which prepares them for ever-more ambitious and successful acts of agency in their communities and world.
How does an educator develop opportunities for students to exert choice?

Having the ability to make meaningful, influential choices in a classroom is a way for youth to engage in school-based agency, building experience, once again, to pursue acts of agency in the larger world.

Students respond positively to choice and autonomy, especially when this choice manifests itself as youth applying their opinions, voice and identities to educational experiences. Choice helps students exert ownership over and develop personal attachment to the outcome of their projects, extending the length and depth of their interest in the subjects being examined.

How does having meaningful choices in a classroom connect to student agency? O’Neill and Pollman (2004), found in their study of project-enhanced, project-oriented and project-based classrooms, that

students’ experiences of participating in the formulation of research questions and data analysis strategies...were correlated with a more empowered role in approaching novel scientific problems. Students in the project-enhanced class (A), in which scientific research was discussed and modeled but students did not participate in the formulation of their own inquiries and solution paths, appeared less empowered to have an active role in approaching novel scientific problems as a result of instruction” (p. 261).

An implication of O’Neill and Pollman’s (2004) study is that choice and an emphasis on student-directed scientific inquiry increased student empowerment and, therefore, their opportunity to develop and enact their agency.

In summary, a focus on agency might manifest itself in an educational setting, in the following ways:

- Learning through which students and the teacher examine, question, expand, deepen and reshape their identity, beliefs and goals
- Teaching that supports student voice, autonomy and choice.
• An emphasis on continual reflection

Emphasizing these processes results in classrooms in which students are constantly working to identify, monitor and enact the processes by which they can achieve their goals. Success in developing student agency might be measured by comparing students to Jackson’s (2003) standards for his: “Ultimately my students are in charge of how they spend their time, how they wish to be seen, who they wish to be. They are active agents, critical decision makers” (p. 580)

Curriculum Shaped Around Students’ “Fund of Knowledge”

Dewey (1938) describes the importance of building curriculum around the identities, needs and goals of students:

the trouble [with traditional education] was that they did not consider...the power and purposes of those taught. ...This...made the process of teaching and learning accidental. Those to whom the provided conditions were suitable managed to learn. Others got on as best they could. Responsibility for selecting objective conditions carries with it, then, the responsibility for understanding the needs and capacities of the individuals who are learning (p. 45).

Zacharias and Calabrese Barton (2003) argue that people have a range of ideas about what constitutes science. They propose that the norms of science are socially-constructed. Fusco (2001) writes that “enactment of science must be understood in relation to the sociopolitical and cultural context in which science is occurring” and emphasizes “science in creation and within the context of a broader community” (p. 872). Because science is socially-constructed and reflects the power structures of a given society, current beliefs about what science may be described as “Eurocentric” (Seiler,
2001, p. 1007) or in the “Western science tradition” (Lee and Fradd, 1998, p. 15). So the existing paradigm of what constitutes science knowledge and skills may not include the views of many minority groups.

The belief that science is indeed socially-constructed has several practical consequences for physics education. First, students enter classrooms with strong, stubborn pre-conceptions about the principles by which the universe operates (Osbourne and Freyberg, 1985) – “constructivism” is the practice of basing education around the ideas students bring with them to a classroom.

Redish and Steinberg (1999) summarize this viewpoint when they write:

(2) What do our students bring to our physics classes? How our students hear and interpret the material presented to them in a physics class is heavily dependent on the experiences they bring to the class. Everyone has some sense that a force is necessary in order to maintain a velocity when walking, driving, or pushing something along the floor. Newton’s second law is inconsistent with the way that many of our students have made sense of their experiences in the world.

When material about Newton’s laws is presented to students, many find the information to be irrelevant and non-transformative, if it does not connect with their identities and social contexts (Pugh, 2004). Ignoring students’ experiences and pre-existing ideas results in students separating the knowledge communicated in their science classroom from reality; as a result, they hold on to previously-held conceptions of how the world works.

So from the lens of critical feminist theory, Project 2061 and Physics 1st are insufficient for remodeling the elitism, conservatism and under-performance that characterize the field of physics education. Project 2061 and Physics 1st are still positivist programs. People far-removed from students decide what science is relevant, useful and engaging to students. Without paying attention to local contexts, these curricula identify what knowledge should be learned, and the timing and style of instruction. Critical,
feminist theory suggests that for marginalized and resistant students to be successful, science, in this case, physics, must be approached as a social activity. Curriculum should be structured with “funds of knowledge” -- the needs, beliefs and interests of students -- in mind. Rahm, Miller, Hartley & Moore (2003) argue that for science to be ‘authentic’ -- “meaningful if seen within the context of the students’ lives” (p. 740) -- it must be precipitated by the interactions among students, teachers, and scientists. Authenticity as an emergent property of the learning process challenges the basis for many science curricula and current pedagogical practices that take scientists’ science as their norm and that assume a priori that such is authentic, i.e., it practices preauthentication. (p. 737)

Dewey (1938) speaks to the challenge of designing curriculum responsive to students’ funds of knowledge. Curriculum must provide students with both freedom to explore and sufficient structure so that a problem is approachable: “The planning must be flexible enough to permit free play for the individuality of experience and yet firm enough to give direction towards continuous development of power” (p. 58). Also, teachers must be able to connect students’ existing experience to helping them acquire larger bodies of knowledge and the ability to analyze problems critically. He writes, “It thus becomes the office the educator to select those things within the range of existing experience that have the promise and potentiality of presenting new problems which by stimulating new ways of observation and judgement will expand the area of further experience” (p. 75).

One can expand this notion that curriculum should be based on students’ “funds of knowledge” to the structure of the school system, at large. Wilson Farmer and Farmer (2000) and Fuller (2000) discuss the tensions between designing a “one best system” that fits all students and neighborhoods versus creating schools that reflect the identity and goals of a local population. Wilson Farmer and Farmer (2000) also question whether the
"one best system" has "legitimate pedagogical objectives" (p. 65) or is, instead, the result of "historical accidents" (p. 65).

**Freire’s Educational Philosophies**

*The Purpose of Education is to Support Students in Becoming "Agents of Change"*

Is there a larger purpose to education than the transfer of knowledge and the provision of skills for people to work in society? Freire argues that a lack of education and traditional forms of education blind students to social power structures and adapts them to accept and function within these confines. Shaul, in his introduction to *Pedagogy of the Oppressed*, writes: “Rather than being encouraged and equipped to know and respond to the concrete realities of their world, [students] were kept ‘submerged’ in a situation in which such critical awareness and response were practically impossible. And it became clear to [Freire] that the whole educational system was one of the major instruments for this culture of silence” (Shaul foreword to Freire, 1970, p. 30). Giroux (2004) similarly writes, "Pedagogy is a moral and political practice that is always implicated in power relations and must be understood as a cultural politics that offers both a particular version and vision of civic life, the future, and how we might construct representations of ourselves, others, and our physical and social environment” (p. 33).
In an educational tradition that Freire labels “banking education,” terms and ideas are often memorized without attention paid to their meaning. Freire writes: “The outstanding character of this narrative education, then, is the sonority of words, not their transforming power. ‘Four times four is sixteen; the capital of Pará is Belém.’ The student records, memorizes, and repeats these phrases without perceiving what four times four really means, or realizing the true significance of the ‘capital’ in the affirmation ‘the capital of Pará is Belém,’ that is what Belém means for Pará and what Pará means for Brazil” (Freire, 1970, p. 72).

Proponents of “banking education” might argue that the system for which they advocate is neutral, unbiased, reflective of reality. But Shaul writes that any educational system reflects social values and is not inherently objective:

There is no such thing as a neutral education process. Education either functions as an instrument that is used to facilitate the integration of the younger generation into the logic of the present system and bring about conformity to it, or it becomes ‘the practice of freedom,’ the means by which men and women deal critically and creatively with reality (Shaul introduction to Freire, 1970, p. 34).

Freire, contesting education that presents existing power structures as just, objective and static, demands that education encourage students to recognize and reflect on the political, social and economic forces that shape their lives. Such awareness, Freire believes, empowers people to transform their own lives and the larger world to be more socially-just and equitable.

Freire terms a process of reflection and action, through education, as consciencetização – “learning to perceive social, political and economic contradictions, and to take action against the oppressive elements of reality” (Freire, 1970, 35). From this educational philosophy, individuals “need to extend their trembling hands...less and less
in supplication, so that more and more they become human hands which work and, working, transform the world” (Freire, 1970, p. 45)

Critical Reflection

Freire argues that there are two processes that must take place in education, if one is to be an “agent of change.” These stages – reflection and action – circle upon themselves; each informs and encourages the other.

Critical reflection is a process that leads to students to a better understanding of the social power structures and the causes of injustice. Critical reflection is essential if education is to result in social progress towards equity -- this type of reflection allows people to see the possibility of transformation in situations that might previously have seemed unchangeable. Greenman and Dieckmann (2004) write that “Developing a critical lens may be seen as pivotal for becoming a reflective practitioner embodying a passion for equity and social justice” (p. 240).

Upon engaging in critical reflection, students are likely to arrive at the conclusion that “the world [is] not...static...but...a reality in the process of transformation” (Freire, 1998). An education based on critical education suggests to students that the status quo does not have to always be reality. Instead, reality can be shaped by the actions of people: “Reality is really a process, undergoing constant transformation” (Freire, 1970, p. 75). As a result of critical reflection, “Individuals who were submerged in reality, merely feeling their needs, emerge from reality and perceive the causes of their needs. In this way, they can go beyond the level of real consciousness to that of potential consciousness much
more rapidly" (p. 117). In using the terms “real” and “potential consciousness,” Freire suggests that people engaged in critical reflection transition from feeling that the world cannot be changed to seeing potential for change in the limits they encounter.

Freire believes that critical reflection involves the recounting of personal experiences. Fahrenwald (2003) recounts an example of how personal experiences can be the foundation for community change initiatives. According to Fahrenwald, nurses in training at South Dakota State University “are encouraged to examine the type of oppression evident in these experiences and to discover ways to address the issue through a population-based public health intervention” (p. 223).

In the Fahrenwald nurse cohort, nurses were required “to analyze the social, political, economical, and environmental factors that have contributed to the inequity” (p. 224). Similarly, Freire demands that critical reflection extend from a focus on individual experience to an analysis of “power, agency, history.” For example, Freire believes that studying the roles of class and race is essential in analyzing oppression. But a focus on race and class is insufficient: “It is important to approach the analysis of oppression through a convergent theoretical framework where the object of oppression is cut across by such factors as race, class, gender, culture, language and ethnicity.” Macedo (1970) writes that Freire “resisted the essentialist approach of reducing all analysis to one monolithic entity of race. For example, African functionaries who assimilate to colonial cultural values constitute a different class with very different ideological cultural values than the bulk of the population....Race, itself, is not necessarily a unifying force” (Macedo introduction to Freire, 1970).
Transformation

Greenman and Dieckmann, extending on the work of Freire, identify two stages of transformation: *awakening* -- to understand the “nested, webbed, tangled, and overlapping dynamics of power, oppression, culture, diversity, and equity” (p. 250), *praxis* -- seeking “immediate change based on one’s own volition” (p. 251).

A participant at the Raza Womyn’s Center, described by Revilla (2004), defined transformation as “when you’re making real changes in your life or affecting other people and when your organization is changing people’s lives. When you create a space that has never existed...to talk about the real situation and to create empowerment” (p. 89).

*How Might Educators Support Students in Being “Agents of Change”?*

Freire suggests that the path to cultivating *consciencetização* is difficult. He writes, “I have encountered, both in training courses which analyze the role of *consciencetização* and in actual experimentation with a truly liberating education, the ‘fear of freedom’ discussed in the first chapter of this book. Not infrequently, training course participants call attention to the “danger of *consciencetização*” in a way that reveals their own fear of freedom. Critical consciousness, they say, is anarchic. Others add that critical consciousness may lead to disorder.” Nevertheless, Freire suggests a series of strategies through which educators and students can arrive at an increased sense of “critical consciousness.”
Students and teachers as joint designers of pedagogy.

In the “banking” model of education, a teacher controls the educational agenda and transfers information to the student. “The more completely she fills the receptacles, the better a teacher she is. The more meekly the receptacles permit themselves to be filled, the better the students they are” (Freire, 1970, p. 72). In this scenario, the teacher is acting, and the student is a passive repository for ideas and information that the teacher generates -- “the teachers acts and the students have the illusion of acting through the action of the teacher” (Freire, 1970, p. 73).

But Freire believes that if students are to use their education to address issues of equity and social justice in their own lives, they must have a voice in the content of their education -- what they learn must reflect their own beliefs and goals. “Democracy and freedom forged with not for people who are oppressed” (p. 48).

Several other educational researchers support and expand upon Freire’s views. Salinas and Reyes (2004) suggest that an advocate educator for Chicano migrant workers must create a “‘political’ theater that help[s] articulate the needs and demands of many Chicanas/os throughout the nation” (p. 55). Also, they feel the curriculum must be sensitive to the lifestyles of children of migrant workers, who are often not at the same school for multiple years and start and end their school year based on labor patterns rather than school-year cycles. Glass and Wong (2003) propose several strategies for building the opinions and skills of a student’s family and community into a formal education setting. They write, “Taken together, school-community gardens, home visits, and community service learning (oral history projects and other activities) offer avenues for participants to determine how culture, language, ethnicity, gender and social class
interact to shape identity” (74). These authors also emphasize that a significant portion of teaching is building relationships with students and families.

If a school and classroom are to be democratic and egalitarian, students must be able to develop curriculum, pedagogical practices, and educational philosophies with teachers. For students to truly trust and, therefore, be open to the ideas of teachers, the reverse must also be true (Freire, 1998). Greenman and Dieckmann (2004) describe a university classroom in which the teacher cultivated critical reflection. This course emphasized agency – students being able to exercise choice in the direction of their goals. The authors write, “Although university and division policies and procedures imposed some parameters, latitude was taken in selection and use of course materials, as well as in negotiation of assignments. At the very least, choices were embedded in almost every aspect of the course, though it was not fully constructivist nor democratic” (p. 248).

In this the process, the teacher is a participant in learning, as in the study conducted by Greenman and Dieckmann (2004), in which the teacher “positioned herself as a co-learner who did not have the answers but perhaps had been asking the questions a bit longer than the students” (p. 249). According to Freire, while the students are engaged in unveiling and discussing power structures and taking action, the teacher too is learning from his interaction with students. “The teacher presents the material to the students for their consideration, and re-considers her earlier considerations as the students express their own” (Freire, 1970, p. 81). “By observing how the novice student’s curiosity works to apprehend what is taught...[teachers] help themselves to uncover uncertainties, rights and wrongs” (Freire, 1998, 17). Teachers must strive to learn and create knowledge with their students, not just transfer information they consider appropriate. Salinas and Reyes...
(2004) cite the example of advocate educators in their study who learned from and designed programs around the resources and ideas of parents and students, and what was most important to their community.

From the perspective of Freirian philosophy, the teacher is not a learned example upon which students are modeling themselves by acquiring the teacher’s knowledge. Freire writes that “No pedagogy which is truly liberating can remain distant from the oppressed by treating them as unfortunates and by presenting for their own emulation models from among the oppressors…Instead, “the oppressed must be their own example in the struggle for redemption” (Freire, 1970, p. 54). The teacher is a guide in the process of education who poses the issues that students raise as problems to be solved, but is not the only example in the educational process of a person with acceptable beliefs and knowledge. Instead, the students can also share meaningful knowledge and experiences and are models to each other from which both teachers and students can learn. Freire writes: "At the point of encounter, there are neither utter ignoramuses nor perfect sages; there are only people attempting together, to learn more than they know now.” Teachers and students work together in shaping and motivating the educational process; teachers are guides and also co-discoverers.

Freire suggests that educators ask students directly about their interests, beliefs and needs. Salinas and Reyes (2004) provide an example of this in their discussion of advocate educators for Chicano students. In their observations, they see advocate educators as responsible for understanding the struggles and goals of the community they are teaching.
Further, Freire believes that when people discuss their own beliefs and those of community members, they are empowered by knowing that their ideas and experiences are a valuable foundation upon which to base education and plans of social transformation. Freire writes that “this view of education starts with the conviction that it cannot present its own program but must search for this program dialogically with the people, it serves to introduce the pedagogy of the oppressed, in the elaboration of which the oppressed must participate” (Freire, 1970, p. 124).

Teacher authority.

Freire does specify that being a democratic teacher does not equate with having no values and exercising no power in a classroom. He writes that teachers, “must not, in the name of democracy, evade the responsibility of making decisions” (Freire, 1998, 43). In addition to being facilitators, guides and problem- posers, teachers have a responsibility to defend the rights of students and make sure that all voices, including their own, are heard (Freire, 1998). Teachers may “speak and act firmly [when] it is done in the interest of the group, not as an exhibition of personal power” (Dewey, 1938).

In addition, Dewey suggests that if schools are to be places where “all individuals have an opportunity to contribute and to which all feel a natural sociability,” teachers must use “thought and planning” to develop learning environments that cultivate “genuine community life...ground[ed] in natural sociability” (p. 56). Teachers must understand, respond to and shape the role of the collective in influencing and altering individual student agency.

To become comfortable with a “democratic” model of education, in which students direct their education and work socially, teachers must overcome their fears of
being displaced, losing control and authority, and being accountable to their students. “How can I dialogue if I am afraid of being displaced, the mere possibility causing me torment and weakness?” (Freire, 1970, p. 90). Often facing such fears is difficult; teachers “feel the need to renounce invasion, but the patterns of domination are so entrenched within them that this renunciation would become a threat to their own identities” (Freire, 1970, p. 156).

If teachers are to achieve this vast range of goals – supporting students in critical reflection, sharing their voice in the design of curriculum, structuring education as problem-solving and inquiry-based, facing their fears of being displaced as keepers of power -- educators must constantly be assessing their own teaching. Teachers are, therefore, students of their own practice – critically reflecting on their own practice and taking action to enact change, where appropriate. Glass and Wong (2003) write that successful teachers “reflect on and critically analyze the background conditions that shape their daily experience in schools, their routine classroom practices, and their needs for professional learning and development” (75). From this critical reflection, teachers take on leadership roles outside their classroom, shaping the school based on their knowledge and reflection.

Similarly, Freire writes, “All practice represents to its subjects, on the one hand, a program of action and, on the other, a continuous evaluation of the program’s objectives...In the end, evaluation is a process through which practice takes us to the concretization of the dreams that we are implementing” (Freire, 1998, 7). Freire believes that teacher development cannot happen through individual motivation alone; society has
a responsibility to support teachers with respect and resources. Freire writes, that teachers must be “well paid, well trained and in constant development” (Freire, 1998, 35).

*Problem-Posing and Inquiry-Based Education*

Once students have expressed their interests, beliefs and needs, an educator’s role is to rephrase the issues raised as problems to be solved. Freire writes that “The task of the dialogical teacher … is to ‘re-present’ that universe to the people from whom she or he first received it – and ‘re-present’ it not as a lecture, but as a problem” (Freire, 1970, p. 109). Revilla (2004) found that from discussions about community issues, women in a Chicana/Latina activist group started to discuss the world (p. 85).

For example, if a person living in poverty says that he cannot buy food to live, a Freirian educator might ask what social structures must be changed for food to be affordable. This type of problem-posing education assumes that people neither have to adapt to existing power structures nor accept that the future is determined to proceed in ways that perpetuate oppression. “Problem-posing education – which accepts neither a ‘well-behaved’ present nor a predetermined future—roots itself in the dynamic present and becomes revolutionary (Freire, 1970, p. 84).

Once an educator has posed an issue as a problem to be solved, students are to use inquiry to unearth solutions to this problem. Freire writes that “Knowledge emerges only through invention and re-invention, through the restless, impatient, continuing, hopeful inquiry human beings pursue in the world, with the world, and with each other” (Freire,
In the Freirian model of education, students discover and re-discover knowledge and, from this foundation, critically assess the structures that govern society. Fenimore-Smith (2004) describes inquiry-based education as promoting discourse and collaboration, both democratic practices (p. 237).

In a science class, one might imagine a chemistry classroom structured around "banking education" in which students memorize information about the structure and function of various molecules. In contrast, in a classroom reflecting Freirian philosophy, an educator might encourage students to record observations of their neighborhood. If students document high rates of asthma and birth defects in their neighborhood, the teacher might pose the issue they have raised as question: "How does pollution in my neighborhood affect the people around me?" Students might inquire into this question by:

1) examining data on the effects of pollution in neighborhoods similar to theirs,
2) evaluating data collected on their own neighborhood,
3) collecting their own data through surveys,
4) encouraging local medical organizations to collect asthma and birth defect information, with consent, from medical exams.

A crucial component of problem-solving and inquiry-based education, according to Freire is this type of community assessment. Just as an educator must explore the context in which he is teaching to develop curriculum, students must "evaluate the context in which the practice takes place, which means recognizing what is taking place in the context as well as how and why it is taking place" (Freire, 1998, 8).

If, indeed, students find that their community experiences high rates of asthma and birth defects, the might then pursue the question: "Why is this?" To understand
exactly if and why pollution affects the people in their neighborhood, students would have to explore the structure and physiological effects of molecules such as carbon dioxide, ozone, chlorofluorocarbons and more. The students, with guidance, are likely to accomplish the task of the original “banking” lesson.

But students have most likely achieved even more -- when students collect and analyze their own data on problems of importance to them and evaluate the validity of conclusions from work done by others, they have ownership over the information they have learned. Instead of accepting the generalizations, conclusions and choices of others, they have evaluated and analyzed each piece of information from their own perspectives and compared it with general beliefs. Because they have a strong grasp and a personal investment in what they have learned, students can then intelligently use their acquired knowledge to ask for and enact change as they see fit.

Through an education based on inquiry, students must also engage in the interdisciplinary nature of real-world problems. Assessing the effects of pollution only from the perspective of chemistry, for example, is a theoretical exercise. Studying and mitigating the effects of pollution requires an understanding of politics, economics, and a vast array of scientific and mathematical fields. Freire argues that if students consider a problem from a broad, inquiry-based perspective, without being limited by the artificial constructs of disciplinary thinking “the resulting comprehension tends to be increasingly critical” (Freire, 1970, p. 81). This type of critical perspective allows students to be aware of the social structures that result in the effects of pollution and, therefore, capable of changing these circumstances.
Freire admits the value of breaking down large issues into smaller parts, for the purpose of analysis and understanding but fundamentally believes that all analysis of reality must begin with a large-scale comprehension of the problem or task at hand. He writes:

“When people lack a critical understanding of their reality, apprehending it in fragments which they do not perceive as interacting constituent of the whole, they cannot truly know that reality. To truly know it, they would have to reverse their starting point: they would need to have a total vision of the context in order subsequently to separate and isolate its constituent elements and by mean of this analysis achieve a clearer perception of the whole” (Freire, 1970, p. 104).

Support in the Science Education Literature for Freire’s Emphasis on Inquiry-Based Education

Arons (1990) writes, “much as we might dislike the implications, research is showing that didactic exposition of abstract ideas and lines of reasoning...to passive listeners yields pathetically thin results in learning and understanding... I am pointing to the necessity of supplementing lucid exposition with exercises that engage the mind of the learner” (p. vii). Zollman, Rebello and Hogg (2002) similarly question the value of courses entirely based on lecture. Stewart and Rudolf (2001) characterize most of the science problems that students encounter in school as “model-data fit problems, in which solver fits available data to an appropriate explanatory model” (p. 207).

These researchers speak to need for physics curricula that include inquiry-based lessons from which students can arrive at their own conclusions. An inquiry-based curriculum is engaging to students and is a reflection of the nature of science, which is more than the fitting of data to existing ideas. For example, Kuhn (1962) describes
scientific revolutions as “displacement of the conceptual network through which scientists view the world.”

Because science involves both inquiry into problems and the questioning of paradigms, the training of students in science (in this case, physics) should reflect these two skills. Stewart and Rudolf (2002) propose that problems require students to “confront the conceptual coherence of their explanatory models” (p. 208). Herreid (2001) describes a case study model in which a student pursues genuine inquiry – he writes that, through this pedagogical strategy, a student “puts...learning to use in order to analyze the situation, decide what the problem is, and figure out what [he/she] need[s] to know how to solve it” (p. 87). Gollub and Spital (2002) similarly advocate for physics courses that support student experimentation and inquiry. These authors are opposed to “cookbook labs, in which students follow a narrowly prescribed procedure to verify established theoretical principles... such labs lead students to describe their lab work as ‘boring’ or a ‘waste of time’ (p. 51-52). An existing curriculum centered on these principles is Physics by Inquiry, in which students use observations to develop their own physical models (McDermott, 1996). Also, Arons (1990), Reese (2000), and Crawford (1968), in their respective texts, recommend investigations that students can pursue on their own to explore physics ideas.

In high-school, students should experience freedom in exploration (Lillard, 1996); they should increasingly design and implement their own complex science investigations and participate in experiments conducted by professional scientists. For example, the American Museum of Natural History, Smith College and the NSF Research Experience for Undergraduates invite students to participate in internship programs in
which they work alongside scientists to answer cutting-edge research questions. Three of
my former students worked at an astrophysics lab at Columbia University for which they
participated in the construction of the receivers used in the actual telescopes the lab is
designing. The value of students conducting "real science" is that they 1) realized the
importance of the science and math concepts they are learning in school for solving real-
life problems in inter-disciplinary ways, and 2) they were able to explore and pursue their
own interests.

*Areas in which I Question Freire*

Three aspects of Freirian philosophy concern me. First, I wonder if his view of
students and teachers is assets-based. Second, I question whether he has thought deeply
about what science is and how science should be used appropriately in making decisions.
And, finally, I disagree with his perspective that the goal of increased democratic
pedagogy be pursued by groups that do not ever criticize their own members and actions.

Freire, in his writing, portrays traditional teachers as "bankers" who do not
encourage critical thinking and student voice. This perspective, in my opinion, does not
recognize the intentions and work of a vast number of teachers who are creative, hard-
working, reflective and activist in their classrooms. Freire, similar to innovative
educational philosophers, seems to discount past educational efforts and intentions as
suspect. He chooses the word *oppressed* to describe the students who lives he hopes to
influence, and I wonder if this view of students encourages pedagogy that is, in part, based on what is rich and vibrant about a community.

Freire, on one hand, discredits science and scientists, and, on the other, uses the power of saying something is scientific, without explaining why he thinks that particular issue should be evaluated from the lens of science.

First, Freire criticizes the ways in which science and technology affect society. For example, he writes, “We must equally avoid other fears that scientism has instilled in us” (Freire, 1998, 29). Freire has a skepticism about science because he believes that scientists present their opinions to be reflective of objective truth: Other authors who cite Freire in their work, for example, Greenman and Dieckmann (2004), are similarly hostile to scientists and scientific ideas. These authors describe one potentially hostile environment to their philosophies, “symbolizing hegemony and resistance to change” as “materializing in the Newtonian-Cartesian worldview” (p. 243).

However, when convenient, Freire relies upon the objectivity associated with science to support his own beliefs. For example, Freire, when discussing teachers’ fears of displacement in a democratic classroom, writes, “one must objectively ascertain whether there are real reasons for that fear” (Freire, 1998, 27). When discussing teacher preparation, he argues, “But with responsibility, scientific preparation and taste for teaching,...we can contribute to the gradual transformation of learners into strong presences in the world” (Freire, 1998, 33).

Freire seems to have a mixed relationship with science, questioning how people use it to make decisions in society, but also feeling that a scientific perspective is useful to him and to educational practices. Despite his ambivalence, he does not explore deeply
what science is and where and how it should be used. Instead, he seems, without much reflection, dogmatically embrace a stance, which suggests that scientific progress and capitalism undermine society. Therefore, I am left to wonder what Freire means by science and scientism, what an objective process is to Freire, whether this objectivity exists, what exactly he envisions as “scientific teacher preparation,” and why this is an appropriate method for training teachers.

Freire writes that “The project of democracy must never be transformed into or understood as a singular or individual struggle...Furthermore, teachers should always stick together as they challenge the system so that their struggle is effective” (Freire, 1998, 7). From my experience as a teacher affiliated with a teacher’s union, I question whether a communal teacher voice is the most effective and ethical way to bring about educational reform. Why can one voice not inspire change? Is democracy not, at some fundamental level, about individual rights, choices and responsibilities? Why should teachers always stick together? Shouldn’t teachers who care about the success of students question the performance of low-achieving teachers and not allow these teachers to continue their work with students, if they do not improve?
Defining Critical Physics Agency: Incorporating Strategies for Engagement and Rigor, Student Agency, a “Funds of Knowledge” Lens, and Freire’s Philosophy on the Teaching and Learning of Physics

An Expanded Definition of Physics Literacy

In the prior section on physics literacy, I emphasized the importance of conceptual understanding and investigating the nature of science within the organizing topics of exploring the universe and developing technology. I then discussed strategies for increasing student engagement and competence in physics, so youth can achieve a complex understanding of physics concepts and science processes. Finally, I discussed the possibility of applying paradigm shifts in education -- an emphasis on student agency, funds of knowledge and Freirian philosophies -- to physics education. I would like to expand my definition of physics literacy by synthesizing these concepts under a new term -- critical physics agency, based on Turner’s (2003) discuss of critical math agency. A diagram of the key elements contributing to critical physics agency is shown below.
Implications of Critical Physics Agency for Assessment

Physics assessment must match the expanded scope of what it means to be physics literate. The purpose of assessment is then, not only to measure conceptual change and an understanding of the nature of science, but to evaluate the connection between curriculum and a students’ funds of knowledge and developing agency.

Fusco and Calabrese Barton (2001) raise the following questions for educators to consider, when designing assessment:

- In what ways can the assessment of performance represent the holistic and historical nature of knowing in science?
- In what ways can inventions and performance assessments be infused with the worldviews and perspectives that particular students bring to the learning and doing of science?
- In what ways can performance assessment emerge from individual and collective responses to local concerns? How can such responses be both the production of science and the production of assessment?
- In what ways is performance assessment a method and a search for methods?
- In what ways can performance assessments include young people in their creation, and thus infuse how young people do and talk science in the context of community? (p. 340)

These questions provide scaffolding for assessment that is concerned with students’ “funds of knowledge” and youth empowerment – whether curriculum is shaped around the content, methods and language that students deem important.
Assessment as a Recursive Tool for Life-Long Learning and Self-Improvement

If the goal of physics education is, in part, to prepare students to grapple, throughout their lives, with ideas and controversies in physics, students must experience assessment as a recursive tool. From this perspective, assessment does not serve the sole purpose of assigning grade to a piece of work; instead, assessment is a mechanism through which self-improvement can occur.

Redish and Steinberg (1999) emphasize the need for ongoing assessment that affects instruction – they believe that educators should repeatedly ask: "(3) How do our students respond to our physics instruction? We often assume that students will respond as we did, or rather, as we might have wished we did, knowing what we know now. To design effective instruction, we must learn how students really respond."

Gollub and Spital, when discussing how teachers might use assessment as a recursive tool for their practice, argue that effective classroom evaluations must "assess the depth of [student] understanding" and must result in teacher’s modifying their instructions based on student performance (p. 50). Similarly, for students, the interview strategy suggested by Marin, Gomez & Benarroch (2004) might be recursive. As a result of its conversational nature, the interviews may convince students that evaluation is not just a numeric endpoint but an opportunity to discuss issues, explore questions, and develop plans for progress.

To develop a sense of agency in science so they can design, enact and reflect upon their own experiments, students should develop their own abilities to use assessment in
science, independent of the requirements of an instructor. Marin, Gomez & Benarroch (2004) emphasize the importance of self-evaluation. For example, students might predict the results of a particular experiment, conduct the activity and reflect on results. If students engage in this type of self-evaluation, they are likely to identify changes in their own conceptual understanding, analyze the scientific process in which they are engaging, and learn how to develop their own internal assessments, a skill that is a life-long learning tool.

For cultivating self-evaluation, Sandoval and Reiser (2004) propose the use of an "Explanation Constructor," a technological tool they have developed for students to record the process by which they respond to questions about phenomena. Through their software, students can record questions, sub-questions, explanations, and evidence; the main points of their discussions are recorded and, therefore, "available and open to inspection" (p. 361). Guiding question at various stages of the process are built into computer program, so students are self-reflective and evaluated by peers before they submit a final product.

Assessment for Critical Questioning

If physics literacy includes the ability to identify controversial issues in physics and then intelligently question and resolve these issues, students must be trained to engage in this type of critical thinking. Therefore, any assessment, whether it be written,
oral or illustrative, should require students to explore the following questions about the
science issue at hand”

“1. Who is in the group?
2. How are they funded?
3. Who do they represent?
4. What are they trying to achieve as an organization?
5. What key values/philosophy or ethical position is explicit in the organization’s publicity
   materials?
6. What evidence are they using?
7. Do they indicate the limits to their evidence?
8. What is the source of their evidence?
9. Do they present contrary arguments?
10. How strong do you think their argument is?
11. What do they want us to believe?

The questions proposed by Oulton, Dillon and Grace (2004) not only give
students the tools to think critically about the strength of a scientific position, they also
emphasize that science is a socially-constructed process. The questions encourage
students to examine how “great factual discoveries of enduring worth [are] mixed with
unconscious social prejudices” (Gould, 2003, p. 4).

This type of assessment can be built into curriculum in interesting, thought-
provoking ways. Oulton, Dillon and Grace (2004) recommend that

For homework, pupils would be asked to compose a critical question that they would like to
ask a representative of each organization if they were interviewing them for a television news
programme. In each case, the pupil would have to state (for the teacher) why they were asking
the question. The teacher would mark the sophistication of each question in terms of the
pupil’s ability to analyse weakness in arguments and their ability to pose questions that could
effectively elicit answers (p. 421).

I would add that once the questions are sufficiently-sophisticated, students should
pose their queries to the actual organizations. This type of real-life questioning makes
students’ academic work purposeful in real-life contexts. Also students become activists
in their communities because they are challenging scientific organizations to reflect upon
their prejudices and motivations.
What Does Cultivating Critical Physics Agency Look Like?

A classroom structured around students' "funds of knowledge"

How does one create curriculum structured around students' "funds of knowledge"? Though a general outline might exist for appropriate concepts to cover in a physics course, the methods by which these topics are explored must be devised with attention to the interests and motivations of particular students. Curriculum must reflect the experiences, beliefs and prior knowledge of students—their "funds of knowledge," if they are to feel engaged (Rahm, 2002; Gollub and Spital, 2002). The disengagement from science that Zacharias and Calabrese Barton (2003) observe in urban middle-school students might be counteracted by a curriculum that "respects the diversity, individuality, sensitivity, and social needs of students and promotes positive discourse among students and teachers across the curriculum and their lives" (p. 22).

I propose that students' "funds of knowledge" be built into curriculum within my definition of critical physics agency, which emphasizes high-levels of physics knowledge, understanding and skill. The challenge to teachers is to build academic rigor into a student-centered curriculum, to guide students, through their interests and beliefs, to the richness and complexity of physics concepts.

To engage students' "funds of knowledge," a physics teacher might propose real-world problems and project-based science, as described by Schneider, Krajcik, Marx Soloway and Elliot (2002). "In project-based science, "it is assumed that students need to
find solutions to real problems by asking and refining questions, designing and conducting investigations, gathering and analyzing information and data, making interpretations, drawing conclusions, and reporting findings” (p. 411). Project-based science allows youth opportunity to pursue their own interests.

Even when subject material is less open-ended and particular curricular goals are to be fulfilled, physics teachers can incorporate students “funds of knowledge” into their lessons by actively researching the beliefs and attitudes of their students, especially if cues for this type of investigation are built into curriculum. For example, Moje, et. al. (2001), describe a teacher who “supported by ideas developed in the curriculum materials, constructed context for introducing the air project. That is, the curriculum called upon the teacher to solicit students’ experiences, and in so doing the curriculum and Maestro Thomas together brought aspects of the students’ everyday Discourses and their knowledge about air, water, and human life to the discussion” (p. 490). From such exchanges, teachers can shape curriculum that reflects the interests and values of students. For example, Maestro Thomas, who began his lesson with a discussion of elements essential to life then shaped the students’ stated interest in a recent hurricane in the Dominican Republic into a discussion or air and water quality in this region.

Similarly, a physics teacher might investigate the interests of his or her students around energy. A community living near a nuclear power plant might decide to investigate operations and waste products from the facility. But a community that has sent a disproportionately large number of youth to the armed forces might be more interested in exploring nuclear reactions through the lens of weapons of mass destruction.
Gollub and Spital (2002) recommend flexibility in the second semester of an advanced course in physics. Their suggestion matches the spirit of a curriculum constructed around students' "funds of knowledge." They write that "schools with more mathematically-sophisticated students might use the second semester for a traditional introduction to electricity and magnetism... Other possibilities might include an introduction to a more recent part of physics, such as introduction to relativity and its applications, physics and astronomy, or an interdisciplinary study of biological physics" (p. 51). Flexibility in the second semester of an advanced course in physics is also ideal for exploring waves, optics and/or electricity and magnetism, especially if, as Sadler and Tai (2001), recommend, introductory physics is focused mechanics.

How is agency connected to physics instruction?

Given its Freirian foundation, a fundamental premise of this paper is that for students to be physics-literate, they must develop a sense of agency in science. In school, youth must have opportunities to use science as a tool for goal-directed action, with the hope that this practice will become a life-long habit of mind, a marker of physics literacy. Roth and Lee (2004) write that a consequence of an emphasis on agency in a science classroom is "the potential for lifelong participation in and learning of science-related issues" (p. 263).

In the section titled "How Might Teachers Cultivate Student Agency in a Classroom?" I identified three principles for advancing student agency through instruction – 1) exploration of personal identity and goals, 2) teaching that supports student voice and choice, and 3) emphasis on continual reflection. In the section below, I
discuss how these principles might be used, in a physics classroom, to cultivate youth agency.

For youth to enact change in the world, they must examine their own identities and beliefs, because this process is fundamental to goal-setting. One way in which students might articulate their physics-related goals is by exploring their identity as scientists and physicists. For example, in a physics classroom:

• If a student thinks about how she is a physicist already, she can pinpoint what aspects of physics that are important to her and connect with her life experience.
• By envisioning herself as a physicist of the future, a student can identify how she fits into the world of physics and articulate goals by which she would alter the physics community and field to better match her beliefs and values.
• Youth can and should be inventors! Invention is a process by which students can explore their identity as scientists and, therefore, a fundamental foundation for developing agency in physics. Also, youth working as inventors enhance their ability to design and create technology in the image of their beliefs, an idea discussed below as a crucial element in physics agency.

One theme of an introductory high-school physics course might be for students to explore current research in physics to evaluate whether the motivations, goals and resource allocation associated with this research resonate with students’ personal beliefs and goals for their community and world (O’Neill & Pollman, 2004; Kaelin & Hubner, 2003). Based on their conclusions, students might engage in various forms of activism:

• participation as interns in physics labs that allows them to contribute to research in areas they consider meaningful
• political campaigns targeted at questioning resource allocation — for example, active participation in the recent debates over the fate of the Hubble telescope and NASA’s commitment to pursuing a human mission to Mars.

Education, according to Freire, does not serve the purpose of having students act as passive recipients of knowledge. Jackson (2003) reiterates this view: “Students are more than “passive players, pawns in games organized and controlled by adults” (p. 580). Instead, education should convince students that they have the potential to profoundly affect the world and enact their goals.

A first step for students in this process is for them to develop the ability to pose and respond to complex, controversial questions and assumptions, of which there are many in physics. Crick (2001) writes that “we would expect that to be functionally literate in terms of engaging with controversy, students would have developed skills of critical inquiry such that they would ask more awkward questions hopefully in a more sensible way, and be put off by stock answers” (p. 34). Meier (1995) suggests that science education should be constructed with attention to students’ long-term agency, their ability to use the knowledge and skills they have learned towards the goal of intelligently evaluating issues in their world and questioning scientific conclusions.

Freire (1970) proposes a definition for this type of critical questioning — 1) inquiry based on the assumption that systems and ideas are dynamic and can be transformed by the actions of people, 2) inquiry with the purpose of understanding social power structures and increasing equity. Critical feminism similarly advocates research for social change, positions knowledge construction as a socially, political and culturally driven process, and supports in-depth and systemic investigations into individual and
social contexts. In my dissertation, I include, under *critical physics agency*, the idea that students develop high-level skills and knowledge in this subject, which serve as the foundation for intelligent inquiry and enacting social change.

In a physics classroom, students might engage in agency activities centered on critical inquiry by:

1. regularly identifying and articulating the assumptions behind physics theories
2. examining the degree to which physicists’ models describe and predict the natural world and modifying and extending physicists’ models, where possible, based on their own intuitions and calculations. For example, students might devise creative methods for representing atoms, molecules and sub-atomic particles in ways that improve upon popular, commercial charts and models.
3. investigating what social factors affect who participates, what happens and what is developed in the world of physics

In the section on physics literacy, I identified two overarching topics: “Physics as a Foundation for Exploring the Structure of and Principles that Govern the Universe” and “Physics as a Foundation for Enhancing and Developing New Technologies.” Critical questions associated with each of these topics are identified below:

*Exploring the structure of and principles that govern the universe*

- What aspects of the universe should our society explore? How? Why? At what cost?
- How is current research into the structure of the universe conducted? How might this process be improved, modified, or expanded?
• What is the evidence for different theories and predictions about the structure and nature of the universe, and what of this evidence is convincing?
• How do the opinions of scientists compare with beliefs and ideas outside the present scientific community?
• What questions in physics merit further exploration?
• How does our knowledge of the universe affect what we create and produce as a society?

*Enhancing and developing new technologies*

• What types of inventions and technological improvements are most useful to communities?
• In what ways can physics-related technologies be destructive?
• What types of technologies merit the allocation of our society’s resources, and why?
• How does one envision, design and build an invention that is innovative, useful, reproducible, environmentally-conscious and durable?

Developing technology is a vehicle by which individuals can significantly shape their world and acquire personal rewards, both intellectual and financial. Yet most students, particularly in low-income, urban neighborhoods, are consumers, not producers of marketable technology. Students often do not have a chance to explore, over the duration of their secondary-school education, what their goals might be in producing technology and generally do not develop the skills and knowledge to understand, design and create technology. After all, they know best what changes would enhance their own
lives and the lives of people in their community. So, students should engage in the process of purposeful design and creation. A course focused on cultivating physics agency, therefore, must support students in exploring the development of new technologies, so that youth can evaluate whether they consider the effects of these technologies on society to be valuable. With the skills to design and/or develop their own technologies, students can begin to create innovations that construct the world in ways that match their goals and beliefs. For example:

- Youth, based on an assessment of community needs, might pursue a long-term project over the course of the year that results in the design and even construction of assistive technologies for the elderly or people with disabilities. These devices could be as simple as a redesigned cane and as complex as a speech to text interpreter for the deaf.
- Youth might campaign for testing physics technology in ways that minimize harm to people and the environment, for example, safe disposal of nuclear waste, community-sensitive testing of nuclear weapons, anti-proliferation.
- Instead of simply learning about the devices that explore the structure of the universe, students should design, build and examine real detectors or simplified models. For example, students might build telescopes, small satellite dishes, and probes.
- Students might examine the structure and properties of scanning electron microscopes, particle detectors and MRI machines.
- Students might model the circuitry of their homes, build their own music players and radios, and solder the parts for circuit boards. By building simple,
everyday devices, students can take ownership of the technology in their lives— they can do more than consume technology; instead, they can understand and develop the skills to create technology.

Research Questions

In this research project, I explored how the principles of critical physics agency develop in the context of an actual 9th grade conceptual physics classroom and how students expressed these principles in their beliefs and actions. I also considered how an emphasis on critical physics agency affected whether a diversity of students developed a rigorous understanding of and a deep interest in physics. Additionally, I investigated if and how a classroom structured around the principles of critical physics agency cultivated young people’s ability to pursue directed action towards their goals.

Specifically, in my research, I asked the following questions:

1. What do five urban youth, enrolled in a 9th grade conceptual physics course, articulate as their critical goals — their goals for participation in physics, for participation in relationships, and for personal and community transformation?

2. In what ways do students work towards their goals in their physics classroom? Specifically:

   - What mechanisms do youth use to pursue their critical goals?

   - How do youth transform curriculum to shape the figured world of their classroom?
3. What are the relationships among critical goals, youth identity, utilization of resources and how youth use physics as a context and tool for agency?
Chapter 4

Methodology

Critical, Feminist, Participatory Ethnography

Seiler (2001) writes that critical feminist ethnography provides “a methodological framework to document, analyze and act on the discriminatory practices supported by schooling (particularly urban schooling)” (p.1003). I chose a critical, feminist, participatory ethnographic lens for my research for four reasons. First, this methodology supports action research -- attempts at linking research with positive social change for participants; second, this methodology, particularly the emphasis on feminism, challenges the ideas of knowledge-construction as “objective”; third, through this type of methodology, a researcher can engage in in-depth investigation into context (structure adapted from Basu and Calabrese Barton, in press, 2007). Finally, I emphasize participatory research because I feel strongly that students should not be passive objects of research studies but should express their voice in the structure and products of research.

Research for social change

I embrace the notion of action research because it reflects Freire’s and my belief that “thematic investigation is only justified to the extent that it returns to the people what
truly belongs to them” (p. 110). Research, in my opinion, must have value to those being researched, not just to the researcher. For example, as a teacher in the classroom where she was conducting research, I tried to constantly improve physics pedagogy in my classroom based on the ongoing findings of my research. In the spirit of cultivating teacher leadership at my new school, I used my experience with action research to work collaboratively with my colleagues in helping them construct similar practices in their classrooms. I aspired for a school and classroom in which students and teachers, alike, were reflective practitioners: conducting research to improve their work and communities, reflecting on the consequences of their actions and then starting the process over.

Knowledge as socially-constructed

Several researchers in science education combine a “critical lens” – a focus on critiquing power structures, in general -- with a “feminist” perspective on knowledge construction. Critical feminism challenges the notion of science as an objective discipline and, instead, suggests that it can include “multiple perspectives and understandings” (Fusco, 2001, p. 862). Critical feminism, therefore, “argues against a positivist approach in which student failure reflects an inability to grasp objective truths” (Basu & Calabrese Barton, in press, 2007). Instead, within critical feminism, “the failures of students who are female or of color [or in another minority group] can be understood as students’ struggles to understand, gain access to, and find relevance in the culture of science as framed by school” (Bouillion & Gomez, 2001, 881). This viewpoint was the motivation for my study because I was open to the idea that limited student participation and success in physics, particularly for minority, low-income youth, was perhaps a systemic failure to
provide students with entry-points into science that reflected their beliefs and values. This perspective made me design this research study to include questions about how agency, "funds of knowledge," student voice and student interest, might connect to enhanced student achievement and engagement in physics.

An in-depth, systemic perspective

The methodology for this study included a life history approach, an attempt to understand youth and their physics goals and action in the larger contexts of their lives (Muchmore, 2001). As a result, we asked youth about their families, prior experiences in school, friendships, non-physics experiences at school and out-of-school experiences and interests. We interviewed families and observed them in school and out-of-school contexts and examined student work.

Participatory research

"Just as the educator may not elaborate a program to present to the people, neither may the investigator elaborate 'itineraries' for researching the thematic universe, starting from points which he has determined" (p. 108). In contrast to an objective, essentialist view of educational research, Freire proposes that students be active participants in the shaping of research. As a result, I chose an interview structure in which youth could direct the conversation towards themes they considered important.
My Role as a Teacher-Researcher-Administrator

In the fall of 2003, after four years of teaching science and math in public and private schools in California and New York, I met the planning team leader and aspiring principal for the School for Social Change (pseudonym). A friend of mine at the Physics Department at Columbia University, where I attended a class each semester, informed me that this team leader was looking for a teacher to help design the science program at her new school. While pursuing my masters degree at Teachers College, I had been thinking about how one might start a new school – I had developed ideas for funding, organization, leadership, hiring and retaining teaching staff, cultivating a sense of mission and educational philosophy. So the fit between me and this new school seemed ideal, a small way to test out and refine my ideas.

But as the planning team met, I found myself more and more involved, by necessity and interest, in the development of the whole school. The planning team, in my opinion, was productive, dedicated and innovative. So only a few months passed before, despite the offer of a Fulbright Scholarship and an existing teaching job, I agreed to work at the school as a science teacher and an aspiring assistant principal, pursuing coursework for administrative certification.

The School for Social Change challenges me in many ways. I am learning about the complexities of running a small public school in a large, bureaucratic system, how to support and lead a team of ambitious, talented adults, how to build student voice and ownership, and how to set priorities amidst the infinite range of tasks that must be accomplished. The values of the School for Social Change match many of my beliefs –
that all students can, with support and high expectations, find and successfully pursue their passions, that teachers are intelligent, capable professionals who can negotiate the complexities of curriculum, mandates and students needs.

My original dissertation plans involved studying the transition of a physics outreach program in South Africa from international to local ownership. Given my commitment to the School for Social Change, I revised my dissertation plans to the focus of this proposal. While conducting dissertation research and working as a teacher and administrator at a new school constitute what feels like an overwhelming workload, I also experience a continual excitement about the overlap between my intellectual and professional life. I find that “teacher research structured around principles of self-reflection...[is] assist[ing] me in understanding [my] own role in the teaching/learning transaction and how to more effectively mediate curriculum to [my] students” (Kraft, 2002, 188).

I am thankful that several students at the science education department at Teachers College, Columbia University, where I am conducting my research, are teacher-researchers and that my advisor has created structures to support us in our complicated schedules. Their understanding of the challenges in being a teacher-researcher help me structure and develop my study.
Dimensions of Teacher Action Research

The Influence of Teacher-Researcher Identity on Teacher Action Research

Teacher action research provides opportunity for an “emic” perspective, an inside view to the culture and individuals one is trying to observe and understand. As a result, the identity of the action-researcher greatly influences the lens he/she brings to research (Delgado-Gaitan, 1994; Patton, 1980). I have included a short description of my personal and pedagogical background and beliefs and how they have contributed to the development, implementation and analysis of my study. I acknowledge that this research is very much based in the context of my identity and that of the case study youth I interviewed. If another researcher had taken on a similar project, on critical physics agency, even with the same students, the structure of the study, the observations emphasized and the analytic lenses might have different. My work is only one representation of the complexity of how students express critical physics agency. As a result, I do not propose that the findings of this research can be applied to other classrooms without exploration of teacher, researcher and student identity in these settings.
However, I realize that there are probably many ways in which my beliefs and background contribute to the structure of my classroom and research, which I am unable to articulate because I am not cognizant of my own biases. These biases affect the observations I have chosen to record, both consciously and unconsciously, and the details of each case study youth that I have chosen to focus in my analysis.

*My Background and Beliefs and Their Influence on Data Collection and Analysis*

My parents are immigrants to the United States from India. Though they are both Hindu, they come from different regions of India (Madras and Calcutta, specifically) and different socio-economic backgrounds and cultural traditions. My father’s father was the first open-heart surgeon in India and, once he became an established doctor, devoted close to fifty percent of his time to *pro bono* surgery. My grandmother, on this side of the family, started a job training center called the “Welfare Society for the Blind.” My father’s family, historically, has valued community service as a part of professional life, a value that I think, in part, has inspired me to work with young people but also embrace the belief that research should result in progress towards social justice.

My parents met in computer science graduate school in California, where I was born. My mother was one of the few women of her generation who received an undergraduate computer science degree in India and convinced her family to let her go abroad for graduate work. She has been a trend-setter as a woman in computer science throughout her career. The year after I was born, we moved to Boston, where I went to
my first school, a Montessori. My family and I moved to Germany when I was five, en-
route to India, where I lived from ages six to twelve. Both my parents continued to work
while we lived in India.

When we lived in the United States, my parents always emphasized the
importance of school. But it was when we moved to India that I first remember us talking
about exams and grades and aiming for the highest levels of success. My parents
articulated these values, as did my aunt, a high-school math teacher, with whom I spent a
great deal of time. I also tried to model the behavior of my cousin, who was three years
older than me and a strong student. I come from a family where academic excellence is a
depth value. This aspect of my identity, I think, drew me to Turner’s (2003) work on
critical math agency -- she emphasizes the idea of students cultivating agency in the
context of developing rigorous and complex content knowledge and skills.

I come from a family of scientists, mathematicians, and engineers. At home, we
often spend time comparing our knowledge of different obscure animals or discussing a
tricky analytic problem. My family views science and engineering as a vehicle for social
mobility and a discipline by which one can create technology and uncover knowledge
beneficial to humanity. For example, my mother believes strongly that she is providing
important new software services to consumers through her company’s product. My father
is especially proud of the ways in which he has been able to leverage communications
technology to help non-profits better-serve victims of humanitarian crises. My cousin is
an astrophysicist in part so that he can contribute to how humans understand their origins
and universe.
These beliefs about science have led me to fight for all students having access to a range of challenging science such that they can make educated choices about whether they want to use science as a vehicle for social mobility and social and intellectual change. By focusing my research on physics agency, I hope to counteract the devaluation of science in low-income, urban schools and the practice of teaching science as a static body of knowledge rather than an opportunity for exploration and personal and social empowerment.

My values and background have also created gaps in what I observe as a researcher, only some of which I am able to articulate. As a young person in school, my family and I rarely discussed how social interactions might affect my engagement and performance in school. My parents simply expected that these interactions were not to negatively influence my performance in school. As a result, I struggle to document social interactions amongst students and to understand how and why these might affect their learning, despite knowing intellectually that these types of interactions are crucial to how many students act and learn in school.

Because I was a strong, successful student throughout school, I am less interested in how students might learn a particular concept (for example changes in their conceptions of the world based on exposure to Newton’s Laws) than in their actions as democratic agents of change. Perhaps because I grasped, at least as demonstrated through assessments, many of the concepts introduced in physics courses, I am somewhat uninspired to investigate how students perceive and learn particular concepts.

Finally, perhaps because of my academic success in school and my detachment from how social pressures might affect learning, I have done a poor job of finding case
study youth who were deeply resistant to following the expectations of my classroom. For example I would very much have liked to interview a student who was failing all his classes and with whom I felt frustration because he regularly refused to practice the routines and behaviors I emphasized in class. I wanted to know whether he viewed his behavior as examples of critical agency -- tackling some injustice in the world through directed action -- and whether we might find ways in which his goals might connect to what he could imagine learning in physics. But he and I developed an increasingly antagonistic relationship over the course of the year because I did not understand how to communicate with him and motivate him. As a result, I was unable to convince him to participate in this study.

Research Setting

School Context

The classroom that my students and I shared and the interviews I conducted with them always took place in our school. As suggested in the literature review (Borko, Wolfe and Simone, 2003; Glasser, 1990), what my students and I believed and how we acted was often influenced by the larger context of our school culture. In the section below, I provide a short description of the culture and practices of the school where my action-research took place. The context of the school is crucial to understanding my relationships with the case study youth, the types of observations and data I collected.
from them and the goals with which I analyzed the data. Again, what happened in my classroom and in the school, according to my research findings cannot be expected from these settings. A key feature that influences critical physics agency is the context of the school in which the research and practice is conducted, and attempts to develop or study critical physics agency in other settings must include an exploration of and acknowledgement of this context.

School Overview

The School for Social Change is a small public school that opened in the Sunnyside Park neighborhood of New York City in September 2004. It was part of a second-wave of small new schools opened with the approval of three authorizing agencies – New Visions for Small Schools, the Gates Foundation, and the New York City Department of Education – as well as a series of other non-profits such as the Annenberg Foundation and the Open Society Organization.

The school opened with seventy-five sixth-graders and seventy-five ninth-graders; eventually, the school will have the capacity to serve 525 students, ranging from grades six to twelve. The school was housed in a campus that it shares with four other small schools; the existing large school in the building is gradually being phased out.

During the period when I conducted research, the school tried to affiliate itself with community based organizations that support youth development, student leadership and teacher professional development. However, many of these non-profits lacked the
financial and human resource capacity to provide meaningful support to the school, and, as of now, most of these partnerships are in flux.

The school received a seed grant spread over four years from the Gates Foundation to support start-up costs, but besides this, the school received regular public education funds from the federal, state and city governments. It was neither charter nor magnet and was designed to attract all ranges of neighborhood students. The school did not screen students for aptitude; ideally, teachers and administrators discussed the mission of the school with candidate youth and families, and who expressed a preference for our school, if they desired, on a ranking card provided by the New York City Department of Education. However the reality for the year during which my research was conducted was that many students were simply assigned to our school by the city, especially in the high-school.

One consequence of how students arrived at our school was that our students had a vast range of skills. While one student took the initiative to speak with me about the possibility of PSAT Test Preparation, so he could improve his admissions chances to small, liberal arts colleges, another could not read most four-letter words and could barely add, despite being a high-school freshman. Students also expressed a diverse range of behaviors and came from different educational backgrounds. Some students regularly exploded in a storm of cursing at their teacher and peers; others came to class, completed their assignments and participated in class discussions. One student came from a middle-school that offered her opportunities to learn video editing; another came from a youth incarceration facility. The diversity of students at our school resulted in critical physics agency taking different forms for different students.
The first year of our school was chaotic – my principal had never led a school before; I, as the unofficial assistant principal, had even less administrative training. We did not know how to order pencils or textbooks! Many of our high-school teachers were brand-new to teaching. Differentiation was an idea we had to introduce in professional development. Our staff, despite our ideals, struggled to meet the varied needs of students.

**Student Demographics and Neighborhood Description**

We had no choice in the location of our school; we were assigned to a campus in Sunnyside Park, which is a mixed Caribbean immigrant and orthodox Jewish neighborhood in Brooklyn, New York. No Jewish students attended our school, most went to schools organized and run by their religious community. I rarely saw students or adults from the two groups interact in the street.

When I conducted the study, most students at the School for Social Change were from the Caribbean diaspora; Trinidad and Tobago, Jamaica and St. Lucia are some are countries from which students’ families had moved to the United States. Some students had grown up their whole lives in New York, but these students were the exception to the rule; many had spent time living in the “South,” and most had moved with their parents from their home country in the past several years. 95% of our high-school students were black. Almost all spoke English as a first language, though many recently-immigrated students spoke English with a different accent and structure than their teachers and peers did in the United States. We only had one ELL student in the entire high-school. About
fifteen of our high-school students had formal IEPs, some of which were created once they started attending our school.

A race riot took place in the neighborhood the 1990s. The city reports a high incidence of HIV for the neighborhood. Several parents who attended the original school in the building where the school was housed stated that for over twenty years the neighborhood and school had been associated with high drop-out, low college acceptance rates and gang-related conflicts. Families reported that they were nervous about having their children attend our school because of the reputation of the large school we were replacing. One parent, a local judge removed her 6th grade child from our school the first day it opened because older students cursed at her and her child in the metal detector line through which each student passed to enter the school building.

School Mission

In the fall of 2003, I joined the planning team for the School for Social Change because I believed I could, in the right circumstances, contribute to school reform low-income, urban neighborhoods. I had taught in several settings by then, ranging from an all-girls’ private school in California to a charter school in Queens with a large population of first-generation immigrant population. I was certified in teaching high-school physics, biology and chemistry and had taught physics, biology, earth science, physical science, calculus, the New York State Math A curriculum, a research science advanced seminar for seniors, and programs in science to third- and fourth-graders.
When I met the aspiring principal of the School for Social Change, I was drawn to her and to the school because of the how she articulated the school mission, which reflected ideas with which I was struggling but to which I was also committed.

The following is extracted from the school’s proposal as illustrative of the ideas that convinced me to work at the school:

The School for Social Change is rooted in an understanding of the parallels and the connections between democracy and education. We believe that when every student is engaged in a rigorous educational experience, expected to succeed, and trusted to make real decisions, they acquire the skills and self-assurance to participate as engaged citizens in a democratic society. We believe that when a learning environment is built upon what Paulo Freire referred to as a “pedagogy of hope,” students begin to have faith in their own ability to transform the world around them. We hold a passionate belief that places like the School for Social Change must exist to provide youth with the tools and experience to become leaders who can make a difference in their own lives and in their communities.

The proposal suggested that the school would be structured around three core principles – Relationships, Engagement and Empowerment. As is evidenced by my research focus, I was particularly interested in pedagogy related to the last of these principles, empowerment, especially as it was articulated by the school mission: “Empowerment: Learning works best when it is accompanied by high expectations, when it is student-led, and when it is intelligently applied to create concrete improvements in peoples’ lives.”

I aspired for my classroom and my school to be places where education was student-led and resulted in personal and social change.

Freire’s work is one foundation of the school’s philosophy. His ideas are most concretely manifest in the school’s expectation that each student each year will complete what we describe as a “Change Project.” From the mission: “Through the completion of this project, students will identify, analyze and address an issue that affects their lives. …The Change Projects will be the cornerstone of School for Social Change. They will
be an opportunity at various stages during a student’s seven years with School for Social Change to examine themselves and their communities and then to utilize these observations in the world around them. The Change Project is based on the central philosophy of School for Social Change that young people can be effective catalysts for change in their communities and that their development as leaders necessitates opportunities to affect change.” The Change Project is, in my opinion, the most concrete manifestation of the school’s commitment to what I term critical agency – learning and actions directed towards personal and social transformation, to counteract social injustice. For several teachers, this commitment to critical agency was an ideal for what practice in school classrooms and hallways might look like each day.

**Teacher Commitment to School Mission**

Many of the teachers who joined the school in its first year shared a deep commitment to the mission of the school. In one professional development, each founding staff member independently described what appealed to him/her about the mission of the school and how an initial conversation with the principal had inspired him/her to apply for a teaching position. As a result, at least in the school’s first year, founding teachers shared some common beliefs about teaching, which, I think, were deeply influential to the culture of the school, and, therefore, my physics classroom, and eventually to the findings of my study.
In my interview protocol, I asked students to discuss how they might envision a lesson for physics class that reflected what topics in physics they were most interested in exploring. This question was driven by my fundamental belief, shared by several teachers at the school and expressed in the school mission, that youth should be co-constructors of curriculum and school structure. As a cadre of teachers, we shared a commitment to exploring pedagogy in which students had choice, could engage in inquiry-based learning grounded in their own questions, and could eventually take on the challenge of planning and enacting entire lessons. The focus of professional development sessions, which was designed with input from teachers, reflects this commitment to cultivating student voice in classrooms. For example, in the fall of 2005, the founding staff and some second-year teachers chose to spend the entire morning discussing how the school had and could better meet its ideals of democratic practice and student voice.

Events at the school reflected this commitment to student voice. For example, in advisory, ninth-graders were allowed to collectively choose their Change Project, based on their interests and beliefs about what to change within the school. One group chose to create a basketball tournament because the youth in this group felt that the school offered too few athletic opportunities. Another group created a spirit week and yearbook, in response to what they felt was a need at the school. The process of choosing a student government required each student in the high-school to identity and articulate the important issues he/she felt that a student government representative might take on. In Albany, students from the educational activism club demonstrated about inequities in New York City school funding. They also discussed these educational inequities with
professors at the Harvard School of Education. Before the presidential election, middle-
and high-school youth from our school registered people in their neighborhood to vote.

As a cadre of teachers, we saw different entry points to student voice in
classrooms. Students led warm-ups in physics class because I felt that this helped youth
take on the role of being experts, rather than the teacher always being the one to present
information. Students chose their own questions as part of an inquiry-based curriculum,
towards the end of the year in social studies. For example, Darlene investigated, through
research and interviews, whether capitalism or socialism was a better system of
government. The 9th grade English teacher, in response to the structured choices that
students were experiencing in physics and social studies, towards the end of her 9th grade
course, developed independent reading groups, in which a group of students chose a book
to read and analyze together. From small entry points into student voice and decision-
making, some teachers were ready to have youth take on the challenge of planning and
entire class period. The 6th grade social studies teacher, like me, wanted to have students
run the last few weeks of her course.

The group of teachers interested in student voice and pedagogy also conducted
discussions and inter-visitations to improve their practice in these areas. For example, the
6th grade social studies teacher, gave me feedback on how I might teach group work skills
that encouraged higher-quality collaboration amongst students. We both agreed that
group work, when enacted successfully, was a way to provide students with the ability to
make decisions amongst themselves rather than having all decisions be made by the
teacher. The 9th grade social studies teacher whom I interviewed, modeled his end-of-unit
project on his observations of how my students tackled the science fair.
Finally, our professional development consultant, who came to school once a week, primarily to work with new teachers but also observed my class and helped me develop lesson plans felt strongly about democratic practice and the inclusion of student voice in the culture of a classroom. For example, in one interview, she said:

Democratic practice has different components. Relationship and respect underlie it. It is about giving people voice...It’s also about really giving students space and telling them, developing their own opinions and helping them do that, back them up. You send students the message – your opinion matters, I’m going to help you to support it, what you say matters. I think rigor is a really important part of democratic classroom. If you are not focusing on the kind of skills that students need when they move beyond that classroom, you haven’t fulfilled a democratic classroom because you haven’t given what they need to go off and do that on their own, for themselves. So I think democratic practice is about giving them voice, giving them the ability to explore what they believe, giving them the ability to be agents of change for themselves and their communities. To do what you need to do, you need to be given the skills and knowledge to do that.

I describe the emphasis on student voice, inquiry-based learning and democratic practice at my school because I feel that the school setting encouraged teachers to pursue these ideas. If I had conducted my study at a different school, youth may have been more tentative and less specific in describing how they could use physics to pursue their personal and community goals. But at our school, the educational culture encouraged students to take charge of their own learning and take initiative to bring about the kinds of change they desired.
Curricula and School Practices that Arise in the Study

In the study, several practices and curricula arise during student interviews. I have described some of these below, as a guide for the reader.

From its inception, teachers at the School for Social Change chose to write narrative report cards for students. Instead of just assigning a grade (or a bubbled-in predetermined comments, as is the practice in New York City schools), each teacher wrote a paragraph about the academic performance and behavior of each student in his/her class. I provide the text of these narratives as evidence for supporting some of the points I have made about students.

In each grade, at the end of each semester, every student was required to prepare and defend a portfolio. Though the portfolio took on different forms in different grades, the general expectation for this portfolio was that students reflect on their work from their classes, summarize key content and skills they had learned, and evaluate their strengths and weaknesses as students. Youth had to present their work to two to four peers, one or two teachers and sometimes outside visitors.

Advisory was a class that met three to five times a week for ninth-graders. I taught one section of ninth-grade advisory. The focus of advisory, which was graded, included cultivation of strong work habits, opportunities to build relationships with a teacher-advocate and a small group of students, the cultivation of a strong connection between a student’s family and one adult at the school, college exploration, and the Change Project. As part of advisory in the spring, ninth-graders chose to visit colleges and universities in
the New York area. They made their choices by matching what they had identified as important in a college (which they explored during the college advisory unit) with the options available to them for a field trip. Student discussions in the data of Eugene Lang College and Polytechnic University stem from this experience.

The Brown-Bag Lunch was a time in which speakers from outside the school spoke to students who chose to attend about careers, higher education, internships and social and political issues. Teachers and administrators invited speakers for these talks, based on their own beliefs and, sometimes, in response to student interest.

The Context of My Physics Classroom

At the time of the research study, in addition to functioning as the unofficial assistant principal at the school, I taught one section of ninth grade conceptual physics. Another teacher, with whom I co-planned, taught the other two sections.

A key point to emphasize is that this type of 9th grade conceptual physics course is highly-unusual and innovative for both New York City (Kelly, 2004) and the country at large (US Department of Education, National Center for Educational Statistics16). The vast majority of physics in the United States is offered to elite juniors and seniors with a focus on computation and problem-solving. In New York City, most students do not have the opportunity to enroll in physics (Kelly, 2004). In New York State, an introductory physics course tends to prepare small groups of advanced, older students for a mathematically-focused standardized test. In contrast, the physics course in this study emphasized conceptual understanding and was open to all ninth-grade students. The
school planned to offer advanced, mathematically-focused courses to juniors and seniors, once all students had exposure to and opportunity in physics.

My co-planning teacher and I designed the conceptual course to introduce students to what physicists study and do and to the concepts of measurement, motion, energy, electricity and current topics in physics. We wanted every student at the school to develop content and skills in physics because we considered physics to be one part of a comprehensive high-school science education. As described in the literature review, our ambition sharply contrasted practices and trends in urban environments, particularly in the small-school movement in New York City. We also hoped to contribute to our school goals for ninth-graders, a year that we believed was pivotal for high-school students. Particularly, we built our curriculum to try and support youth in building literacy and analytic skills, feeling an engagement with school as a challenging yet supportive environment. Finally, we wanted to help youth expand their abilities to process instructions, study, take initiative, challenge themselves and be independent with their own education, and thoughtfully question practices that felt unclear or unjust in their school and the larger world.

Our curriculum was grounded in the following standards and existing curricula: Project 2061, NSES, AAAS, the NY State Physics standards and authors such as Hewitt, Giancoli, Arons and Eisencraft. We also wanted to help our students develop their skills in practicing in science and tried to support students in building the math skills required by New York State for the Math A exam. To evaluate conceptual understanding through assessments, we pushed students to explain their reasoning (Gollub and Spital, 2002), create detailed conceptual maps (Liu, 2004), and vary the contexts in which they applied
the knowledge they had learned (Marin, Gomez & Benarroch, 2004). We drew upon rubrics to evaluate students’ comprehension of the nature of science (Sandoval and Reiser, 2004; Licata 1999; Oulton, Dillon & Grace, 2004).

Finally, I was very much interested in cultivating classroom practices of project-based learning, inquiry, self-reflection and student creativity and initiative. I felt that the last two were often absent from science classes, and I wanted students to feel that these were in fact integral to a career in science.

I have already discussed my philosophies for my physics course. For daily lessons, in addition to structuring most classes around the workshop model (Warm-Up, Mini-Lesson, Activity/Project Time, Reflection), I used the following checklist, as often as possible to plan my lessons.

- Students help plan or enact lessons.
- Youth have a choice of topics, project and/or presentation form
- The lesson emphasizes rigor (including depth of knowledge and skill)
- Youth learn something new from the mini-lesson each day
- The lesson involves development or reinforcement of some math skill
- The lesson provides opportunity for creativity, activism and opportunities to be a scientist
- Students regularly evaluate class
- The lesson includes open-ended questions/projects/debates
- The lesson incorporates student interests.
- The lesson invests responsibility in students

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A final element of pedagogy that I valued in my classroom was the idea of authentic assessment. As a result, almost each project, during the year, included this practice. For example, when students described technologies they wanted to invent using their knowledge of physics, I mailed these to a competition with a related essay topic, from which student could win a home computer. When students studied Mars, as part of their measurement unit, I mailed their opinion letters on the exploration of Mars to NASA. They received a formal response from the agency. For the science symposium, students had to present their research to teachers and students across the school. For the science fair, they had to defend their experiments to practicing scientists who acted as judges.

Key Events During the Physics Course to Which Case Study Youth Referred

During the interviews for this study, students referred to several key events that took place during physics class. As a guide to the reader, I have introduced these key events below: the “If I Were a Physicist” project, the Gummy Bear experiments, demonstrations on electricity, the debates on Einstein and dark matter/dark energy, the science symposium and the science fair

The “If I Were a Physicist Project.” The physics course began with a project in which students explored what people with careers involving the physical sciences study and do. Students were to find pictures and sections in the text as well as lab supplies in
the classroom that caught their interest. From these, they were to hypothesize about what they thought physicists might study and do. In addition, they were expected to envision themselves in the role of a physicist and identify what types of questions and activities they would pursue in this role. A second portion of this unit involved students analyzing graphs about trends in physics. These graphs reported on the racial and gender breakdown and national origin of people who pursued careers in physics and the income levels associated with physics-related jobs. This graph interpretation activity was a foundation for a discussion about barriers to a career in physics and how students might circumvent these. For example, the focus group discussion about whether Einstein could be black was, in part, generated from this unit. Through the unit, I also tried to set a precedent for inquiry-based learning and students envisioning themselves as scientists.

Gummy Bear. Two experiments with Gummy Bears seemed to have captivated the minds of several case study youth because they had not anticipated investigating such a familiar object. The first experiment was part of the measurement unit and involved students taking home a gummy bear, placing it overnight in water and measuring changes to the size of the Gummy Bear in the morning. Many students predicted that the Gummy Bear would dissolve, but, in fact most found that the Gummy Bear inflated and lost some its bright color, because it absorbed water.

I conducted the second Gummy Bear experiment in the context of the unit on energy – my specific goal, through this experiment, was to have students identify differences between how matter and energy behaved. I placed a small amount of potassium chlorate in a test tube, heated the test tube with a blow torch till the potassium chlorate turned into a clear liquid of potassium chloride (oxygen gas was also released). I
then dropped a sliver of the ear of a Gummy Bear into the test tube. It combusted, shooting out yellow and purple flame and turning the sides of the test tube black with soot. A smell of burnt sugar permeated the air.

*Electricity Demonstrations and Unit Project.* Students began the unit on electricity with explorations of static charge. The moved between stations, working with scotch tape, styrofoam, aluminum cans and aluminum foil, balloons and paper to study how objects acquired charge and interacted when they were charged. Students seemed engaged with the hands-on nature of these experiments and the use of everyday materials. Almost every student completed the activities at each of the stations. Though students were moving around the room, there were no verbal or physical conflicts between students that day, and my principal, in observing the classroom, said that she felt almost all students were focused on answering the questions posed at each station.

To demonstrate the idea that energy can be converted to different forms, I plugged the speaker of a radio with a plug connected to an LED. In close proximity to the LED, I placed a solar panel, which was in turn connected to a speaker. The students saw the LED flicker as a result of the electrical signals entering it through the radio and listened to the radio station play out of the speaker connected to the solar panel. We discussed how electromagnetic radio waves were being converted to electrical energy in the radio, light energy transmitted by the LED and received by the solar panel, electrical energy in the speaker, and sound energy in the air.

For the final project for the electricity unit, students were to decide how they would configure circuits such that they would model a porch light and doorbell turning on simultaneously and three lights in adjacent rooms turning on separately. They also had
to explain why an LED worked better in the porch light circuit than the small white light bulbs with which they had been working. The project required that students show an understanding of series and parallel circuits, voltage and current in these circuits, graphing and problem-solving with Ohm’s Law, and the workings of LEDs.

Debates on Einstein and Dark Matter/Energy. For the unit on nuclear energy, students were expected to prepare for and participate in a debate on whether Einstein’s research on energy had positive or negative consequences for the world. To determine and defend their position, they were to use their: 1) understanding of nuclear fission and fusion, 2) the problems they had solved on Einstein’s famous equation relating mass and energy, 3) research on nuclear power plants, and 4) reading about the destruction caused by the atomic bombs in Hiroshima and Nagasaki. Students worked in groups to pursue this project. In theory, every student was supposed to speak during this debate but many did not, despite having completed several of the preparatory assignments in class. One of the case study youth relied on this debate as a model for her lesson because it suggested to her that science could involve the exercise of opinion even on topics studied by experts such as Einstein.

Science Symposium. The science symposium was the culmination of the motion unit that we covered in the fall. For the symposium, students were to apply what they had learned about motion to a choice of three projects: 1) how to design a parachute such that it could land a satellite created to explore Jupiter’s moon Europa for signs of life, 2) how to build “safe and fun rollercoaster,” and 3) how to escape the gravitational pull of a black hole. Students worked in pairs or alone, according to their choice, and I expected each group or individual to present his/her work to student and teacher evaluators from...
across the school. Some students were able to connect the lessons on motion to their projects; many ended up relying on research from the internet. My co-teacher and I substantially revised the scaffolding for the symposium in our second year teaching conceptual physics at the school – we made sure that students worked on their projects daily, so it was easier for them to see the connections between everyday lessons and the symposium.

*Science Fair.* A key event during conceptual physics was the science fair. The emphasis of the science fair, in the ninth grade, was for students to explore questions to which they did not know the outcome and for which they were able to collect data. My co-teacher and I proposed some topics to students; many decided to choose their own questions. Their topics had to fulfill three requirements – 1) the project had to focus on a question to which the student did not know the answer; 2) the student had to be able to collect specific data on the question; 3) the project had to be relate to a topic in physics we had covered in class or was addressed in the students’ textbook.

For the project students had to identify a question that could be divided into multiple parts. For example, a group that asked: “What makes object float?” divided their questions into the following: “Do objects float better in hot or cold water?” and “Does the mass of an object affect whether it floats?” Student then had to generate hypotheses about these sub-questions, design an experiment to answer the questions, collect data, which they organized in tables and presented in graphs, and analyze the data such that they could compare it with their hypothesis. The bulk of this work was done during classroom time. We conducted lessons on each step of the scientific process that we expected from students and tried to approve their progress on each step. Students had to present their
work at the spring science fair and were evaluated by practicing scientists from the community.

Data Collection

Data for this study included case studies, family interviews of case study youth, and collection of student work, participant observations, field notes and teacher interviews as well as self-reflection on my part as the researcher. I collected data in the spring of 2005, relied on some archival material from fall 2004, and returned to case study youth with a few follow-up questions and observations in the fall of 2005 and spring of 2006.

Archival material: I used archival material to document students' expressions of critical physics agency and the connection between these expressions and student understanding, engagement, and goal-directed action. Archival materials included written records of conversations with individual and groups of students, observations of students, and student journals, class work, homework, projects and assessments. I also relied upon my and other teachers' records and planning notes about community practices such as advisory, town halls and 9th grade team planning.

Case Studies: Through case studies of five students, I collected in-depth, rich, contextual data that is both ethnographic and phenomenological in nature. The five in-depth interviews that, in part make up the case studies, focused on how students express critical physics agency and how this idea connected to student understanding, engagement and goal-directed action. For each case study student, I also conducted one
interview, which focused on how advisory and other school-based systems influenced the development of a student’s critical physics agency.

Case studies were based on pre-set questions but also permitted the conversation to move in directions that made sense to the researcher and participant, given the theme of the interview. During interviews, students engaged in “think-alouds” in which they envisioned original experiments and lesson plans connected to the unit they were studying.

I developed especially close working relationships with my case study students. For example, these students helped design curriculum for one or more of the units during which I collected data. I was especially interested in how this experience contributes to their sense of agency in my classroom.

Family Interviews of Case Study Students: In an attempt to understand students’ backgrounds, beliefs and life experiences, I conducted family interviews, over the course of the study. Knight, Norton, Bentley & Dixon (2004) emphasize the importance of recognizing the diversity of adults who influence the decisions of minority, low-income youth: “Ninth graders in this study named the stories of family members- aunts, sisters, parents, and cousins-as entry points that influenced students’ college-going decisions. A reconceptualization of family versus parent involvement can be implemented in family-school partnerships that respect, understand, and utilize the multiple interpersonal relationships through which students find support” (p. 116). I chose to conduct family interviews in light of the importance of family in students’ decision-making.

Themes of the family interviews were as follows:

• how families felt and thought about science,
• the importance families placed on youth becoming scientifically-informed citizens and pursuing a physics-related career
• how students discussed their physics education at home
• how physics connected with students’ everyday lives
• whether and how families noticed growth in their child’s understanding, skills, engagement and agency, while they were enrolled in physics.

Student Work: Over the course of the two units, which were the focus of my study, I collected assorted student work from case study participants. This work included their projects, class work, homework, journals, warm-up, labs and assessment in the year-round binders that I required each student to keep, as well as materials that students chose for their inter-disciplinary end-of-year portfolios. Project topics included student inventions and their ideas about how they would change the world, as physicists. Journal entries included writing about personal goal-setting in physics and student beliefs about the origins of the universe. When I analyzed this material, I looked for ways in which students expressed critical physics agency and evidence of how their expression connected to their understanding, agency and goal-directed action. For each student in my study, I requested access to grades, attendance and lateness records.

Participant Observation: I relied upon participant observations as another source of data for documenting how students expressed critical physics agency and how this idea influenced their connection with and success in physics. As part of participant observation, I documented instances:

• when students raised issues and questions that contradicted the teacher and curriculum and asked students about their motivations for these actions
• when students asked questions and made comments reflecting their engagement in a physics topic.
• when students interacted with each other and with their teacher
• when students directed decision-making in the classroom

Field Notes: The purpose of gathering field notes was to collect data on the culture and practices of the school. In particular, I explored how youth develop agency in their non-physics experiences at the school. For example, did participation in an after-school leadership program affect whether students develop strategies in agency? How did students negotiate challenges in the cafeteria and lunchroom, and how did the decisions made by the school about structuring this experience affect how students developed agency? My field notes helped me build a context for student learning that extended beyond my observations of my classroom and particular students. I documented rituals at the school such as town hall meetings, after-school activities and advisory but also special events such as student reaction to brown bag lunches with outside speakers. Finally, I looked into the development of student agency in classrooms besides my own, in non-academic formal settings, such as advisory, and the school, informally and at-large.

Teacher Interviews: Several teachers participated in my research study. To develop a culture of best practices, based on the experience and expertise of educators at the school, teachers and the principal regularly visited classrooms at my school across grade- and subject-level boundaries. We termed this process “inter-visitation.” Generally, the teacher being observed asked the visiting staff member to focus on one pedagogical area. In my case, as part of my research, I asked my observer to focus on some aspect of
critical physics agency. I conducted teacher interviews, based these inter-visitations, in which staff described their observations of how students were engaging in and expressing critical physics agency.

Self-Reflection: Knowing that a researcher brings assumptions and a particular world-view to any context she studies (Delgado-Gaitan, 1994), alongside my documentation of the school and students, I engaged in heuristic inquiry during this research project. I used a regular journal to record and reflect on my own experiences as teacher-researcher, developing and enacting original curriculum at a new school. In particular, I recorded my developing goals and beliefs in creating and implementing curriculum for my class, so I could track how these opinions changed, in the context of student skills and interests.

**Participant Selection**

I offered the option for participating in the study to all ninth-grade students at my school, regardless of whether they were in my section or that of my co-planning teacher. Only a handful of students ended up turning in consent forms. My sample ended up representing both male and female students, students who identified themselves within different ethnicities, and youth who achieved a range of grades in my physics course. Three of the case study youth whom I ended up interviewing were enrolled in my physics section; one was enrolled in the section of my co-planner but was in my advisory. The fifth was originally in my co-planning teacher’s section and transferred to mine mid-year.
In his sophomore year, given our positive relationship, this student also ended up in my advisory. In short, despite having opened the study to all students, the youth who participated ended up having some personal connection to me through physics class or advisory. I did not succeed in drawing students to the study who engaged in acts of resistance (Abowitz, 2000). I also ended up having high-performing girls in the study and academically-challenged boys, which is reflective of general but not absolute trends in the school population.

**Trustworthiness of Data**

To improve the likelihood that my data were reliable – that they reflected a range of opinions rather than a particular skewed perspective or methodology -- I relied upon triangulation of theory, methodology, data and analysis. For example, I used various researchers’ definitions of agency to create a broad umbrella under which I documented instances of agency in my study population. My data relied upon a diversity of sources, from which I was able to develop a rich, complex picture of what constitutes critical physics agency. For example, I asked other teachers at my school to observe a physics classroom, with the goal of observing instances of critical physics agency. These observations served as a check for the objectivity of the data I collected. Through my surveys and interviews, I asked subjects to link their general opinions and ideas to
concrete events and examples, hopefully, increasing the accuracy of the data collected in
my study.

To what degree were my data generalizable? In other words, can the conclusions
from my study be applied to similar populations in similar contexts? Because the
composition of human populations and their environments cannot be perfectly
“controlled” and because my data was primarily qualitative, I do not propose that the
conclusions I made from this dissertation are easily transferable. For example, one cannot
assume that critical physics agency would take exactly the same form in another low-
income, immigrant physics classroom as it did in my study.

Analysis

Grounded Theory

All qualitative data were transcribed and coded to explore connections between
classroom practices, school organization and students’ developing critical physical
agency. To analyze data, I relied upon a modified version of grounded theory (Strauss
and Corbin, 1990). According to Brown, et. al., (2001), grounded theory is based on the
ideas that theories are to be built rather than tested. I consider my analysis technique to be
a “modified” version of grounded theory because I created initial codes based on my
conceptual framework, with a specific eye to funds of knowledge and critical agency.
Within these major codes, I developed sub-categories, during a process of open coding.

In the axial stage of coding, I identified themes that I wanted to pursue in my analysis, for example, students’ critical goals, the mechanisms they used to pursue their critical goals and transformation of curriculum. By completing these stages, I was able to label and categorize data, link ideas, and develop a theory that encompasses what I considered to be main categories, ideas and connections in the data. In the initial coding of my data, I used the characteristics below to identify, from my observations, situations in which students expressed elements of critical physics agency.

Table 1: Elements of Critical Physics Agency

<table>
<thead>
<tr>
<th>Elements of Critical Physics Agency</th>
<th>Evidence that Students Expressed a Particular Element of Critical Physics Agency</th>
</tr>
</thead>
</table>
| Student demonstrated rigorous understanding | • Student received high grades in conceptual physics topics that were related to a standards-based curriculum  
• Students cultivated expertise in a particular area of physics  
• Students explored a physics topics, beyond class expectations and/or class time allocated to this assignment  
• Students taught each other concepts and relied upon each other’s knowledge and skills for being successful on physics assignments. |
| Student was actively engaged | • Student answered and asked topical questions in class  
• Student wrote thoughtful responses to class and homework assignments.  
• Student, through body language and interview responses, conveyed that she was awake, alert, and actively participating in tasks at hand such as labs, projects and discussion  
• Student designed and implemented complex experiments and challenging projects  
• Students expressed a positive interest in attending physics class and in pursuing further education and career in physics  
• Student articulated an interest in a physics career  
• Student came to teachers for help, questions and additional work, outside of normal classroom hours. |
<table>
<thead>
<tr>
<th>Students drew on “funds of knowledge” to understand and apply what he/she was learning</th>
<th>Student arrived in class on time and stayed involved until the period was over</th>
</tr>
</thead>
</table>
| • Student expressed and evaluated his/her prior conceptions about how the universe operates.  
• Student chose how to study a particular subject, in the context of what was relevant, useful and engaging to him.  
• Student used family knowledge and skills in learning physics.  
• Student brought artifacts and documentation of her experiences outside school to physics.  
• Students drew upon out-of-class experiences shared with his peers, while participating in classroom physics activities.  
• Student’s social affiliations influenced with whom and how work in physics class is conducted. |
| Student participated in Freirian process of critical reflection and transformation | Student recognized and reflected on the political, social and economic forces that shape his life.  
• Student saw the possibility of transformation in situations that might have previously seemed unchangeable.  
• Student and teacher evaluated data to arrive at joint conclusions, instead of teachers informing students of conclusions they should accept. In this paradigm, students and teachers were “co-discoverers.”  
• Student viewed her classroom as an environment in which problems were posed and solved through data collection, analysis and invention.  
• Student was engaged in inter-disciplinary, complex problems and real-world challenges. |
| Student engaged in processes related to directing actions towards his/her personal and/or community goals | Student engaged in processes of agency – identity exploration, goal-setting, enhancing relevant knowledge and skills, and ongoing reflection -- in the context of his/her physics classroom environment  
• Student pursued, based on his/her beliefs, small-scale change of personal value and/or large scale social change, in the context of the physics he/she as learning  
• Student exerted choice in the projects she pursued, the questions she asked, the direction of classroom discussion, and the means by which she collected and analyzed data, and solved problems. |

The findings chapters emerged from the coding I used to analyze data, which, in turn was drawn from the discussion of agency in the conceptual framework portion of
this paper. The coding that helped generate the chapter on critical goals was: “Description of Types of Goals that Youth Have,” which was further broken down into 1) Critical Reflections and Beliefs, 2) Academic and Intellectual Goals, 3) Social Goals, 4) Personal Goals and What Youth Envision for the Future. From coding on “Instances of Critical Physics Agency,” I developed the findings chapters on mechanisms for pursuing critical goals and transformation of physics curriculum. I was able to discuss the effect of physics classroom resources and school context resources on how case study youth developed physics agency because of coding in both of these categories. For a complete coding tree, please refer to Appendix B.

Introduction to Findings Chapters

In the findings chapters, I first discuss the critical goals of the case study youth I interviewed. In the next chapter, I explore the different mechanisms and resources that youth use in and from physics to move towards their critical goals. In the chapter titled “Critical Physics Agency Expressed through Youth Transformation of Physics Curriculum,” I examine how youth express agency with respect to changing the figured world (Holland, 1998) of their physics classroom. I also discuss how this agency results in the enhancement of two new ideas, their epistemic authority -- a student’s expertise and knowledge -- and positional authority -- a student’s social standing with respect to the classroom community (Holland, 1998).
Chapter 5

Critical Goals of Case Study Youth

Schools and society often describe low-income minority youth as lacking the motivation to direct for their own success and to bring about positive change in the larger world (Sanchez, 2005; Merry, 2005). These youth have limited access, in comparison with their more privileged peers, to engaging, creative opportunities in schools and contexts in which they would express their voice and shape their relationships. Even within this study, youth were quick to describe how black youth from their neighborhoods were more likely to be targeted by police, be incarcerated and receive reduced levels of funding for their schools as compared with schools in the “white suburbs.”

Several authors suggest that a key feature of agency is goal-setting, particularly when these goals result in awareness of and action against power structures of the kinds above that constrain youth because of their race and income (Blackburn, 2004; Dans, 2002; Holland, 1998). In this study, youth articulated four “critical goals” encompassing their lives as young people both in and out of school and, specifically, for their participation in physics: 1) Learning Goals, 2) Finding Opportunities to Express Voice, 3) Participation in Relationships, and 4) Participation in the World as Activists.
I have chosen the term “goals” because the four categories of ambitions above reflect directions in which students hoped to direct their lives and their physics experience. I have described the goals as “critical” because the nature of these goals permitted youth, through personal agency, to consciously and unconsciously combat the stereotypes and limitations imposed on them as urban, low-income minority youth. The data on goals expressed by youth in this study paint a picture of students as critical agents of change -- budding intellectuals with scientific mindsets who could articulate and act on their ideas for transforming their own lives, their community and the larger world. (I specifically discuss why each of the four learning goals is “critical” in the sections below.)

In this chapter, first, I provide a brief overview of each case study youth to introduce the students to the reader. In the subsequent sections of the chapter, I include a short description of each “critical goal” in question and then discuss how data on particular case study youth draw out the subtleties of how these critical goals were expressed. I have chosen to create sub-headings for each student within each critical goal rather than analyzing themes across youth because consideration of each youth as a whole being is essential for understanding the critical goals. The key findings for each “critical goal” are summarized in Table 2. I conclude the chapter with a discussion across case study youth of how critical goals were shaped by the figured worlds (Holland, 1998) in which kids move and how critical goals supported and challenged students in building a science presence.
An Introduction to the Case Study Youth

Darlene: Darlene was an engaging, motivated 15 year old girl who was born and raised on a farm in Jamaica and then moved to the United States. Darlene and her mother had been separated for several years, so, she had moved between relatives, which cultivated in her a self-acknowledged spirit of independence in her. She felt that what was unique about her was her “kindness.” Echoing her description of herself, Darlene’s teachers said that she often helped them and other students and was both “sweet” and “responsible.” Darlene had two close friends at school with whom she enjoyed spending time in places of interest across the city such as museums and the waterfront.

Darlene was a strong student who was on honor roll at our school for the duration of the year. In physics and in other classes, she tended to complete all her assigned work and sought out additional challenge by choosing the most difficult projects available to her. At school, she participated in many different extra-curricular activities – she spoke in most detail about track and field and GlobalKids, an after-school activity that helped students be informed about and be activists in the larger world. As an adult, Darlene said that she hoped to become a lawyer, though she was also interested in finding out more about careers in science. By helping people around the world, Darlene wanted to model the behavior of her aunt who was a pastor.

Grant: Grant was an outspoken, emotional 15 year old boy who grew up in Trinidad and Tobago and had lived in the Sunnyside Park neighborhood of Brooklyn for ten years with his father, step-mother, two sisters and uncle. He had a strong relationship
with his family, particularly with his father, who was frequently available to discuss Grant’s academic progress and behavior.

Grant had been incarcerated for armed robbery, and several students reported to the school principal that he participated in a gang. As a result of his incarceration, he joined our school mid-year, with no high-school credits for the first semester of his freshman year. Grant’s experience with incarceration encouraged him to reflect on what motivated his peers to engage in what he considered to be negative or damaging behaviors. His world-view included the belief that young black men were more likely than other groups to experience trouble with the police. Still, what he articulated as the solution to this problem of discrimination was the decision to carefully regulate his own behavior; he did not engage in a discussion of how society might change to be less discriminatory against young black men.

Grant wanted to grow up to become a mechanical engineer. He was particularly interested in designing buildings that efficiently provided services to people and creating technologies that reduced world-wide pollution. In physics, he wanted to pursue hands-on projects related to these topics. He also wanted to establish himself as a leader and role model at our school, in contrast to his reputation as a mediocre and sometimes failing student who was often in trouble with his teachers and the school.

Grant had ambitious goals for his academic work, leadership capacity in school and professional life but struggled to align his daily actions with his aspirations. He struggled with his school work throughout the year, across disciplines. He often felt frustration with his teachers, sometimes walked out of class in anger, and engaged in fights with other students. His emotions could change quickly from being playful and
cheerful to being upset. Grant was frequently absent (35 days) and late (38 days), which contributed to his poor performance in his classes, because he rarely made-up the work he missed.

*Linda:* Linda was an articulate, sociable, diligent 14-year-old who was close to her family. She had lived in the United States her whole life and was one of the few students at our school who was a Spanish speaker — her father was from Puerto Rico. Linda began the year with an unusually high rate of absence, but, over the course of the year, became increasingly confident, punctual and present. She was a strong reader. She had high grades in physics and in other subjects and completed assignments with attention to subtle concepts that other students missed. She had several friends in school with whom she entered the school building, worked in class and spent time at lunch and in the hallways.

Linda wanted to grow up to be a doctor, so she could help people who had limited access to health care. She also felt that this type of career would make her family proud. Linda did not express any career interests specifically related to physics, but she did view learning physics as an opportunity to better “understand how the world works.” Linda liked to share her opinion in class and present what she had learned to other students.

*Kanisha:* Kanisha was a 14-year-old girl from who lived in Brooklyn with her mother, sister and father. Several of her family members had attended college. Kanisha felt a great deal of pressure from her family to do well in school; in turn, she wanted to succeed academically and professionally, through high grades and a career in journalism, architecture or fashion, so she could impress her family. Kanisha aimed for and achieved scores in the 80s and 90s in her academic classes. In physics, when Kanisha received a
progress report with any zeroes on it or did not receive the help she wanted in class, she could quickly get angry. At these times, she sometimes made derisive comments to students who were less socially-confident than she was.

Kanisha described herself as “smart, outgoing and pretty.” Her mother said that Kanisha had always been a strong, engaged reader. Similar to her good friend Linda, Kanisha was able to grasp, more quickly than other students, what was expected of her from assignments. In school, Kanisha interacted with a group of five or six female friends at school – they worked together in groups, often sat at the front of class and participated in class. Kanisha, in particular, could make cutting, hurtful remarks to students who were less popular than she was.

Kanisha held what I consider to be a “populist” view of science – she felt that everyone had the potential to be a scientist, that people such as electricians, who might not consider themselves to be, were actually scientists, and that science could be done with everyday materials.

Nicholas: Nicholas was a 14-year-old boy who moved from St. Lucia to Brooklyn just before the start of the 2004-05 school year. He lived with his father and his stepmother in an apartment where he found it difficult to concentrate or find privacy because of the confined space he shared with his family. Nicholas expressed feeling unloved because his mother had left him and he felt distant from his father, despite how actively Nicholas’ father was involved in his son’s life. At school, Nicholas struggled to cultivate positive relationships with his peers and teachers. He and other students often called each other names and got into arguments; his teachers felt he could be loud, rude and unproductive. In the first semester of his ninth grade year, Nicholas struggled in all his
classes, but by the end of the year, he passed all his subjects and achieved his highest grades (in the 90s) for physics.

Nicholas was deeply passionate about robotics and about joining the army. He wanted to fight in Iraq, as had his cousin, and bring terrorists to justice. He felt that if he could develop bomb-sensing robots the he could save the lives of soldiers and also more effectively seek out the enemy. Nicholas’ commitment to the robotics team at school cannot be over-stated. For the duration of the time when the team was preparing for a “Botball” inter-school competition at Polytechnic University, which he also used for his science fair project, Nicholas came to school early, worked in my office at lunch and stayed late to build and program his robot. This experience supported him in building positive relationships with other ninth grade students and with adult mentors, corresponded with a substantive increase in his science grades, inspiring him to search for related opportunities and internships.

Critical Goals

1. Learning Goals

The 9th grade social studies teacher said, in an interview, that students had “a side to them that was inherently curious.” This phrase is an apt description of the case study youth – all of them were committed to expanding their understanding of the world. I
consider the goals that youth expressed for their learning as “critical” because they dispel notions that students of these backgrounds are not motivated or somehow non-intellectual. In contrast, through their work and comments, all the case study youth clearly expressed a desire to engage in inquiry and challenge themselves. These findings challenge popular stereotypes about the beliefs of low-income, urban youth.

In terms of the students’ learning goals, three ideas are salient: 1) Youth, in this case study, shared a desire to develop their knowledge and skills by through independent hands-on work -- conducting original and independent experiments, building devices and inventing new technologies; 2.) Youth expressed a commitment to acquiring new and high-level content understanding and developing expertise; 3.) Youth discussed their desire to be intellectually-challenged. While the students shared these types of critical learning goals, how they enacted these goals varied. For example, Darlene picked the most difficult options for class projects while others. Grant created an independent research project for himself, beyond what was expected from him in class, and presented on his findings.

*Darlene’s learning goals: desire for challenge, independence and originality.*

Darlene was an avid learner who was highly motivated and held lofty goals for herself, including a desire for challenge and independence. Despite not expressing a preference for a career in science, Darlene seemed to have a “a scientific view of the world – she wanted to find out about the world through her own experiments and observations, even if this process was initially difficult for her. She also wanted to learn new ideas that felt useful to her.
Darlene took pride in being independent, which she attributed to the fact that she had lived away from her mother and with a variety of extended family for several years. In a reflection on the science fair, Darlene said she enjoyed the unit because she could start class on her own and be independent: “I liked not waiting for the teacher. Because normally when you go to class, you wait till people get settled and teacher gives directions. [For the science fair,] I knew where I was and what I had to do instead of waiting for the warm-up.” Darlene also expressed her independence by trying to find answers herself through her own investigations. In goals she set for her year in physics, Darlene wrote about her desire to “Think like a scientist. Design experiments of [my] own.” Darlene believed that computers could provide the “wrong” answers and, therefore, she wanted to do her own experiments to find the results to scientific questions. Many students felt the opposite; they wanted to find answers on the internet rather than do their own experimental research, because the latter required more effort over an extended period of time. Darlene struggled with the number of hypotheses she was expected to generate for the science fair. Despite struggling to create multiple hypotheses and experiments for her science fair project, Darlene said that she enjoyed “getting to check the results and test ideas in different ways.”

Darlene’s was a student who wanted to successfully tackle challenging academic work. She described herself as a “motivated and determined” and, in an assignment early in the year, set herself the goal of “answering all questions” in physics. Darlene achieved honor roll every term that she was enrolled at our school. Her overall average for the year was an 86.5%, and she enrolled in electives beyond the regular school day (Culinary Arts
and PSAL) that gave her more credits than her peers by the end of the year. Her teachers described her as: “a hard-worker, a top student, highly-intelligent, energetic, eager.”

Specifically, Darlene wanted to challenge herself and succeed in physics. She generally completed work with great attention to detail – when I looked at her physics binder, she had completed almost every piece of work assigned to her. After she completed the 9th grade science fair, one of the first reflections she expressed was her intention to pursue a more challenging problem for the science fair the following year, which she hoped to model on the robotics project she has seen other students complete. Specifically, she said, “I think that next year I’ll pick a topic that is even more challenging.” Darlene also aspired to take advanced physics classes that would challenge her more than her current conceptual physics course. She said, “because my physics class it’s a normal physics class we wouldn’t do so much, so in the next class you can imagine we’d go to even higher levels and do more experiments.”

Darlene wanted to learn new ideas in physics, especially those that she felt were useful to her. She said she enjoyed science because “it’s interesting and I learn new things that have to do with real life.” For the science fair, Darlene said that she had wanted to do “something different” from other students; so, she chose to study how objects float rather than a topic we had already explored in class. During the science fair, Darlene said that she felt “really good, I felt we were doing something really extraordinary. In three weeks, we knew what we were doing, we would just go to it. It felt like we were in an art museum showing off our work.” She also took pride in a comment from a judge that described her project as “original,” different from the types of experiments other students had pursued.
Darlene, during an interview, discussed her desire to “mix chemicals and different liquid substances to create something totally new.” When asked about what had most interested her about her physics class, she referred to the demonstration in which I used a radio, LED, solar panel and speaker to convert energy between different forms. Darlene enjoyed this activity because she learned something she had never known before. As part of her desire to be original and engage in new ideas, Darlene wanted to investigate topics she did not understand such as gravity on the moon and in a spaceship. She wanted to know more about black holes and how the universe would look in a billion years, topics that she decided to research for the January science symposium and for the lesson that she planned because she “didn’t learn everything” by working on the symposium project.

Darlene also expressed her excitement about ideas that felt useful to her. She summarized why she approved of the electricity project by saying: “you are always going to live somewhere, you are always going to need electricity.” About math, Darlene said “I like math in science class. I love math and the fact that I have one of my favorite classes fit into science...Math takes me to a difference place... In my math class, we take a problem and make it into a real-life situation, like building a house and you have to make numbers and equations.”

*Grant’s learning goals: becoming an academic leader and associated challenges*

Grant tried to establish himself as an academic leader in his school but struggled a great deal to achieve his ambition. He was excited about learning new ideas in physics and especially passionate about building and fixing devices, creating working technologies and pursuing his own investigations.
Grant’s wanted to establish himself as an individual who went beyond what was expected of him academically and set an example for other students. For example, by selecting himself to be the first student at our school to conduct an informational brown bag lunch for the community, Grant tried to distinguish himself from other students. He also wanted to find a summer internship to not only advance his understanding of mechanical engineering, but also to represent his school, through this opportunity. Grant attempts in the realm of leadership were evident. In Grant’s report card, his English teacher wrote: “Grant is a real leader and very charismatic."

However, Grant’s intentions stood in sharp contrast with his reputation as a student who had been in jail and was allegedly part of gang, as reported to the principal by his peers. Grant did not pass any of his classes in the second semester of his freshman year – he had to attend summer school to receive the credit he needed to move on to tenth grade. In describing himself, Grant said, “I am a hard-working student at some points of the time but I play around a little too much.” His math teacher wrote: “When Grant chooses to do his work, he does well...However, Grant very rarely chooses to turn his work in.” This gap between Grant’s reputation, history, actions and aspirations was also evident in how he participated in my physics class. In physics, he often left his classwork incomplete, just putting on his name on the top of some assignments or completing only one page of a multipage test. He almost never submitted homework.

Despite setbacks, Grant retained his belief in his aspirations. He regularly committed to fresh starts. For example, in one interview, he said: “I feel that I played around first semester but I decided to be more focused in my work second semester.” But he often relapsed into his original behavior -- during the second semester of his freshman
year, Grant continued to be distracted in class and often felt the need to leave class because of conflict with his peers and teachers. On one occasion, after-school, Grant caught up on several nights of physics homework and class work. But he rarely repeated these efforts to catch-up on work at other points during the year.

In my class, Grant’s inconsistent participation often meant he misunderstood key concepts in physics, even though he expressed a strong interest in learning new ideas. For example, in his description of the Gummy Bear experiment, Grant said that his teacher put “potassium chloride with the gummy bear and it evaporated, which created oxygen,” In fact, in class, we had discussed how we created oxygen from the heating of potassium chlorate, which had caused combustion rather than “evaporation.” I had described combustion as the release of energy, which was the focus of the unit in which the demonstration was situated. We had further extended this idea to the process of digestion, combining food with oxygen to harness the energy in the food’s chemical bonds, with a by-product of this reaction being carbon dioxide, not oxygen. Though Grant remembered the experiment, he was clearly not able to describe the reactants, process and products of the reaction accurately.

Despite the fact that Grant did not “get” the big idea, he found the experiment amazing – his reaction to the experiment suggested that it connected to his love of learning. Specifically, he said, “I thought it was fascinating that you put in the potassium chloride with the gummy bear and it evaporated, which created oxygen.” The experiment was a surprise for Grant -- he said that he had never worked with a Gummy Bear in this way, and seeing it combust made him think differently about what happened when his stomach digested food.
Grant also articulated misconceptions about electricity, nuclear energy and the structure of the atom, though we had discussed these ideas in class, and he was excited about the associated demonstrations. In short, though Grant could invest deeply in his academic work, he was an inconsistent student and had trouble expressing a deep understanding of the content to which he was exposed in physics.

Grant, like Darlene, expressed a desire to engage in authentic inquiry. He wanted to fix, create and build objects on his own. For example, he reported that he took objects, such as his sister’s toys, apart and then put them back together, on his own, at home. Sometimes he mixed the parts of cars, as a challenge, to see if they worked with the new parts. He enjoyed building the Twin Towers for a school math project, out of household supplies. At Polytechnic, after seeing the “big labs on the 4th floor – the mechanical lab, biochemical lab, and lab that deals with pipes,” Grant chose the mechanical engineering lab as his favorite. While at Polytechnic, Grant was excited about the cement boats and the bricks made out of cans that he saw. He wanted to intern at Polytechnic so he could engage in similar challenges. His dream project was to design and construct a high-rise, high-tech building that provided a setting in which people could efficiently take care of everyday business.

Grant showed a commitment to extending classroom assignments into deep, self-motivated investigations. For the science fair project, he spent time with me, outside of class, learning to solder. When he worked alone on soldering, in contrast to times in and between in class when he socialized with other students, he carefully isolated himself so he could avoid having anyone else touch the soldering equipment or even share the space around him. He constantly reminded me to purchase solar panels for him, and then spent

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time in and out of class meticulously connecting the solar panels with different types of motors.

For the project, he conducted multiple trials for his experiment, a process that most students dismissed or completed hurriedly. Grant observed that, between multiple trials, there were variations in his results for how many times per second the same panel spun the same motor. Unlike other students who ignored small variations between their trials, Grant looked for an explanation for his observation. He decided that the variability depended on how much the “sun was pushing.” In part, he came to his conclusion because he observed that the panels could not work with the radiation from a light bulb, and so he concluded that different sources could produce different amounts of radiation, most pronounced in comparing a light bulb with the sun. On the day of the science fair, when he was arrested because of an alleged incident with a youth at the nearby subway station, he told the officers that before going to the precinct, he needed to present his science fair project! The time, thought and commitment Grant placed in the science fair project suggested his deep investment in independent investigations.

_Linda’s learning goals: understanding the world._

Linda’s critical learning goals were to learn physics to better understand the world and to independently engage in authentic inquiry and hands-on projects, with an attention to learning the subtle details behind complex concepts.

Linda felt that physics was a discipline through which she could better understand the world. She said, that “everyone should learn...physics because everything has to do with physics -- basically, I have just always wanted to know why certain things happen. Linda believed that developing this understanding required that scientists had to both
learn existing information and conduct experiments—both were practices in which she
was interested. Linda showed her commitment to and skills at learning existing
knowledge in physics by completing a large fraction of her classwork and homework.
However, she also was engaged in hands-on projects and experiments. During the unit on
electricity, Linda was fascinated by the idea that changing the position of one wire in the
circuit made a difference in how the circuit worked. She said that she had not known, till
that point, that scientists even studied electricity—she thought that scientists were limited
to investigating chemicals. Specifically, with regard to the electricity unit, Linda said,
“we were able to connect more than one thing at a time, I never knew we could do that
with all the wires...it made me feel like a scientist.”

Similar to Darlene and Grant, Linda was deeply committed to engaging in
authentic inquiry. For Linda, this meant that she wanted to develop novel experiments
and carry them out. In one interview, she said, “Basically what we have now today, most
of the scientists have invented...like electricity and using medicine.” For her own part,
Linda wanted to challenge herself by engaging in projects that no one had achieved
before: “I want to build a remote to go back in the past. Something you won’t find in a
laboratory.” For her science fair project, she generated the creative idea of using same-
size water bottles with different amounts of water inside to test her hypotheses about how
weight affected the speed at which objects fall.

Linda enjoyed working independently on projects and she completed assignments
with attention to subtle, complex concepts. For her math building project, as specified by
the assignment, she used multiple shapes to construct a bird-house. According to her
father, she worked on all aspects of building the bird-house by herself (design, assembly
and painting), except for acquiring the building materials and cutting the wood, for which she received help from her father. She painted the bird-house bright red and even designed a little ledge on which a small bird could rest.

Linda's commitment to exploring the subtle details of an assignment was also evident through her discussion of the science fair. She could articulate what variables she and her partner considered important in investigating how fast objects fall. She even made claims about how two variables might have a combined effect on the falling speed of the object, which I did not see in any other project. Linda also could explain what variables she and her partner were controlling and why she was conducting multiple trials, topics about which few other science fair groups could speak. She compared her data to her hypotheses – she concluded about this process: “I learned it was okay to be wrong so people can get the right answers, so things can be worked better later on in the future when they get the right answer. I think it’s better you do it wrong and get the right answer, so you can be better when you try something else in the future, or so when you experience something, you will know the answer.” Linda was comfortable analyzing the discrepancy between her hypotheses and results, whereas many other students tried to make their results match their hypotheses.

*Kanisha's learning goals: high-quality work, deep understanding and exploring everyday materials.*

Kanisha’s critical goals were to producing high quality work, develop deep understandings of the big ideas in physics, and use physics to explore everyday materials. Kanisha wanted not only to succeed in school but also to develop deep ideas of science as
part of that process. This was evident in how Kanisha often went beyond the requirements of an assigned project, and in how she thought about and engaged in the practice of revising her work. According to her mother, when Kanisha built her “shape project” for math class, she was not happy with the first version she created and went to Home Depot to get new materials so she could start again from scratch.

Kanisha and her partner Dawnita chose to redo many parts of their science fair project, after their first attempts at collecting data. For example, the pair tried to use food coloring in the hot and cold honey to differentiate them when they were poured together. But they were often not ready with the food coloring, so by the time they tried to pour the hot into the cold honey, the hot honey was too thick to pour easily and not sufficiently distinct in temperature from the cold honey. When they tried to compare whether hot or cold coffee floated better, they had to reduce the amount of coffee they put into the water and then redo their experiment. Many other students in class went ahead and collected data even when their actual procedure did not match what they had originally wanted to do. Dawnita and Kanisha started over multiple times with data collection so they could pursue the investigation they had originally articulated.

Kanisha said about revising her work, “I got a chance to learn from my mistakes. My project, I didn’t do so good on. If I did it again, I would ace it ‘cause now I know what to fix and what was my mistakes.” For future projects, Kanisha said that she had learned to look at the instructions and rubric more carefully, plan experimental steps with more attention to detail and read over what they wrote for their final poster before presenting it to an audience. Despite the challenges they faced in setting up their experiments, Kanisha and her science partner Dawnita’s detailed poster suggests that they
grasped what they were trying to investigate, how to organize data, what results had emerged from the data, and how these results compared to their hypotheses.

A second critical learning goal for Kanisha was to develop and use an understanding of physics to fix objects and to understand what everyday materials do. For example, she enjoyed playing with wires to fix electrical devices, sometimes with the help of her father or uncle. She said, “if something is broken in my apartment, I try to fix it.” Kanisha said that she felt like a scientist when the VCR at her house was broken but she “put it together and it worked.” At home, she tried to be an inventor but found that “things didn’t work out, the devices didn’t work.” Kanisha also said that she tried her own small experiments with materials when she was younger and that she liked “mixing things to go into heat – I like to see things blow up, and see smoking things.” Kanisha felt that through chemical reactions with everyday materials, she might learn something she and others had not known before. Kanisha was particularly excited about the investigations for which she dissolved gummy bear in water and the demonstration in which she observed me combusting a gummy bear. With respect to the first investigation, she said that she was excited to study an item that people ate regularly, the experiment helped her envision what might happen to a gummy bear inside a person’s stomach. Kanisha, in her interview about the combustion demonstration, summarized her feelings by saying, “Who would have thought that something I use every day could do that? The person who came up with the food coloring experiment was really exciting.” Consistent with her interest in studying everyday materials, for her science fair project, Kanisha, with her partner Dawnita, chose to heat everyday materials such as honey and a balloon to see how heat affected whether they sink or rise.
Nicholas’ learning goals: developing expertise in crafting working technologies.

Nicholas’ critical learning goals included a desire for developing expertise in building, which was expressed through his intense engagement in designing and creating a robot. Nicholas was committed to developing functional technology – he repeatedly revised the structure and programming for his robot, until it completed the task he wanted it to do. He also wanted to learn new ideas, particularly about electricity.

Nicholas had always enjoyed science, particularly building. His father said, “Since he was back in St Lucia, he has always liked science. He used to cut carts out of cardboard as a little boy.” Every night, while building these carts, his father that Nicholas would ask repeatedly for help.

In high school, through robotics, Nicholas found expression for his interest in building. He and two other friends decided to participate in the KISS Botball competition, a challenge held across the country, which provides students of diverse backgrounds with experience in the design and programming of robots. Nicholas was more passionate about the KISS Botball competition, which he also used as his science fair project, than about any other learning opportunity that he encountered in school. To work on his robot, over several months, Nicholas came to school early in the morning, came upstairs at lunch, stayed after-school and went, without a chaperone, on every day possible to the Botball training sessions at Polytechnic University.

In Nicholas’ mind, a connection existed between learning physics ideas and developing applications from this knowledge. For example, Nicholas felt that studying series and parallel circuits would help him wire a house and understand the circuitry of a robot. Originally, for the science fair, Nicholas wanted to use his knowledge of circuits to
build a laptop of his own. Nicholas also believed that understanding principles in engineering and computer science would help him developing functioning robots.

In his quest to develop a working technology from the information he was learning about mechanical engineering and programming, Nicholas was willing to revise his work innumerable times till his robot performed in the ways he desired. Programming, for Nicholas, was a sequential act of writing, testing and revising. If the robot did not respond as expected to his code, Nicholas changed the program. I watched Nicholas and his friends, all of whom were struggling academically and one of whom was struggling with a learning disability, constantly reprogram their robot so its direction, speed and claw positioning fulfilled their desires for its behavior. Similarly, I observed Nicholas taking the hydraulic arm model at Polytechnic University and improving it to better suit the structure of his robot. Unlike other students, for the science fair, Nicholas did not just test his hypothesis once; his process was a recursive pattern of build--program--test because there was a particular outcome he was trying to achieve. At the robotics competition, Nicholas watched other team’s robots and repeatedly adjusted his robot to improve its performance on trial game boards, even after his team had lost in the qualifying rounds. Throughout the summer after the competition, Nicholas worked on his robot. He called me almost every day for a month to ask how he might adjust the robot’s arm or to inquire into whether I had found him a computer on which he could program at home.

In general, Nicholas said that he enjoyed learning physics because this discipline exposed him to new ideas that he had “never known about before.” In his evaluation of the energy unit in physics, he said that his favorite part of the unit was “everything,
because I learned new things.” He felt that the sign of high-quality project in physics was
evidence that he had “learned something [he] never knew before.” He specified that he
most enjoyed building series and parallel circuits in class and creating charge using
styrofoam blocks because these experiences were new to him as well. From the
foundation that he gained in electricity through physics, Nicholas wanted to build motors
and further investigate voltage and current, again pushing the boundaries of what he
knew about physical principles operating in the world.

2. Finding Opportunities to Express Voice

Holland (1998) and Dewey (1938) suggest that one system for pedagogy and one
curriculum cannot meet the needs of all students. Instead, students should have
opportunities to shape their learning communities and classrooms. The youth in my study
wanted to find and create opportunities to do exactly this -- to express their voice.

In contrast to the positions articulated by Holland and Dewey, low-income, urban,
minority youth are often characterized as having neither the desire nor the need for choice
and voice in their education (Merry, 2005). In this study, I consider the students’ goals
around voice to be a critical response to this characterization -- all the youth I interviewed
wanted to participate actively in and shape their class and school.

In this study, case study youth communicated three key reasons for expressing
voice: 1) share and test understanding and expertise, 2) taking up opportunities to shape
their physics classroom in the context of their own values, and 3) providing peers with
opportunities for voice. All the case study youth expressed interest in not only expressing
their own voice but in creating this opportunity for their peers. Differences played out in terms of for case study youth in what kinds of opportunities for voice they sought out and created, differences that were largely tied to their "funds of knowledge." For example, Kanisha wanted to create science learning opportunities for herself and students that helped them explore and prepare for different careers, reflecting her desire to be academically- and professionally-successful. To demonstrate her epistemic authority and to help other students, Linda chose to express her voice by sharing her understanding of complex topics, a key focus of her academic life.

*Darlene’s expression of voice.*

Darlene sought out and purposefully created opportunities in physics to share her opinion on open-ended questions and wanted to design similar spaces for other students to successfully defend their opinions. She also wanted to be able to communicate the originality and uniqueness of her own ideas and her school to the larger world.

Darlene’s first experience with a debate format in physics was when our class argued about the impact of the equation $E=MC^2$ on the world. She found it exciting that she might disagree with Einstein’s research. As a result, when I asked her to design a lesson for class, she chose a similar debate format about a different topic, so students could investigate open-ended questions to which there were no “right” or “wrong” answers and could develop and express informed opinions. Darlene tried to ensure that every student would have a position to defend by having each student in class write a paper on the topic she and I agreed upon: the effect of dark matter and energy on the future of the universe.
When Darlene reflected on the success of the debate, many of her comments were related to how students expressed themselves. She felt that despite the requirement of the preparatory essay and the fact that students saw each other everyday and knew each other well, they were not comfortable presenting to each other – they would rather accept a failing grade. Darlene argued that the ninth-graders might benefit from a public-speaking class. Darlene concluded that for students to be successful with a debate, they had to move gradually towards a full-class debate. Darlene remembered that “when we went to Eugene College...There was a teacher, big table and chairs around it, we could do that....Judge on one side, three people on one end, three people on the other, they present, judge decides which one.” She also suggested that the initial debates in physics resemble a “portfolio presentation,” the debates could be smaller and less threatening to students. Darlene and I discussed that these sorts of smaller trials might lead to a larger trial at the end of the year.

Grant’s expression of voice.

Grant sought out and even created opportunities to portray himself as an academic leader, a different identity from his history as an incarcerated youth and potential gang member who could be disruptive and unfocused in class. He created the idea of a student-focused brown-bag lunch to pursue this goal of leadership. He also used the lesson-planning opportunity to his communicate the importance he placed on projects being an
opportunity for students to express their creativity and identity and feel successful in their academic work.

Grant wanted to portray himself a leader who could teach others – he acted on this desire by creating a brown-bag lunch in which he presented his knowledge of mechanical engineering to teachers and students. In an interview, Grant said that the viewed the brown-bag lunch as an opportunity to express his knowledge and opinions, such that he could convey himself as a motivated and accomplished student. By being the first student to conduct a brown bag lunch, he felt that he would set himself apart from his peers as an academic trend-setter. By conducting research, beyond course requirements, on mechanical engineering, he believed he could earn himself credit in math and physics and portray himself as an expert.

When I asked him to design a lesson for physics, Grant expressed his interest in teaching a lesson about building. What he valued in the outcome of this building project was that the assignment be attainable to students and afford them the opportunity to show off creativity and individuality. For the project, Grant said that he would have students use four different shapes and the theory of optimization ("how much waste do we have after building our project") for his lesson, the same parameters that his math teacher had created for Grant and his peers. Grant said that he intentionally chose a project similar to what students had already done and that only required easily-available household supplies. Grant suggested through his comments that the assignment should not so much challenge students to learn something new but instead should be a project that students already knew how to do, so they could be successful. He also felt that the most important way of judging the success of building projects was to evaluate if they were creative, if
the product “showed feelings.” During his visit to Polytechnic University, Grant similarly appreciated how creative students had to be to pursue the “student challenge” projects. Associating the success of products with their emotional content and creativity differentiated Grant from other case study students who referred more often to the importance of meeting the expectations of a teacher and fulfilling the requirements of the assignment and its associated rubric. Grant used the building lesson he wanted to teach as an opportunity to express how much he valued opportunities for creative expression of identity.

Linda’s expression of voice.

Linda expressed a desire to use physics to communicate her understanding and opinions. In part, she wanted other students to listen to her comprehension of a topic and, through this, develop a better grasp of the topic at hand. She also wanted to have opportunities to test out and discuss her ideas and contribute her opinion to how science was structured at our school, so she could advance herself and other students towards a medical career and increase the amount of choice available to students in coursework.

Linda said that she liked to state her opinion and participate in class. Specifically, she said:

I like to give people a better explanation, take something that can’t be seen and make an example. It’s normal for me, I like to speak and give my opinion on certain things, I am a very outspoken person, I don’t hold anything, I tell you why I feel a certain way about things. It’s not new to me. I just met these people this year, coming to this school, so I was kind of nervous presenting in front of everybody ‘cause I’m new. But I feel that I gave a
good explanation of how these are used and I gave a good example of how these things work in fusion and fission.

In physics overall, Linda felt that she had the opportunity to express herself. She seemed to respond particularly well to the opportunity for debate: “I do think I get to be myself, I get to express what I learn, give my opinions. I may not be able to talk all the time but basically I can say my opinions about how I feel about certain things, express myself, so they get to know how I am. Like when we had the debate on dark energy and how we had to state our opinion, why it was a good or bad thing to the world. How I felt about dark energy, I expressed my opinion to my classmates.”

Linda enjoyed working in a group in physics class because she wanted opportunities to discuss her ideas about what to conclude from the data she was collecting or the information she was learning. During the science fair, Linda and her group members proposed different conclusions to each other and discussed, which was the best idea. She wrote two of her unit evaluations that discussing ideas with other people helped her understand concepts better and change her opinions about physics content.

Kanisha’s expression of voice.

Kanisha wanted to express her opinions in physics so that she could pursue her ambition of receiving high grades and communicate her beliefs about how science should be taught.
She often asked for help in class when she felt stuck with an assignment, for example, during the science fair project, when she and her partner had trouble using their materials to decide whether hot or cold objects floated better. When Kanisha did not receive help at the time she asked for it, she grew loud and increasingly vocal in her frustration with me, until she received the help she needed or knew when she would get my attention. When Kanisha received a progress report that indicated she had received less than full marks on a particular assignment, she sometimes walked out of class in frustration of expressed her frustration loud enough so everyone in class could hear. She would either angrily speak with me in class about her grades or see me after class to find out what work she needed to catch-up on or discuss what work she felt she had submitted that had not shown up on her progress report as complete. Kanisha was able to use her voice to advocate for her own grades and design strategies to make-up work she was missing.

Kanisha sought out opportunities to communicate her beliefs about the nature of science and how science should be taught. She also wanted to make sure that curriculum gave students exposure to different careers and wanted to have input in the types of coursework that was available to advanced students.

Kanisha repeated in multiple interviews that she felt that all people were scientists. She said, “I think I am scientist, everybody creates something, they don’t feel like scientists but I think everybody is a scientist. She viewed science as “looking for evidence, being a detective, and findings clues, like in a scavenger hunt.” She also felt that science involved “creating something” and fixing things. From these definitions, Kanisha concluded that the “cable man who fixes wires” and the “Con Edison guy who
does the phones," though perhaps not acknowledging it to themselves, were scientists. Kanisha proposed the idea that science can be done by all and accessible to all, a contrast to a view of science as an elite domain, practiced only by trained individuals, using prescribed steps. Also, Kanisha felt that people did not just naturally pursue careers in science; instead, they had to encourage themselves to be a scientist and envision themselves in the role of a scientist to become one. Finally, Kanisha expressed the opinion that science investigations could be completed with everyday objects and materials.

*Nicholas’ expression of voice.*

Nicholas wanted to do more than just learn information about robots and computers; he also wanted to express his understanding by of computers and robotics and use his knowledge to help and educate his peers and community.

When I asked Nicholas about a lesson he might teach to other students, he elected to instruct students about robotics. He decided that he would teach the students basic information about design, sensors and programming and have them actually design and program robots, which would compete in a within-class competition. He repeatedly followed up with me about implementing these ideas – he would ask me if I had bought the robots for the in-school robot competition he envisioned.

Nicholas’ ideas came to fruition in the second semester of his sophomore year, when he and I found a venue to teach a unit on robotics in the “Medicine/Engineering Academy.” However, even during his freshman year, Nicholas began teaching about
robotics – for example, during his portfolio presentation, Nicholas taught a small group of students, two teachers and some outside-of-school visitors about how to write basic programs for a robot. At the Brooklyn Library, in the summer of his freshman year, Nicholas taught patrons at Brooklyn Library how to use the computers at the facility.

Nicholas often volunteered when I asked a student for help with organizing the school laptop carts – figuring out which computers needed maintenance, coiling the wires, re-labeling each computer, putting in configurations to connect the printer to the laptops, and more. He also set-up computers for students to work on in my office, by connecting monitors and hard drives, finding and connecting ethernet cables and investigating how one might set-up a shared network at school. Nicholas constantly e-mailed me, called me and came to my office to ask questions about how to complete his projects and regularly asked for new opportunities in this area.

3. Participation in Relationships in and beyond School

Case study youth expressed different ways by which they wanted to alter their participation in relationships in and beyond school. In particular, they tried to cultivate strong, positive relationships with their peers, teachers and mentors outside of school, make strategic choices about their partners in class and friends in school, and to act as social role models for their peers. I consider the goals of case study youth regarding their participation in relationships to be “critical” because students chose to cultivate relationships to promote their academic and professional success, in contrast to popular
negative perceptions I have described about low-income, urban youth. Though students all had goals for their participation in relationships, variations existed in whether the youth focused on enhancing their relationships with peers or teachers. Youth also differed in whether they cultivated these relationships in class for academic success (Darlene, Kanisha) or outside the context of class for social acceptance (Nicholas).

*Darlene’s participation in relationships.*

Darlene tried to work with partners, who were not necessarily her best friends, but whom she believed might help her finish the project she had set out to do. Darlene generally respected peers who challenged themselves and had little tolerance for students who misbehaved in class. She also tried to be a role model and confidante for younger students.

Darlene often felt that she was left to do the bulk of the work for a group assignment. In summarizing her group work for the Einstein debate, Darlene explained that she and one other student ended up doing prepared all the debate materials for the group. Because she wanted work distributed more evenly amongst group members and wanted to succeed on assignments, Darlene wanted to choose her own partners, rather than having them assigned. In one interview, Darlene stated, “I do not like it when the teacher puts me with someone and all the work gets put on me and the person gets the same grade I get. If I can pick my own partner, I will pick someone who is committed to getting the work done.”
When Darlene did have the opportunity to choose her partners, she chose not to work with her best friends. For the science fair, Darlene chose Audrey as her partner, rather than her best friends, because she wanted to try out new working relationships and “divide up work so it gets done.” Specifically, she wanted to have as a partner “someone who will really commit to doing this project with me and really complete it.” In my observations of Audrey and Darlene, as they worked on the science fair project, Darlene completed the bulk of the work. Further, Darlene, in an interview, stated that Audrey did not complete the part of the project to which she was assigned by Darlene and, therefore, had nothing to present at the science fair. Darlene said, “I don’t even know what she did, she wasn’t doing anything, so I gave her that -- whether objects floated in different substances – water and something else, but she didn’t talk at presentation.” Unsurprisingly, at the culmination of the project, Darlene decided that next year she would “pick a different partner. Audrey was good and everything but I would pick someone who wants to work on the project.”

Darlene was critical of students when they misbehaved in class and admired and sought out relationships with people who challenged themselves. For example, she liked the dean at Eugene Lang College, whom she interviewed, because “he had so much goals, he very educated about what he wants for Eugene Lang.” Darlene said that she respected Charles, a peer of hers at school, because she saw him as committed to his work and to intellectual challenge. Charles described himself as different from his peers because he cared about school and “didn’t want to be thrown around by life.”

Darlene was a self-designated peer mentor, committed to supporting sixth graders at our school, in particular helping them to succeed academically and resolve conflicts
with teachers or other students. These students, according to Darlene, listened to her when she asked them to go to class. I once saw her in the hallway encouraging an angry sixth-grade boy to return to his classroom. Darlene said that other students “play with them [the 6th graders]” but Darlene thought of herself as a role model to the sixth graders. She tried to make sure that the sixth graders felt included and supported at school, specifically by being friendly with them and helping them find constructive strategies to respond to conflict with peers and teachers.

*Grant’s participation in relationships.*

Grant respected teachers who challenged him. He sought out help with tackling his personal challenges through the support of his teachers and school. An important aspect of being in an educational setting, for Grant, was the opportunity to cultivate one-on-one dialogue with his teachers. Through this dialogue, he hoped to receive the mentorship he needed to achieve his personal goals. Grant articulated his desire to be a mentor for younger students and youth who were struggling with personal challenges or with their academic work at school. Nevertheless, over the time when I interviewed him, as was true in his academic life, a tension emerged between his aspirations and actions -- his relationships with teachers and students were fraught with conflict.

Grant said that he respected teachers who challenged him to do better work and improve in his attitude, diligence and behavior. For example, Grant had strong positive recollections of his 5th grade teacher who always gave him regular homework. Grant described the pressure as “kind of good, it prepared me, that’s why I can get a lot of work
completed if I set my mind to it. In deciding which field trips he would attend over the course of the school year, he said, more than once, that he would go wherever I was going. Similar to his sentiments about his 5th grade teacher, he said that he appreciated being challenged by me to improve academically and behaviorally. He referred to his advisor and to me as being “like his mom” in that we “always kept an eye on him.”

In general, Grant said that he felt that at his school “Teachers are caring. They help me get credit to make-up work.” He also appreciated favors teachers did for him, such as staying after-school to work with him and loaning him money for his subway fare. Grant said that he considered the people at school to be like his “family.” In part this was because Grant relied on our school for more than an education and grades. For example, he regularly took his narrative report cards to his probation hearings. He relied on school to be a safe space, where he was less likely to get into trouble than on the street amongst his peers.

Grant wanted to be educated in a small learning environment. After visiting Eugene Lang College, where he observed that the classrooms were small and structured physically around discussion rather than lecture, Grant said that it was “always better if you have a smaller environment, you get more learning, and the teacher is always there to help.” He added he was opposed to large college classes, which he envisioned with at least 350 people per class. Grant liked the School for Social Change because it was small enough for a teacher to “see you individually, so that you can get individual attention.” He added, “kids are less likely to get into trouble – everyone here knows everyone. Everyone talks to each other. There are no put downs, we have a small argument or a big argument, two weeks later they’re talking to each other. This is a positive environment,
everyone is the same, equal, no one has to worry about anything.” At his school, Grant said he felt confident asking for help when he felt he needed it. Grant thought that his experience at the School for Social Change was a contrast to what he observed at James Madison, the school to which he was assigned for a few days. At Madison, he felt that there were too many students and that he would not receive the attention he needed.

Grant’s attempts at leadership extended beyond the academic realm to his relationships with younger or less social students. In his own words, he wanted to be a “role model to younger students.” For example, he explained that when he saw a particular 6th grader prone to regular emotional outbursts, in the hallway, he would try to help this student manage his anger so he could return to class. Grant wanted to be a mentor to this young man. Grant also often chose to work with and tried to say a friendly word to Nicholas, a youth in Grant’s class who moved to our school mid-year from Trinidad and was already struggling with school, when his father died suddenly. Sometimes when Nicholas was very serious and quiet and refused to do his work, Grant would go over to Nicholas, ask Nicholas if he wanted to join his group, share a joke, or encourage him to engage in his assignments. Sometimes Grant tried to be a leader and role model in class. In one observation of Grant, I noted that he “asked the class a few times to be quiet. When the class was being so disruptive that I had to raise my voice to talk over students, he came forward to take notes.”

Despite his the closeness he felt to his teachers and his aspirations for academic and social leadership, Grant engaged in disruptive behavior in class. He would sometimes angrily exit my room if asked to not dance, sing, listen to headphones, eat or talk with friends during class. Sometimes he would not return. One explanation he gave for his
behavior was that he was bored with the students in his section. At other times, he would ask to work outside my room. Grant was often late to school and developed conflicts with other students. At the beginning of second semester, he engaged in a physical fight, a new student at our school recently returned from a superintendent’s suspension. Towards the end of this incident, Grant threatened to assault the other student with a gun. Though he considered a 9th grade girl, Nakira, to be his friend, he regularly got into verbal and physical fights with her. Several times, Grant became involved in yelling matches with other students in the hallway and came close to fighting other students both in- and out-of-class. Also, students reported to the administration that he allegedly joined a gang within the school.

Despite the conflict in which Grant was often embroiled, he had a sense of how he wanted to act differently. Similar to his academic goals, Grant, when faced by setbacks, returned time and again to his goals for social leadership. For example, he said that it was important to “control feelings. If you have a job and bring your problems from home, you might get fired. Then you have more problems to worry about. If you have a problem and you’re mad and upset and paranoid, you might come to work with an attitude, and your boss might want you to do something and you might curse at him... you might get fired, something might happen that’s bad.” Though these statements were often in contrast with how Grant acted, they seemed like an ideal, which he repeated to himself regularly and which he used to try and guide his behavior. Over the course of the year and a half that I knew Grant, before writing this paper, he did get into fewer fights in class and improve his behavior. For example, in the fall of tenth grade, he was only suspended once in-school, in contrast to several times during the prior spring.
Linda’s participation in relationships.

Linda saw collaboration in science as a way for her to get her work done quickly but also test out her developing ideas. She had a strong bond with another case study student, Kanisha, but, similar to Darlene, chose not to work with her close friend for physics assignments if this did not help her learning and grades.

During the science fair, Linda expressed her excitement about group work. When asked about her science fair project, Linda provided details not just about the process of the experiment but also about the success of her collaboration with her partner. For Linda, working with someone else was integral to the process of doing science. She felt that working in a group sometimes distracted her in classes other than physics, but, in physics, she found the partnership helpful because this collaboration not only made her get her work done quicker but also helped her discuss and test out new ideas. Regarding the dark matter/energy unit, she wrote: “Working in a group really helped me try to understand but if I would have worked by myself, I would of never got the assignment done.” Also during this unit, Linda said that listening to other people’s ideas made her evaluate and change her opinion about whether dark matter affected the universe.

Despite the close bond between Linda and Kanisha, they did not choose each other as partners for the science fair project or for other partner assignments in physics during the year. Linda ended up working with another friend for the science fair project. Linda made this decision because Kanisha was absent on the day that the science fair project began. Linda began her science fair project with another partner because, unlike
many other students in class who waited for their favorite partners to return before they began an assignment, Linda wanted to start right away, so she could complete her assignment.

Kanisha’s participation in relationships.

In an assignment where students had to evaluate the effects of working in groups on their academic performance, Kanisha concluded: “Two heads is better than one. So working with someone else, you’ll get better answers.” But Kanisha was not willing to work with anybody – she chose to work with students based on who she thought would be most successful in helping her succeed academically. Kanisha could often be angry and stubborn in class, she often tried to defy classroom rules, including being disrespectful to other students. However, she often chose to move past this anger and resolve conflicts because she cared deeply that she be successful in her academic and professional life and could recognize that her comments might hurt other students. Kanisha’s powerful social position in class could even be channeled to make class more productive for both the students and the teacher.

Kanisha, during the science fair, chose her partner based on who she thought would make her most successful in completing her project. Despite being social with other girls in and out of physics class, Kanisha said, “Me and Dawnita always do our projects together since the beginning of the year. They always get done. With other people, I don’t know if I count on them, so I just stick with one person” Dawnita’s
performance in physics indicated that Kanisha had made an appropriate choice: Dawnita was a top physics student. She sat at the very front and center of class with Kanisha, taking diligent notes, completing all assignments on time, and regularly submitting homework. During the summer after her freshman year and three days a week during her sophomore year, she interned at a chemical engineering lab at Polytechnic University, where she studied liposome-based delivery systems for cancer medications. She was the only student at our school to enter the New York City Science Fair. When I asked Kanisha if she felt frustrated that Dawnita was often absent or late, Kanisha said, “She still makes it up.” Kanisha said that she saw her friends in class, at lunch and when she passed between classes. But she stated that it was not important for her to work with her friends at all times, because “in the real-world, I’m not always going to have my friends around.” Perhaps this attitude explains her choice of Dawnita as a science fair and classwork partner.

Kanisha expressed anger with students and teachers in class but chose to repair her relationships after a conflict either because she gained awareness that her comments were hurtful or because she wanted to ensure her academic progress. For example, Kanisha would get angry with other students or make fun of them, especially at those that had fewer friends than she did or were quieter than she was. Once when she was angry about a progress report, she said loudly, multiple times, in front of the class, that the room smelled because of another student. This student, at the time, was homeless, lived in a shelter, had no money for clothes, was ostracized by her peers and was getting into trouble at school for stealing. However, the following day, when Kanisha was calmer, she willingly and quietly discussed the hurtful nature of her comments, and she agreed that
what she said was inappropriate and apologized to the other student. When Kanisha received low scores on a progress report, she often loudly communicated her frustration and sometimes walked out of class. However, she generally returned the following day to discuss what she was missing and how to resolve the problem. This pattern of engaging in conflict with teachers and students but then addressing the conflict later continued for Kanisha throughout the year.

Kanisha had several friends and was comfortable expressing her opinion and needs. As a result of what we considered to be the social power of her and her friends, when many students were being disruptive in their social studies class, the teacher and I asked Kanisha, Linda and Christine to take on leadership roles in class. We hoped they would choose to act like model students. We emphasized to them that disruptive behavior in class reduced the amount they could learn – all three were strong students who cared about their grades; we thought that this argument might make most sense to them. According to the social studies teacher, the girls temporarily rose to the challenge by changing their own conduct and by admonishing students who were being disruptive. The social studies teacher said that these changes in behavior did not last through the course of the year, but I also do not think that the teacher met again with them to discuss their progress as role models and leader.

Kanisha described her desire to design buildings, be an architect and create clothes for models, all actions that would help her participate in the larger world. But her motivations for these actions were less grounded in a desire to transform problems and injustices in the world and more stimulated by her desire to be famous and recognized, in part to impress her mother and family. In an interview, she said, “My mother wants me to
go somewhere, and I want to do it for her. She helped me through a lot of things, I want to show her what I can do.’”

Nicholas’ participation in relationships.

Nicholas, as reported by teachers and students and also through my observations, could be extremely disruptive in class and was often teased and disliked by his peers. Nicholas wanted to change the negativity of his personal relationships.

Nicholas was often extremely disruptive in class -- he stared and rolled his eyes at students and made strange noises. He cleared his throat loudly and called out unexpected and often rude comments. He burped loudly in class. In math class, his teacher finally required him to sit at the very front of the room, so his back was towards other students. Nicholas described his behavior as “acting dumb.”

Many students seemed to dislike Nicholas or make fun on him. At one point, my advisory discussed Nicholas’ behavior with him present in the room -- our goal, with Nicholas’ agreement, was to use this open discussion as a means for improving his interactions with other students, perhaps by having his peers support him in this endeavor. But the conversation degenerated into several students stating that Nicholas should just be moved to a different school. Nicholas himself acknowledged that other students were uncomfortable with him; he said, “A whole bunch of students think I take crack, but I don’t, I don’t. I make faces and make students laugh in the classroom.” One
day in class, a student called Nicholas an “Africaan,” which from the student’s expression seemed to be a term of ridicule.

Several girls at various times reported that Nicholas made sexually-explicit comments to them. After a discussion of the inappropriateness of his comments, Nicholas was suspended on more than one occasion. Girls also accused Nicholas of repeatedly bothering them – taking their materials, talking to them in class. On one occasion, he spit at a girl while she was walking in the hallway. She almost physically attacked him but was restrained by teachers and friends. One girl described Nicholas as a trouble-maker, and several girls emphasized that he did not face any consequences for his behavior. In one discussion, Christine singled him out over everyone else in her class, for his behavior despite the fact that other boys were often disruptive in class as well.

Nicholas wanted to change his social identity in the classroom – he articulated a desire for respect. For example, Nicholas said, “the thing I enjoyed most [about the science fair] -- a whole bunch of people came over to my group and wanted to see bunch of things.” In physics class, Nicholas appreciated the respect he could acquire by engaging in high-quality work: He said, “I do get respect sometimes when I do my work. Because when they pass me, they ask for help. I respect other students, I ask them for help. In this science fair, people respected me, yeah.” Nicholas also expressed his wish for a few close friends. He said, “I enjoyed working with my team...We’re always friends.” Finally, Nicholas actions suggested that he wanted to cultivate mentoring relationships with adults – throughout the year, he regularly asked for opportunities to spend time with adults who could share their expertise on how to build robots and fix computers.
4. Being an Activist by Increasing One's Participation in the World

The fourth critical goal that I discerned from the data for this study is that the youth wanted to use physics to participate in a world beyond school. To tackle these problems, case study youth identified injustices or problems that they hoped to affect by conducting exploratory research and engaging in actions that resulted in social change – in this sense, their goals were critical.

Grant. Grant was interested in the social implications of the physics content and skills he was learning. He wanted to create devices that reduced pollution and wanted to design a building that would meet the diverse set of needs faced by people in his community, such that they could conduct their daily business more efficiently. For example, for his science fair project, Grant chose the topic of solar energy because he thought his work would help create a world in which solar power replaced oil and solar-powered cars would cut down on pollution. Furthermore, Grant’s dream, as a mechanical engineer, was to create a high-tech, efficient building in which people could take care of all their needs such as “welfare, housing and paying bills,” instead of going to multiple locations around the city. He felt that what he was learning about electricity and measurement was important information for him to acquire if he were to pursue this project.

Grant’s ideas about physics and participating in the world beyond school extended to larger socio-historical issues as well. Grant, in particular, seemed to be interested in the social implications of physics research. In one interview, he discussed
“how the atomic bomb stopped the war in Japan.” Also, during his portfolio presentation, he was able to respond to probing questions about whether the United States should have dropped the bomb on Hiroshima.

**Linda.** Linda said that she wanted to be a doctor, so she could provide needy people with health care. Specifically, she wanted “to be a pediatrician and go to countries where there is less health insurance, and give them better health.” She said, in one interview, “I want to understand how things work better and have a chance to help people.” She felt that physics was a discipline that helped her “understand how everything in the world works” and, therefore, provided her with essential knowledge for becoming a doctor.

**Nicholas.** Nicholas hoped to design robots that could replace humans at war. He wanted to create a robot that could search for terrorists, particularly Osama bin Laden, so soldiers did not have to die in the war in Iraq. In one interview, Nicholas said, “I want to send robots to Iraq to sense out bombs.” He envisioned a robot similar to “the Game Boy Advance” that he had used in the Botball competition. This robot could track color, and Nicholas felt that this capability might allow a more sophisticated robot to track terrorists, the consequence of which, in Nicholas’ mind was that the soldiers in Iraq could come home sooner. He even took the design for this robot to his mentor at Polytechnic. Nicholas seemed very concerned about ending the war in Iraq, in part perhaps because of his cousin’s experience fighting there. For example, after the nuclear physics unit, despite our discussion of the terrible impact on civilians of nuclear weapons, Nicholas said that he wanted to drop an atomic bomb on Iraq to end the war.
Summary

In Table 2, I document the findings from case study youth with respect to their critical goals. In the section below, I have tried to summarize key points that emerge from this data and similarities and differences between different case study youth.

With respect to learning goals, case study youth expressed a desire to: 1) develop their knowledge and skills through independent hands-on work -- conducting original and independent experiments, building devices and inventing new technologies, 2) Acquire new and high-level content understanding and developing expertise, and 3) Be intellectually-challenged. However, the topics in which the youth were interested varied based on their beliefs, interests and values — their “funds of knowledge.” On one hand, Nicholas wanted to learn about new ideas under the topic of electricity, because this information connected to his desire to build robots that could reduce the danger to soldiers in Iraq. Kanisha had a deeply populist view of science — in her opinion, science was done by all and with everyday materials. So, she wanted to learn new ideas and conduct investigations in physics that related to the exploration of everyday materials. Darlene felt that she had developed a strong sense of independence by being separated from her mother since she was a child. How she valued independence played out in the types of knowledge and investigations she sought out in physics. Darlene wanted to independently conduct research on challenging topics such as the structure of black holes and come to her own conclusions regarding scientific questions, instead of just relying on existing information she could access on the computer. Grant, in light of his desire to
create new technologies that were useful in the world, spent time learning new skills and information related to soldering solar panels and constructing buildings.

Four of the case study youth also discussed the importance of developing deep understandings of “big ideas” or specific topics in physics. This commitment emerged in different forms for the different youth, and youth pursued understanding in different ways. For example, rigor took the form of “academic leadership” for Grant, a desire for “challenge” and “independence” for Darlene, or the production of high-quality work with attention to the subtle details of assignments for Kanisha and Linda. Nicholas and Kanisha were comfortable revising their work multiple times in their respective quests for working technologies and high-quality work. Grant and Linda wanted to learn information well enough to present it to other students. Darlene wanted to research topics that she did not entirely understand through her classroom assignments. Clearly, the case study youth were committed to cultivating a deep understanding of science. This finding, along with the curiosity of youth about new ideas and their commitment to self-motivated investigation, contrasts the perceptions of youth as unmotivated and uncaring about academic success.

In this study, case study youth sought out and created opportunities for expressing voice because they wanted to share and test their ideas, respond to opportunities for shaping their physics classroom and science education and offer similar opportunities for voice to their peers.

Four of the case study youth saw expressing voice as an opportunity for conveying and comparing epistemic authority; some saw an opportunity to plan a lesson in physics as a setting in which they could offer a similar opportunity to peers. Darlene
enjoyed opportunities to share an informed opinion on controversial physics topics and tried to create opportunities for her peers to do the same. Nicholas, by presenting himself as a teacher and technician, wanted to convey his knowledge of robotics and computers. Linda viewed presentations as a chance to share her understanding of a complex topic and group discussions as a setting in which students could sort through competing ideas. Grant wanted to share the information he had researched on mechanical engineering, in part to create the identity of “academic” leader for himself.

With respect to participation in relationships, youth such as Kanisha, Darlene and Linda wanted to select partners who would help them achieve academic success. Linda specifically saw group work as an opportunity to hear other people’s ideas, test out her own and use this dialogue to arrive at an informed conclusion. Nicholas and Grant sought out mentoring relationships from adults within and outside the school as well as respect from their peers.

Grant and Nicholas could articulate how they could use physics to be activists in the world, respectively for energy-efficiency and saving the lives of soldiers. Linda viewed an education in physics as essential for moving her towards her goal of becoming a doctor, a profession that she felt would allow her to provide resources to under-served people.
<table>
<thead>
<tr>
<th>Critical Goals</th>
<th>Darlene wanted to...</th>
<th>Grant wanted to...</th>
<th>Linda wanted to...</th>
<th>Kanisha wanted to...</th>
<th>Nicholas wanted to...</th>
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</thead>
<tbody>
<tr>
<td>1. Learning Goals</td>
<td>a) Experience independence and challenge.</td>
<td>a) Become an academic leader</td>
<td>a) Understand how materials and objects in the world interact.</td>
<td>a) Produce high-quality work</td>
<td>a) Develop an expertise in building and creating working technologies through his own investigations in robotics</td>
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<td>b) Learn new ideas through class and her own investigations, be original</td>
<td>b) Learn new ideas about how materials interact</td>
<td>b) Independently engage in authentic inquiry with attention to the subtle details behind complex concepts</td>
<td>b) Develop deep understandings of big ideas in physics</td>
<td>b) Learn new ideas in physics</td>
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<td></td>
<td>c) Explore ideas that felt useful to her</td>
<td>c) Engage in authentic inquiry to build and fix devices and create working technologies.</td>
<td>c) Use physics to explore everyday materials</td>
<td>c) Use physics to explore everyday materials</td>
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<td>2. Finding Opportunities to Express Voice</td>
<td>a) Share informed opinions on controversial topics in physics and create opportunities for her peers to do the same</td>
<td>a) Establish himself as an academic leader with epistemic authority</td>
<td>a) Convey her epistemic authority and help other students understand complex ideas</td>
<td>a) Find the help she needed to get high grades</td>
<td>a) Share his epistemic authority regarding computers and robots and help and educate his peers and community</td>
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<td></td>
<td>b) Convey how much he valued students having space in which to be creative, express their identity and feel successful.</td>
<td>b) Test out and discuss her scientific ideas</td>
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<tr>
<td>3. Participation in Relationships in and beyond School</td>
<td>a) Select partners who were not necessarily her best friends but whom she believed might help her succeed on shared projects b) Build relationships with people who challenged themselves c) Be a role model and confidante for younger students.</td>
<td>a) Have his teachers to challenge him</td>
<td>a) Collaborate in physics, as a way to get work done quickly but also to test out developing ideas.</td>
<td>a) Work with students who could help her succeed academically.</td>
<td>a) Cultivate friendships and a community and be respected by his peers</td>
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<td>b) Receive support for his personal challenges and receive mentoring from his teachers and school c) Position himself as a role model and friend for younger students and youth facing personal and academic challenges d) Separate himself from his peers on the street</td>
<td>b) Focused physics collaboration on pursuing academic achievement.</td>
<td>b) Defy classroom rules and put-down other students but resolve these issues when she was calmer c) Use her social standing to improve the focus of students in class, so students could learn more. d) Impress her family with her academic/professional success.</td>
<td>b) Develop relationships with adults, including his father and mentors within and outside school</td>
</tr>
<tr>
<td>Critical Goals</td>
<td>Darlene wanted to...</td>
<td>Grant wanted to...</td>
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| 4. Being an Activist by Increasing One's Participation in the World | N/A | a) Create devices that reduced pollution  
b) Design a high-rise building that would meet diverse needs of people in his community.  
c) Connect physics content to social implications | a) Help people with poor access to health care by being a doctor and use physics knowledge to advance towards this goal. | N/A | a) Have robots replace some of the life-threatening tasks completed by solders in the war in Iraq |
Cross-Cutting Themes

Based on my data and its correspondence to existing literature, I have altered the initial and more general model I had for exploring identity (Figure 3) to include the four critical goals of case study youth in my paper to my model of critical physics agency.

**Agency**

<table>
<thead>
<tr>
<th>Transforming Identity as Expressed by Case Study Youth Moving towards Four Critical Goals</th>
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<tr>
<td>• Learning goals</td>
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<tr>
<td>• Engaging in opportunities to express authority and voice</td>
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<tr>
<td>• Altering participation in relationships</td>
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<tr>
<td>• Participating in the world through activism</td>
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</tbody>
</table>

*Figure 8: Model for Agency Based on Data Regarding Critical Goals*

Across the four critical goals that case study youth articulated, two themes emerge: 1) Critical goals connected to students building a “physics presence” and 2) Critical goals were shaped by and helped to shape the students’ figured worlds. In this section, I discuss similarities and differences in how case study youth expressed these themes, based on their varied identities and life contexts.

*How Critical Goals Connected to Youth Building a “Physics Presence”*

The critical goals articulated by youth reflected their desire to cultivate an enhanced “physics presence,” to stand-out as special in and through physics. This quest
for presence manifested itself differently across youth based on their “funds of knowledge.”

Darlene, similar to several other students in the study, wanted to successfully meet academic expectations and, thereby, do well in school. But she also wanted to engage in independent inquiry, so that she could stand out from her peers as “original.” For example, Darlene chose a science fair project that was different from what she felt her peers were pursuing. She took satisfaction in her success at finding the answers to her science fair questions through her own experiments and expressed a deep sense of pride when the science fair judge who worked with her similarly considered her work to be original. Darlene also chose the most difficult project for the science symposium, research on black holes, and then extended her knowledge of this topic through her independent investigations for the debate she designed. So, Darlene’s story suggests that she hoped to use independent inquiry to cultivate distinctive originality in her physics presence.

Grant wanted to establish himself as a self-motivated, trend-setting student. For this reason, he chose to develop the brown-bag lunch. In two ways, Grant’s choice of pursuing the brown bag lunch communicates his identity as an innovative self-starter. First, it was his idea to make the brown-bag lunch a forum for students to express their expertise; second, Grant creatively proposed that he might receive credit for this work. Grant expressed his self-motivation by taking the initiative to conduct research at home from a textbook that we did not use in physics class. He spent time outside of class with his math teacher and me to receive feedback on his essay and presentation. Similarly, he worked with me beyond the hours regular class to develop skills in soldering. Grant’s
actions and statements show that he extended what happened in his physics classroom to create a presence for himself of being an academic leader, someone who set an example for other students by creating new spaces in which to develop and communicate science knowledge.

Linda wanted to distinguish herself as a student who understood complex ideas at a level that she could teach these ideas to other students. For the science fair, Linda explained that she enjoyed collaborating in a group because she could discuss the data she and her partner were collecting and rely on both their intellectual capacities to establish conclusions. Instead of just completing the minimal requirements for assignments, as did many other students, Linda wanted to discuss and test her ideas with others, until she was satisfied with her opinion. At times, as in the case of the debates, she changed her opinions based on her dialogue with other students. Linda's story implies that she sought out a physics presence that conveyed well-considered, informed opinions and deep understanding.

Kanisha wanted to set herself apart as an academically-successful student and communicate her "populist" philosophy of science. For the first goal, Kanisha was willing to revise her work time and again till she achieved the quality she desired. She was also comfortable resolving her feelings of frustration and anger when she did not receive the help she desired or received a low score on an assignment, so that she could complete her assignments with the greatest success. Finally, Kanisha selected partners for her physics projects that, in her opinion, allowed her to attain the highest levels of success possible on projects. Second, Kanisha defined herself in class, through her choice of topics for the science fair project and the lesson she had the opportunity to design, as
someone who wanted to convey the idea that science was about everyday people exploring everyday materials. Kanisha, in these ways, cultivated a physics presence connected to academic success and promoting a particular philosophy about the nature of science.

Nicholas wanted to create a "physics presence" in which he was an expert builder and creator of working technologies. To this end, he sought out new physics ideas that would help him construct a robot, such as knowledge of circuits, programming and mechanical engineering. By the second semester of his sophomore year, Nicholas had succeeded in his quest for this sort of physics presence to such a degree that he was a co-planner of curriculum for the medicine-engineering academy, a mentor to students in class who were struggling with their robots, and a technician for students who wanted their help at home fixing their computers.

Summary: Though the youth in this study conceived of different ways in which they hoped to stand-out from their peers, they all wanted to establish themselves as exceptional. Once again, the data from this study suggests that, despite being low-income, urban youth, students were committed to excellence and distinction. The youth had varied ideas of how they might use physics in pursuit of their critical goals ranging from Linda who used a deep exploration of material in class to Grant, who created opportunities outside of class to establish epistemic authority.
**How Critical Goals Were Shaped By and Shaped Students’ Figured Worlds**

Students’ critical goals were shaped by their *figured worlds* (Holland, 1998) -- the context in which they had experience and their *funds of knowledge* (Gonzalez & Moll, 2002). For example, Darlene described herself as always having to be independent, because of her separation from her mother; this theme of independence appears multiple times in her academic life. Grant’s goals of being an academic and social leader were influenced by his experience of having missed school because he was accused of a crime. Nicholas was familiar with his cousin’s challenges as a soldier in the war in Iraq; preventing soldiers from being injured in the war was a important way in which Nicholas hoped to transform the world through robotics. Kanisha and Linda both wanted to achieve academic and professional success, in part, to impress their families, whom both felt had supported and inspired them.

Youth also thought of their critical goals as ways to shape their figured worlds, by designing curriculum and structures for their physics classroom, by altering their participation in relationships in and beyond school and by changing the larger world through activism.

By designing lesson plans for physics -- by shaping the *figured world* of their classroom -- youth could communicate their educational values. Grant created a lesson for which he emphasized creativity as a standard for judgment. He also designed the lesson such that his peers already had experience with the project and could, therefore, find easy success with the assignment. Nicholas created a lesson that involved authentic assessment, a robotics competition, as an opportunity for putting the knowledge students
learned about robotics and computers into practice. Kanisha envisioned lessons, which helped students understand that physics involved investigations of everyday materials and could help students gain experience with different careers. Kanisha also used her voice (sometimes by expressing anger but at other times by asking questions and meeting with me outside of class) to pursue her commitment to academic success.

Case study youth wanted to alter and shape their participation in relationships in and beyond school. The nature of each student’s relationship varied across the different identities of the youth. For example, Darlene valued challenge and, therefore, desired opportunities to meet and work with people who shared this sentiment. Grant sought out relationships with adults that provided him with one-on-one mentoring and support with his personal challenges. Nicholas, similar to Grant, sought out adult mentoring within and beyond school, in part to build positive relationships, which he felt he lacked in his life. Kanisha, in her relationships with teachers, often defied classroom rules and expressed anger and frustrations, but resolved these conflicts because she did not want to hurt her peers and to make sure she received the highest grades possible.

With regard to being activists, Nicholas, Grant and Linda had aspirations connected to their experiences in physics that would shaped the larger figured world in which they lived. Nicholas wanted to develop robots to reduce soldier casualties in the war in Iraq. Grant, amongst other social goals wanted to create pollution reducing devices. Linda wanted to help people gain better access to medical care, which she felt required that she be trained in particular types of physics. But what youth had to report on this topic was limited. Their goals were much more focused on learning, voice and relationships than transformation of the larger world.
Chapter 6

Mechanisms through Which Students Pursued Their Critical Goals

In this chapter, I discuss the mechanisms students used to progress towards their critical goals. Specifically, these mechanisms include: a) Pursuing physics-related careers, b) Engaging in and creating opportunities to learn about the universe and materials in it and c) Taking on the role of a scientist. For each mechanism, I have identified physics resources that youth drew upon to progress towards their critical goals. Within each section, I have tried to contrast instances when students used physics as a context versus when they used physics a tool for expressing agency. I conclude my discussion of each mechanism with a table summarizing the main themes that emerge for each student from the analysis.

In the second section of the chapter, I discuss subtle differences in how case study youth expressed the three mechanisms for pursuing their critical goals and the varied resources that youth used in pursuing agency. A theme that emerges is that in their efforts to pursue their critical goals, students utilized resources outside traditional physics content and skills that supported them in using physics to make change. From this discussion, I expand the models for agency that I originally developed through the literature review and conceptual framework. I also explore what the data suggest about
The Process of Agency: Mechanisms Students Used to Pursue Their Critical Goals

Mechanism 1: Students, by pursuing physics-related careers, sought to transform their identities

In the sections below, when I refer to students pursuing a “physics-related career,” I mean that youth either discussed interest in a career that required coursework in physics at either the high-school or college level (medicine, engineering, robotics) or a profession for which youth could articulate the need for physics content and skills (architecture and construction).

Grant, Nicholas and Linda could specifically articulate connections between a physics-related career and their critical goals content knowledge and skills. Nicholas and Grant spoke in most detail about pursuing physics-related careers (robotics and mechanical engineering, respectively). Linda described how learning physics might be useful in preparing her for a career in medicine. So, I have chosen to focus on these three students in my discussion of this mechanism.

Exploring the physics-related careers they had identified helped Nicholas and Grant pursue their critical goals and transform their identities into builders and creators of technology. Also, through pursuit of physics-related careers, Nicholas and Grant were able to alter their social identities at school. All three, through a physics-related career or
a profession that required knowledge of physics were able to enhance their skills as activists in the world. In the section below, I discuss the connections between pursuing physics-related careers and students’ critical goals, the different resources Grant, Linda and Nicholas drew upon, and how they used physics differently in this process.

*How Grant, Linda and Nicholas used their pursuit of physics-related careers to advance their critical goals.*

Both Nicholas and Grant reported learning goals related to building and creating working technologies. Pursuing careers related to physics allowed both the boys to advance towards these learning goals. For example, research for his brown-bag lunch allowed Grant to learn about the different skills and training required for designing and creating mechanical structures. The field trip to Polytechnic helped Grant realize that developing working devices and technologies required not just hard work but also creativity. The field trip also introduced Grant to the challenges he might face as a builder and the skills he would need to develop working technologies. Grant participated the brown-bag lunch and the field trip because of his interest in a career in mechanical engineering. Through this exploration, he was able to pursue his critical goal of becoming a more knowledgeable, thoughtful builder.

Revising his robot time and again taught Nicholas to build a strong, self-contained robot. Learning programming required Nicholas to read from manuals, test out sample programs, spend hours trouble-shooting with his Polytechnic mentors and with me. The growth in Nicholas’ understanding of computers and programming was evident when, without looking at his notes even once, he confidently taught the participants in his portfolio session how to program motors to move a robot backwards, forwards and in
circles, for varying amounts of time. Nicholas’ pursuit of a career in robotics helped him develop from a novice interested in robotics to a competent programmer and builder.

Nicholas and Grant both relied on pursuit of physics-related careers to find opportunities for expressing their voice – they developed expertise in particular physics-career related topics, which they then shared in ways that altered their positional authority.

To communicate his research on mechanical engineering, Grant could have written a research report based on information from the text on mechanical engineering that he borrowed from me. Instead, he consciously chose an original forum for sharing his mechanical engineering expertise -- he established himself as the first student at the School for Social Change to conduct a brown-bag lunch. Grant was conscious of the impact of his choices on how his community perceived him -- he viewed the talk as “a great way to present my project to my teachers as well as my peers” and a presentation that “will look good on me.” He believed that this presentation would set him apart as a student who was willing to engage in extra academic work and be a positive trend-setter in his community.

Through his pursuit of a career in robotics, Nicholas was able to share his knowledge and have this opinion be influential to others. Opportunities for voice, developed through Nicholas’ exploration of a career in robotics, allowed him to transform himself from a social outcast to a respected practitioner of physics. Through the application of his epistemic authority, Nicholas was able to become the resident computer expert at school. Based on his reputation, students even asked him to set up computers for them at their homes.
Nicholas and Grant were also able to use their exploration of physics-related careers as a resource for altering their participation in relationships. Through his engagement in robotics, Nicholas was able to create a positive community for himself. Pursuit of his career in mechanical engineering often required Grant to build one-on-one relationships with his teachers, which in turn, helped him advance towards his goal of receiving mentoring from adults and separating himself from the influence of his peers on the street.

To pursue a career in mechanical engineering, Grant often took the initiative to cultivate personal relationships with adults. For example, of his own initiative, he asked for feedback on his brown-bag lunch presentation from both his math teacher and from me. In the process of learning more about mechanical engineering, he created an opportunity to engage dialogue with two of his classroom teachers, outside the context of the work expected of him because of class. Grant spent time with me trying to learn how to solder, -- again, he built a relationship with a teacher around cultivating a mechanical engineering skill. During his visit to Polytechnic, Grant started a quiet conversation with one of the students in the chemical engineering lab while the other students were listening to the chief scientist in the lab speak. His goal was to learn more about the mechanical devices in the lab worked. During his visit to Polytechnic, Grant discussed with his tour guide, a college student older than him, the possibility of internships at the university. He continued this dialogue about internships with me into his sophomore year. Though each of these interactions was driven by Grant’s interest in mechanical engineering, these contexts also allowed Grant to learn from an adult, beyond the content knowledge expected of him in a classroom, and, in some cases, to receive ongoing mentoring.
Grant also felt that pursuing an internship in mechanical engineering at Polytechnic University would allow him to distance himself from peers in his community who engaged in practices such as theft. An internship at Polytechnic, according to Grant, would require him to take directly there from school. He would not have the opportunity or time to connect with peers who might tempt him to engage in criminal activities. Once again, pursuit of a career in mechanical engineering was a way in which Grant envisioned making changes in the relationships in his life.

For Nicholas, physics was originally a figured world for him to experience negative social interactions with peers. But physics was also a context in which Nicholas was able to pursue a career in robotics, which corresponded with a decrease in eccentric behavior and gained him the respect and admiration of his peers. This, in turn, helped him find success in meeting his critical goals for participation in relationships: cultivating friendships and a community, developing relationships with adults, including his father and mentors within and outside school, and being respected by his peers.

Engaging in robotics reduced Nicholas' eccentric behavior – for example, when he presented on robotics for his end-of-year portfolio, he abandoned his twitches, unfocused gaze and rude comments, hallmarks of his behavior in class. Written comments about Nicholas' conduct during the portfolio presentation highlighted his poise and articulate communication of ideas, a sharp contrast to what I observed teachers and students saying about Nicholas in class, for example, that he was "disruptive," and "a trouble-maker." Nicholas said that students sometimes told him that he was similar to a drug addict "taking crack." Nicholas' presentation of his robots at the school science fair also resulted in a larger group of students respecting him. He said that students "came
over to his group and wanted to see a bunch of things," a distinct difference from what often happened in class, where students went to Nicholas to bother and make fun of him or vice versa. When Nicholas and his team won the top award for the science fair, according to Nicholas, many students expressed their surprise that he could win an award. The experience of the robotics competition changed how students perceived Nicholas.

Participating in robotics also provided Nicholas with a peer community. He said about robotics, "Yes, we were respected because we’re a team. We worked hard, even if we didn’t get so far in the tournament. I enjoyed working with my team, we had some confusion, we got into a fight. Sometime, the day of the competition, Stephen was playing around, talking to people, he wasn’t helping me out. We started arguing. But the next minute, I said, ‘Stephen, come help me, come help me.’ He came over, I wasn’t that mad. We’re always friends.” This small group provided Nicholas with camaraderie and opportunities for friendship. Nicholas also found new friends through the robotics competition where he said that the students from other schools at the competition viewed him as a robot-builder rather than a disruptive student.

Nicholas’ participation in robotics seems to have cemented his relationship with me as a mentor. He often asked to work in my office - my office provided him with a quiet, focused space at school where he could pursue his interests without interacting socially with other students. When he got into trouble with a teacher or the principal, he sometimes requested to spend his suspension in my office, quietly working on his robot, helping manage the school laptop cart, installing computer software or connecting computer hardware for the school. As a result, of our positive relationship and Nicholas’
frequently disruptive behavior in other teachers’ classes, I spent a fair amount of time in
his freshman year advocating for him, temporarily removing him from class, speaking
with him about his decisions, and trying to find opportunities that would help him prepare
for a career in robotics, such as internships and regular access to a computer. My
relationship with Nicholas as a mentor continued through the summer as Nicholas called
me and e-mailed me for advice on how to design and program his robot and set up the
donated computer he had received. The following year, because of our positive
relationship, Nicholas was moved into my advisory. Through his pursuit of robotics,
Nicholas developed a relationship with me as a mentor, who supported him outside of his
physics class and across academic years.

Nicholas’ experience in robotics helped him find mentors outside his school. When he met Lamar and KeFong, graduate students at Polytechnic, who were helping
high-school students learn the basics of programming, he tried to go to Polytechnic
University every day before the robotics competition to get their help with programming
and mechanical design. After the competition, he tried to stay in touch with Lamar and
work with him at the beginning of the following school year to get a jump-start on the
2005-06 competition.

Finally, Nicholas’ engagement in robotics created an opportunity for his father to
actively participate in his son’s success. Nicholas’ father attended the robotics
competition and expressed his pride in his son’s success and hard work.

Both Nicholas and Grant could connect the physics-related careers they
envisioned with how they imagined themselves participating as activists in the larger
world. Nicholas saw a direct link between robotics and reducing American casualties in
the war in Iraq. Grant felt that a career in mechanical engineering would allow him to create energy-saving devices and high-tech buildings. Linda viewed physics as a discipline that would help her pursue her critical goal of helping under-served individuals by becoming a doctor.

The research that Grant conducted on mechanical engineering, his mechanical engineering-focused science fair project on solar panels, and his exploration of mechanical engineering through the field trip at Polytechnic University allowed him to acquire some of the content and skills he needed for his goals as an activist. Specifically, Grant hoped to bring about change in the larger world by developing technologies for devices consuming less energy. He wanted to use solar energy to replace oil so cars would produce less pollution. Also, Grant also wanted to design and build a high-rise building in which people could efficiently take care of various forms of business such as paying bills and receiving money. A deeper of understanding of mechanical engineering helped Grant learn about design, electricity and building, all of which connected to his goals for participation in the world.

Linda wanted to become a doctor, so that she could provide health care to people who had limited access to medicine. Linda felt that learning physics would prepare her for a career in medicine because it would train her to “understand the world.” Specifically, she felt that the Gummy Bear experiment taught her about digestion in the human body. She also envisioned inter-disciplinary lessons that would teach her about technologies that doctors might use, such as MRIs and X-Rays, as the best way for physics to prepare her for a career in medicine, which, in turn, would advance her towards her critical goals for participation in the world.
Nicholas knew wanted to improve the chances of American soldiers surviving war. In an evaluation of the energy unit in physics, he explained that he had developed the belief, over the course of the unit, that studying science would help him take on a role in the military besides that of fighting. Specifically, he wanted to study robotics so that he could design technology to prevent soldiers, like his cousin, from dying in war. He said that he wanted his robots to be able to seek out terrorists and bombs, instead of soldiers having to do this life-threatening work. He even went so far as to create a design for this type of robot and show it to Lamar, his mentor at Polytechnic. He felt that his work was original and necessary – he wrote on his science fair poster: “If any one in the world knows the answers to my questions, it is the people I am working with.”

Resources that Grant, Linda and Nicholas drew upon in linking physics-related careers with critical goals.

In addition to relying on content knowledge and problem-solving skills from the units on energy, forces and electricity, Grant, Linda and Nicholas relied on several physics and school resources as they pursued critical goals through exploration of physics-related careers. Specifically, they drew upon choice, positional authority to alter structures established by teachers and access to special resources, mediated by their relationships with teachers as mentors.

The cases of Nicholas and Grant suggest that choice was a key feature for them in cultivating agency. For Grant, relying on what he learned from his advisory unit to make a thoughtful choice about his college field trip was influential in the development of his interest in mechanical engineering. Nicholas and Grant benefited from the choice
afforded to them by the structure of the science fair and were able to use this choice as a foundation for exploring his critical goals.

The field trip was not a resource that Grant encountered through physics class; instead, he drew upon a school resource, an advisory unit on exploring colleges. The advisory unit required students to match the academic work they most enjoyed and how they envisioned their careers to particular college majors. Then students researched different colleges to find out which locations offered programs that fit their interests, financial constraints and desire to finish in two- or four-years. 9th grade teachers then offered students a choice of college visits for which to sign-up. By combining their exploration of their college interests with a description of the field trip sites, student chose colleges they wanted to visit on the day of the field trip. Through this unit, Grant was able to thoughtfully choose a field trip setting that best matched his interests.

Students had a great deal of latitude in choosing a topic for their science fair projects. Without wide latitude in his choice of experiments, Nicholas would not been able to pursue his robotics project in class. If my co-teacher and I had limited the choice of topics, we certainly would not have chosen robotics as one option, given the cost and complexity of the material. Choice in the science fair topic permitted Grant to engage in a project related to mechanical engineering. Because of the opportunity to engage in a science fair project related to his career, Grant was able to develop his skills at soldering and explore how solar panels worked.

Positional authority was a resource that students drew upon in cultivating agency. The opportunity at our school for students to alter the structure of teacher-designed events was important for Grant’s engagement in expressing voice. Specifically, he was
able to transform what teachers originally envisioned as lunch-time seminars for adults from outside the community to convey their expertise into a forum through which students could also share their knowledge.

Linda did refer to an activity in class, which was relevant to her pursuit of medicine and, in general, felt that physics was important because it helped her better understand the world. However, she responded with enthusiasm to having the positional authority to shape what she learned – she wanted the option of changing the curriculum of her physics class to include a discussion of technology that doctors used. In general, Linda wanted students to increase the choice students had in their classes, so they could tailor what they learned with their interests.

Nicholas’ positional authority in negotiating the parameters for what constituted a successful final project also contributed to his agency. For example, the iterative process that Nicholas used for building and programming did not match the more straightforward outline of the scientific method that students were to use for the science fair. However, he and I agreed that as long as he documented a few instances of using the scientific method, he did not have to document his scientific inquiry process for each program he wrote. I decided to assess him, partially on his discussion of the scientific method but partially based on his final working product, considering this evidence for having engaged in the scientific method multiple times. Nicholas’ position in the class as an individual who could change the requirements for success on an assignment – his positional authority in the classroom – was crucial to his pursuit of robotics and cultivating his critical goals.

By relying on my mentoring relationship with him, Nicholas gained access to several school and classroom resources that supported him in his pursuit of voice. The
school lacked a technology coordinator but many technology tasks required attention if students were to have computer access. Nicholas was able to fill this gap between needs and resources, he gained access to the computer hardware and software at school, as a result of my beliefs and the school philosophy that students should be activists in their community and co-developers of their school.

Nicholas and Grant, through their close mentoring relationship with me, gained access to science programs and competitions, beyond what happened in the classroom, a key resource that they used to pursue their critical goals. The depth of knowledge required by the Botball competition allowed Nicholas to develop an expertise, which he was able to bring back to his community, as evidence of how he could be motivated and intellectual, rather than just disruptive. Exposure to internships related to pursuing a career in mechanical engineering allowed Grant to at least envision a way to separate himself from peers whom he considered to be negative influences.

In crafting his opportunity to express voice through the brown-bag lunch, Grant was able to take home materials from the physics “library.” He also had access to outside of class time with his math teacher and me, so that we could read and respond to drafts of his projects. His personal relationships with his teachers and their willingness to support him in an independent project as well as their flexibility in adding this type of work to his grade were sources of support for him in developing voice and pursuing his critical goals.

The role of physics as context or tool in linking physics-related careers with critical goals.

Over the course of this study, physics changed from a context to a tool by which Nicholas could pursue his critical goals. At first, Nicholas seemed unaware that pursuing
robotics would help him move towards his critical goals for participation in relationships. In his interviews, he did not any time suggest that the reason he was pursuing robotics was to improve his relationships. But by the end of the interview process, Nicholas was at least conscious of the effects that his hard work had on people’s perceptions of him. For example, he said, “I do get respect sometimes when I do my work. They pass me, they ask for help. In this science fair, people respected me.” By the end of the science fair, Nicholas was conscious of the effect of his epistemic authority in robotics on his social connections. As a result, he was able to view physics as a tool for improving his participation in relationships. In contrast to his altered view of how physics related to his goals for participation in relationships, throughout the study, Nicholas viewed pursuing robotics as a tool for achieving his goal for participation in the world, specifically reducing casualties from the war in Iraq.

Grant used the exploration of a physics-related career as a tool for pursuing his critical goals – he consciously chose to present what he had learned in his research to establish himself as an academic leader in his community. What is interesting about Linda is that, unlike Grant, who wanted to use his knowledge of physics directly to make changes, Linda saw physics as an important stepping stone in the science education she needed for becoming a doctor. To her, becoming a doctor mattered and physics was a tool in helping her move towards her goal.

Observations and interviews of the two boys suggest that the connections they felt towards physics-related careers were far more detailed and concrete than those expressed by the three girls. The girls were stronger students than the boys, as reflected by their grades, and less likely to get in trouble at school, as reflected by the number of times
students were asked to leave class or were suspended. A possibility of gender differences in envisioning physics-related careers and issues that might be associated with this difference are questions that should be explored by future studies.
Table 3: Youth Progressed towards their Critical Goals by Pursuing-Physics-related Careers

<table>
<thead>
<tr>
<th>Key Resources</th>
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</thead>
<tbody>
<tr>
<td><strong>Grant:</strong></td>
</tr>
<tr>
<td>• Choice in his college field trip, organized through advisory</td>
</tr>
<tr>
<td>• Choice in the science fair topic</td>
</tr>
<tr>
<td>• Positional authority to change the structure of student-designed events</td>
</tr>
<tr>
<td><strong>Linda:</strong></td>
</tr>
<tr>
<td>• Positional authority to alter what topics were covered in her physics class and to increase the choice in courses available to her and her peers</td>
</tr>
<tr>
<td><strong>Nicholas:</strong></td>
</tr>
<tr>
<td>• Choice in the science fair topic</td>
</tr>
<tr>
<td>• Positional authority to negotiate how the requirements for the science fair project</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physics as Context v. Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grant</strong></td>
</tr>
<tr>
<td>Grant used the exploration of a physics-related career as a tool for pursuing his critical goals – he consciously chose to present what he had learned in his research to establish himself as an academic leader in his community.</td>
</tr>
<tr>
<td><strong>Linda</strong></td>
</tr>
<tr>
<td>Linda relied on physics as a tool for providing her with content that she felt was relevant to a career in medicine.</td>
</tr>
<tr>
<td><strong>Nicholas</strong></td>
</tr>
<tr>
<td>With respect to participation in relationships, physics changed from a context to a tool for agency. Throughout the study, Nicholas viewed physics as a tool for achieving his goals for participation in the world as an activist.</td>
</tr>
</tbody>
</table>
Mechanism 2: Students, by engaging in and creating opportunities to learn about the universe and materials in it, sought to transform their identities

As described in the methodology section, the conceptual physics class, which the case study youth took, attempted to provide them with an overview of different physical laws, particularly in the areas of motion, electricity and energy. Also, the class introduced them to how materials interact and taught them how to record and analyze data. Case study youth expressed high levels of engagement in particular learning opportunities and sometimes created opportunities for further study, on their own initiative. These experiences of high engagement around physics content and skills often allowed youth to make progress towards their critical goals.

Different case study youth engaged in different units and lessons to achieve their learning goals. For example, Nicholas, Darlene and Linda expressed their fascination with new aspects of the electricity topics, while Darlene and Kanisha discussed their experiences with the combustion and expansion of the gummy bear. I have chosen to focus on Linda, Darlene and Kanisha, in this discussion because a great deal of how Nicholas and Grant pursued their critical goals was mediated by their exploration of physics-related careers.

How engaging in and creating opportunities for understanding the universe helped Darlene, Linda and Kanisha pursue their critical goals.

Engaging in and creating opportunities to learn physics content and skills allowed Darlene, Linda and Kanisha to pursue their learning goals. For example, through physics
activities such as the LED demonstration, Darlene was able to learn new ideas about energy. The option in physics to choose between more and less difficult projects allowed Darlene to feel challenged. By having voice in the topic of her science fair project, Darlene was also able to pursue her critical goal of being original. Linda was able to use physics activities such as the series and parallel circuit lab to better understand how the world worked, specifically with regard to electricity. Kanisha, through activities such as the Gummy Bear and the choice available to her in the topic of her science fair project, was able to progress in her learning goal of exploring everyday materials. Because Kanisha had the option of revising her work and completing missing work, even if she expressed anger and frustration around these issues at first, she was able to achieve the grades and high-quality work she valued.

Engaging in and creating opportunities to learn physics content and skills also resulted in spaces in which the three girls were able to advance towards their critical goals for voice. Debates in physics and the science fair allowed Linda to advance towards her critical goal of testing out her ideas through discussion. Having the opportunity for presentations allowed Linda to pursue her critical goal of conveying her understanding to other students, adding to her positional authority.

The type of engagement Darlene exhibited in physics, working hard and taking on additional responsibilities when students around her were irresponsible about completing their work for assignments resulted in her altering her participation in relationships, in the way she desired. Through her hard work, Darlene established herself as a student who was diligent and focused. For example, Charles said that he only talked to “people like Darlene or Julene who do their work, they’re on top, they won’t sit around fooling
around, they get good grades.” Based on this judgement of Darlene’s personality, motivated, academically-successful youth such as Charles decided to associated with Darlene, which, in turn, allowed her to meet her critical goal of creating relationships with students who challenged themselves in school.

Resources that Darlene, Linda and Kanisha drew upon in linking opportunities to learn about the universe with critical goals.

Darlene, Linda and Kanisha, while engaging in and creating opportunities for learning physics content and skills, relied on several physics and school resources to pursue their goals for learning and relationships. Specifically, they drew upon various types of choice, lab activities and demonstrations that taught them new ideas, and assignments that permitted debate and discussion.

Darlene relied on the choice available to her in physics to express her agency. For example, she wanted to select a difficult project for the science symposium and an original topic for the science fair to expand her knowledge. Engaging in these sorts of difficult projects also allowed Darlene to establish herself as a student who hard-working students, which affected her options for friendships with peers in ways that she desired. Darlene also wanted to have the option of completing the work assigned to other people in her group, to ensure that she could receive a high grade on and complete understanding of a project. The choice available to Kanisha in the science fair allowed her to shape this experience into one that supported her critical goals of exploring everyday materials. Finally, Kanisha relied on flexibility in deadlines for missing assignments, so she could achieve the academic success she desired.
When Linda described assignments that engaged her interest and also connected to her critical goals, she referred to labs such as the series and parallel circuits activity that exposed her to new ideas. Darlene discussed the demonstration with the solar panel, radio and LED that made her think differently about energy. Kanisha, similar to other students, was able to pursue her critical goals through exposure to demonstrations on topics that were new to her or that used materials in a way she had not previously envisioned, for example, both demonstrations with the Gummy Bears.

Linda, to express an opinion, relied on the opportunities to present and debate in class. For example, in the energy unit, Linda used my request for volunteers to present their models of fusion and fission as an opportunity to convey her understanding of complex ideas to other students. The dark matter/dark energy unit allowed Linda to pursue this critical goal of testing out her ideas. She wrote, in her evaluation of this unit that listening to other people's ideas made her evaluate and change her opinion about whether dark matter affected the universe. Also, in her evaluation of the energy unit, she said that working with other people helped her understand things she did not know.

*The role of physics as context or tool in linking opportunities to learn about the universe with critical goals.*

Darlene and Kanisha made conscious choices about using physics to advance towards their learning goals. For example, Darlene actively sought out the difficult and original projects. Kanisha constructed her science fair project related to exploration of everyday materials.

In contrast, Linda relied on the resources provided to her in physics for presenting and discussing ideas, and Kanisha turned to the flexibility in deadlines for submitting
assignments to raise her grades. Neither actively created these opportunities herself – physics was a context through which Linda and Kanisha pursued these critical goals. Similarly, physics was a context through which Darlene’s hard-work and academic success resulted in her building relationships with other motivated students.
Table 4: Youth Progressed towards their Critical Goals by Engaging in and Creating Opportunities to Learn about the Universe and Materials within It

<table>
<thead>
<tr>
<th>Key Resources</th>
<th>Darlene:</th>
<th>Linda:</th>
<th>Kanisha:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Choice between projects of varied difficulty and to tackle work that other people in her group did not complete.</td>
<td>• Lab activities on electricity that taught Linda new information.</td>
<td>• Choice in science fair topic.</td>
</tr>
<tr>
<td></td>
<td>• A demonstration on energy conversion that taught Darlene a new physics idea.</td>
<td>• Opportunities for debate.</td>
<td>• Flexibility in deadlines for missing work.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Opportunities to work in groups such that Linda could test out her ideas amongst her peers.</td>
<td>• Demonstrations and assignments on Gummy Bear combustion and water absorption that taught Kanisha new ideas about materials.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physics as Context v. Tool</th>
<th>Darlene:</th>
<th>Linda:</th>
<th>Kanisha:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Darlene used physics as a tool for achieving her learning goals, while relying on physics as context for building the social relationships she desired.</td>
<td>Linda relied on physics as context for expressing her voice.</td>
<td>Kanisha used physics as a tool for pursuing her learning goals, while relying on the flexibility in assignment as a context for improving her grades.</td>
<td></td>
</tr>
</tbody>
</table>
Mechanism 3: Students, by taking on the role of a scientist, sought to transform their identities

Through the science fair, youth had the opportunity to “take on the role of a scientist.” Specifically, they asked their own questions, generated their own hypotheses, designed their own experiments and collected and analyzed their own data. Case study youth, through the process of “being scientists,” were able to pursue their learning goals, express their voice, and alter their participation in relationships and the larger world, thereby, transforming their intellectual, social and activist identities. Because Nicholas’ exploration of robotics and the science fair experiment overlap significantly, I have not discussed him in this section.

How taking on the role of scientist and helped students pursue their critical goals.

Taking on the role of being a scientist allowed case study youth to pursue their learning goals. All youth through the science fair were able to pursue their desire for authentic inquiry. Darlene was able to use the science fair to be original and seek out challenge and, therefore, pursue her critical goals. Through his solar panel project, Grant progressed towards his critical goals of learning more about how materials interact, building and fixing different devices, and at least thinking about how to create useful technologies, such as energy-storing machines. Through the science fair, Linda was able to learn more about physical principles that govern the world, such as gravity, and to develop a subtle understanding of the concepts underlying experiments. Kanisha was able to produce high-quality work and demonstrate a strong conceptual understanding of how temperature affected the everyday materials she studied.
With respect to voice, Kanisha was able to convey, through her science fair, that everyday people like her with limited training in science could engage in science with everyday materials.

By taking on the role of scientist, students were able to alter their participation in relationships in the ways that they desired. For example, Grant was able to support of youth struggling with academic and family issues and, in this way, be a social leader. Darlene and Kanisha tried to select partners whom they felt would help them succeed in their projects.

*Resources student drew upon in taking on the role of scientist with critical goals.*

Choice and inquiry were key features of what made the science fair engaging to students and flexible in encompassing their varied critical goals. All the case study youth were interested in pursuing their own investigations. Darlene, Kanisha and Grant relied on choice in selecting partners for the science fair in pursuing their critical goals. Darlene and Kanisha wanted to select their partners for ensuring academic success. Grant agreed to work two youth who were struggling with family trouble and with their academics, which allowed him to engage in social leadership.

Students such as Grant and Kanisha also relied on me to gain access to the materials they needed —through me, they respectively were able to use a microwave and soldering iron.
The role of physics as context or tool in “taking on the role of a scientist” with critical goals.

The science fair required students to choose questions to which they were not certain of the answers and collect and analyze their own data. These requirements provided a context through which the case study youth were able to learn new ideas and be independent thinkers engaged in their own inquiry projects.

However, Grant expanded the nature of the project by working outside of class to solder his solar panels and to complete multiple trials and data analysis for his project, to make-up for the several occasions he had been absent for, late to or walked out of class. He also pushed back at the constraints imposed upon him when he asked the police officers who were taking him to the local precinct, on the day of the science fair, to allow him to stay for his presentation. Grant’s actions suggest that he was not just a student trying to meet the expectations of the science fair. His active effort to work on the science fair, outside the classroom and despite constraints, suggest that the science fair was a tool that Grant used to pursue his critical goals. Similarly, Nicholas exerted the same type of energy outside of class and used the science fair as a tool to pursue his critical goals. Darlene and Kanisha used the choice they had in selecting partners in physics as a tool to advance their critical goals of academic success.
### Table 5: Youth Progressed towards their Critical Goals by Taking on the Role of a Scientist

<table>
<thead>
<tr>
<th>Key Resources: Across case study youth, choice and the option for inquiry allowed youth to pursue their critical goals.</th>
<th>Darlene:</th>
<th>Grant:</th>
<th>Linda:</th>
<th>Kanisha:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Access to resources such as the microwave</td>
<td>• Access to resources such as the soldering iron and out-of-class training in using this device</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

**Physics as Context v. Tool:** Across case study youth, the science fair was a context through which youth were able to pursue their learning goals, especially their desire for authentic inquiry.

| Darlene used the science fair as a tool by actively selecting partners for improving her chances of academic success. | Grant worked on the science fair outside of regular class time to pursue their critical goals; in this way, the science fair was a tool for learning. | N/A | Similar to Darlene, Kanisha actively used the choice she had in selecting partners for improving her chances of academic success. |

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Cross-Cutting Themes

The Relationship among Mechanisms, Critical Goals and Resources for Agency

Findings from the case study youth suggest three mechanisms that youth used to pursue their critical goals: 1) exploring physics-related careers, 2) seeking out exposure to physics content knowledge and skills, and 3) taking on the role of a scientist. Also, data from this research describes relationships among the identities of students and the resources they relied on to engage in particular mechanisms for agency.

Nicholas and Grant were students who relied deeply on the mechanism of a physics-related career to pursue their critical goals. They were students with concrete ideas, and in Nicholas’ case, an almost obsessive commitment, to the physics-related careers they wanted to pursue. They were both interested in creating working technologies, and both were occasionally disruptive students who greatly improved their focus when they could engage in hands-on science and receive individualized attention and mentoring from their teacher. Of concern and important for further investigation is the gender split between students who could concretely envision physics-related careers (boys) and students who did not (girls). Ironically, the three girls, despite not articulating a particular interest in a science career, did express a “scientific mindset.” For example, Linda wanted to understand how the world worked, Darlene wanted to be original and answer questions about the world through her own experiments’ Kanisha wanted to know how everyday materials might react and behave.
Key resources that students relied on in connecting a physics-related career to their pursuit of agency were:

- flexibility in choosing a science fair topic (Nicholas)
- the opportunity to observe the different projects (Darlene)
- positional authority to negotiate what a successful science fair project might look like (Nicholas)
- an advisory unit on college choice (Grant)
- a library of physics texts from which students could selectively choose (Grant)
- physics content on motion and forces (Grant)
- physics skills related to graphing, problem-solving and experiments (Kanisha)

Across the pursuit of a range of critical goals, all case study youth utilized the mechanism of engaging in and creating opportunities to learn about the universe and materials within it. Linda learned a vast range of material to express her opinion across units and to explain challenging material to other students. Grant particularly relied on information from a unit on energy to advance towards his critical goal of building energy efficient devices that reduced pollution. Kanisha engaged in experiments with everyday materials and challenged herself to produce high-quality work across physics units.

Key resources that students used for engagement in physics content and skills included:

- demonstrations or lab activities that exposed students to new ideas or used materials in ways students had not seen before (all)
- teacher availability outside of the classroom and access through the teacher to special scientific equipment (Grant)
• The unit on energy (Grant) and hands-on projects in electricity (Nicholas)
• choice in partners (Kanisha, Darlene) and choice in the difficulty of assignments (Darlene)

The science fair curriculum required all students to take on the role of a scientist. But students used this mechanism to pursue different critical goals in distinct ways. For example, Linda was, through her free fall project, able to be inventive and study how materials in the world interact while Nicholas used the science fair to build and create new technologies.

Key resources that students used in taking on the role of a scientist to achieve their critical goals include:
• the requirements of inquiry (all) and hands-on experimentation (all)
• flexibility and choice in the materials that could be used for the science fair (Kanisha), in the topics students could pursue (all), and in the partners one could select (all)
• the requirement of collaboration for the science fair (Linda)
• opportunities for creativity (Linda) and originality (Darlene) within the science fair

Choice and flexibility are key resources that emerge across mechanisms, which reflects the literature on agency – O’Neill and Pollman (2004) emphasize that student choice in the “formulation of questions and data analysis strategies… was correlated with a more empowered role in approaching novel scientific problems.” However, this study also suggest the importance of other forms of choice to student agency – having freedom in selecting partners, the difficulty of assignments to pursue, when one spends time on a
project, who decides the nature of a successful assignment (student or teacher), and when class and homework assignments can be submitted.

Case study youth used physics as both a context and tool for pursuing their critical goals. When youth, such as Grant and Nicholas, had a clear vision of pursuing a physics-related career, they used physics as tool to explore this interest. Linda and Kanisha largely relied on existing resources from class to pursue their critical goals; therefore, physics was a context rather than a tool for achieving their learning goals. Darlene, on the other hand, actively created opportunities for herself to learn physics content and, therefore, relied on physics as tool for her learning goals. Youth also used physics as a tool for altering their participation in relationships, by selecting partners who were more likely to contribute to their academic success. Nicholas changed his perception of physics from that of a context to that of a tool, making himself a more conscious actor in his pursuit of agency.

In the following diagram, I have represented the ideas of the three mechanisms for agency as graphics that break through constraints to agency such as structure and power relationships emerging from race and class (Brickhouse & Potter, 2001) and teacher beliefs (Howe & Stubbs, 2003). To symbolize the potential for these mechanisms to help students advance towards their critical goals, I have altered the box symbolizing constraints on agency to a dotted line. Within each mechanism, I have also represented key information about identity and important resources.
Mechanism 1: Physics-Related Careers
Associated Identity: Interested in creating working technologies, generally disruptive youth who improved their focus and motivation when they engaged in hands-on science and received individualized attention. Gender split merits further investigation
Key resources:
- flexibility in choosing a science fair topic and advisory college visit
- positional authority in choosing what a successful project looked like
- a library of physics texts from which students could selectively choose
- content on motion/forces and skills related to graphing, problem-solving and conducting experiments

Mechanism 2: Engaging in/Creating Opportunities to Learn Physics
Content/Skills
Associated Identity: All case study youth utilized this mechanism.
Key resources:
- demonstrations/lab activities that exposed students to new ideas or used materials in ways students had not seen before
- teacher availability outside of the classroom and access through the teacher to special scientific equipment
- choice in partners and in the difficulty of assignments

Mechanism 3: Taking on the Role of Scientist
Associated Identity: The science fair curriculum required all students to take on the role of a scientist. But students used this mechanism to pursue critical goals in distinct ways.
Key resources:
- the requirements of inquiry and hands-on experimentation
- flexibility and choice in the materials that could be used for the science fair in the topics students could pursue, and in the partners one could select

Figure 9: Revised Model for Agency Including Mechanisms for Progressing Towards Critical Goals
Chapter 7

Critical Physics Agency Expressed Through the Transformation of Physics Curriculum

Introduction

In this chapter, I focus on how critical physics agency is expressed by each case study youth in his/her effort to transform their physics curriculum through co-planning. As evidence for agency, I use examples in which students tried to make decisions about 1) the content and skills that were covered in physics class, 2) how this material was presented and 3) how students worked together.

Taking on the role of curriculum developer and co-planner in the classroom, as I asked students to do in their interviews, required that youth reflect on how they wanted to shape their physics classroom. As a result of students' active, creative role in the process of transforming class structures and curriculum, I consider all examples in this chapter to be instances of how youth use physics as a tool for agency. However, different students expressed different degrees of involvement in transforming curriculum by using physics as a tool for agency. A key finding of this chapter is that students decided to enact lesson plans and, therefore, engage in agency when they could leverage epistemic authority and expand both positional and epistemic authority that was tied to their beliefs, values, backgrounds and aspirations – their funds of knowledge.
In the final section of the chapter, I consider how findings from the case studies substantiate and expand existing literature on agency. Specifically, I discuss how youth are able to take on new forms of authority when they can recruit resources to make change in figured worlds, such as their physics classroom.

How Case Study Youth Envisioned and Enacted the Transformation of Physics Curriculum

Darlene

Darlene developed and enacted a lesson structured around the format of a debate. She wanted to provide students with the opportunity to express their opinions on a controversial, open-ended topic, by using the knowledge they had acquired in a relevant unit. Her choice of this format for the lecture was grounded in her interest in a career in law but also in her exposure during the nuclear energy unit to the idea that science topics might be controversial. For the design and enactment of her lesson, Darlene leveraged her the knowledge she had already acquired through the science symposium on black holes and expanded that knowledge. She also structured the lesson in a way that connected with her funds of knowledge, particularly beliefs she held about the legal career for which aspired.
Darlene’s envisioned curriculum.

Darlene proposed that she would design a lesson on black holes because she felt that her original experience with this topic during the science symposium had not provided her with the expertise she desired in this area. For the lesson, she decided to conduct research on black holes, and, in this process, she studied “fusion rate, how it connects to helium, the black dwarf and its gravitational pull.”

With her physics lesson, Darlene wanted to model the structure of a legal case: “The structure to be the opening statement, presenter’s side to the judge, topics or whatever. The third – they will go back and forth using a buzzer. If you don’t agree and you if don’t what the right thing is, you can buzz and then defense The closing statements, the jury will discuss their points and see who is most convincing and judge.”

To develop her lesson, Darlene relied on the debate format I had used for the nuclear energy unit. However she modified this structure by instituting a requirement for each student to write a paper on the topics of dark matter and dark energy. She felt that this would allow each student to have material from which to contribute to the debate, rather than the groups relying on one or two hard-working members for the evidence they needed to defend their position.

Darlene created rules of conduct for the debate that required students to not interrupt each other, takes notes, treat each other respectfully, and submit a written report along with their oral arguments. She also initiated a rubric for the debate, which evaluated whether the groups participated in the debate, how respectful they were to other teams, and the level of detail in their written report.
Decisions to enact the lesson plan.

Darlene expressed her interest in actually enacting the lesson she has designed. However, I wanted to move on from the topic of black holes because I did not feel certain that students who had not chosen this option during the science symposium would suddenly be interested in this topic. And I wondered if students who had chosen the topic would want to revisit it. I also wanted to expand the range of topics to which students were exposed. As a result, I worked with Darlene to use her debate structure to investigate the nature and influence on the universe expansion of dark matter and dark energy. I relied on Darlene’s rules in the final version of the instructions for the debate that students received. I simply added a form that would provide some structure in which students took notes. I also used elements of her rubric in the final version of the project but added concrete guidelines about what information I expected students to address within the topic of dark matter and dark energy. Darlene’s enacted lesson plan therefore involved the blending of topics in which she and I were interested and a format, which she has first encountered in my class.

I was not able to observe Darlene in her role as a judge for the debate. So I have relied on Darlene’s reflections on the lesson as a description of transpired. Darlene was the judge for the debate in her class; she chose not to play this role in the other sections of physics, including mine, because she did not feel that other students would listen to her. Despite what we considered to be detailed planning, both Darlene and I felt that the debate was unsuccessful (she called it a “disaster”). In both her and my section of class, many students did not participate in the actual debate. Within groups, there was confusion as to who was speaking and in what order. Some groups, even during the debate,
did not know if they on the pro or con side of the argument. Also, students did not seem to understand how to link what they had studied about dark matter and energy to an opinion on how these would shape the universe.

During the week when students prepared for the debate, the class felt rushed – many students had not filled out their research sheets or completed their debate packets. Kanisha, who normally wrote in unit evaluations that she had grasped the main concepts, reported instead that she needed to learn “much more about the topic.” Linda wrote: “I didn’t really understand what was going on with dark matter and dark energy.” The students did not seem terribly invested in or excited about the topic that Darlene and I had created. For example, on the day of the debate, many students were late or absent, in contrast with the science fair, a day on which almost every student with some version of a project was present. Also, a large number of students had their heads down in class during this unit and on the day of the debate, and their answers to questions were not thorough or detailed.

Darlene’s observations of the problems on the day of the debate, inspired her to envision more ways in which class could be changed to support students, such that she could better transform her figured world. Darlene and I both agreed that the ninth-graders might benefit from a public-speaking class. Also, Darlene felt that for students to be successful with a debate, they had to move gradually towards a full-class debate. She wanted to begin my modeling what she considered to be the small class setting at Eugene Lang College, which she had seen as part of an after-school program in which college students worked with our high-school students, with respect to college readiness. Darlene envisioned three students on each side of a judge around a table; the sides would present
and the judge would decide which argument was more convincing. She also suggested that the initial debates in physics might resemble a “portfolio presentation” – student presenting to a small audience. Darlene and I discussed that these sorts of smaller trials might lead to a larger trial at the end of the year.

*Relationships between Darlene’s authority and the design and enactment of curriculum.*

Similar to Nicholas and Grant, Darlene, for enacting her lesson, drew upon epistemic authority she had acquired on black holes (through the science symposium) and on law, through her ongoing interest in this discipline. Also, teaching the lesson allowed Darlene to explore questions she had about black holes, which allowed her to expand her epistemic authority and cultivate skills she felt related to the practice of law, which connected to how she envisioned her professional future.

Ironically, the lesson that Darlene co-planned with me may have failed because it did not create space for her peers to expand their own epistemic and positional authority. There was no flexibility in the topic of the debate. Students had too little time to conduct and understand research. Darlene commented that despite students seeing each other everyday and knowing each other well, they were not comfortable presenting to each other. And they did not have time to enhance their positional authority with respect to each other because we did not focus on practicing presentation skills in class.

*Grant:*

Grant chose two areas in which he designed lessons— the first, a brown-bag lunch on mechanical engineering, was a choice that he enacted; the second, a building lesson,
he simply described. Grant also wanted to alter the structure of his science classroom to resemble the colleges he had visited. To design and enact the lessons he envisioned, Grant relied on four resources: the parameters of the building project from his math class, permission to make the brown-bag lunch seminars student-centered, time and materials from his teachers, and the option of a field trip to local colleges. Engaging in the design of the math building project allowed Grant to communicate his values about projects and their assessments, but Grant did not mention a connection between this project and authority. Enacting the brown-bag lunch allowed Grant, similar to Nicholas, to leverage epistemic authority on mechanical engineering and also alter his positional authority.

Grant's envisioned curriculum.

Grant wanted to lead a brown-bag lunch in which he provided information to students, through his own research and problem-solving, on mechanical engineering. Grant envisioned this opportunity as a setting in which he would present his findings to students, teachers and administrators who chose, based on word of mouth publicity and flyers, to attend his talk. He expected that his audience would have an opportunity to answer questions, at the culmination of his talk.

During an interview, Grant also expressed his interest in teaching a lesson about building, unsurprising given his ongoing interest in hands-on work in physics. The building lesson plan that Grant described very much resembled a project assigned by his math teacher. He said that he would have students use four different shapes and the theory of optimization ("how much waste do we have after building our project") for his lesson, the same parameters that his math teacher had created for Grant and his peers.
Finally, Grant expressed his desire to alter our high school to better resemble Eugene Lang College and Polytechnic University. He desired the small classroom set-up that he saw at Eugene Lang College because he felt that this type of environment allowed students to receive individualized attention from their teachers. He also wanted his school to develop the types of science labs that he saw at Polytechnic University. Specifically, Grant observed that the science labs at Polytechnic had "tables with stools, all the supplies" and students wearing lab coats, which Grant felt would make him "feel more scientific." In both settings, Grant noted that students could choose their classes rather than being stuck interacting with one cohort of students for several years.

*Decisions to enact the lesson plan.*

Grant chose to enact his ideas for the brown-bag lunch but not for the building lesson. The brown-bag lunch idea he proposed was distinct from his ideas for the building lesson in several ways. For example, the mechanical engineering talk emerged from Grant's career interests while the building project emerged from the math curriculum his teacher had designed. Grant showed more investment in his brown-bag lunch, as evidenced by that fact that he discussed the lunch in multiple interviews. Also, on his own initiative, he sought out the resources he needed to pursue his idea (for example, a textbook on mechanical engineering to take home and time with his math teacher to tackle a mechanical engineering problem).

When Grant presented the brown-bag lunch, several of his peers attended the presentation, as well as a few teachers and the principals. He had created and posted fliers to publicize the talk, based on my encouragement. The content of his talk included what mechanical engineers do, types of problems they solve, and a description of their training.
and income. Grant also explained why he wanted to be a mechanical engineer and the education he thought he needed to pursue to achieve his goal. Despite being loud and gregarious in the hallways and in class, Grant was extremely soft-spoken during his presentation. He read most of his presentation without looking up from his paper. He seemed more comfortable and informal when he answered questions at the end of the presentation.

*Relationships between Grant's authority and design and enactment of lesson plans.*

The opportunity to conduct a brown-bag lunch provided Grant with opportunities to expand both his epistemic and positional authority. For the talk, Grant was compelled to conduct some research on a career in mechanical engineering, a topic that had not been covered in his physics curriculum. Grant also tackled a mechanical engineering problem that allowed his to refer to "calculus," an idea that his peers had not yet encountered in math class. As a result, Grant acquired an expertise that distinguished him from his peers, similar to how Nicholas' experience with robotics competition provided him with knowledge unique from what his peers knew.

Grant's talk also allowed him to cultivate positional authority -- he saw the brown-bag lunch as an opportunity to express his knowledge and opinions, such that he could create a new identity for himself as a motivated and accomplished student.

Through the building project, which he did not enact, Grant communicated what he valued in projects -- he focused most on students being creative and easily achieving success. However, at no point did Grant discuss this building project as a means by which
he could personally alter his epistemic and positional authority, perhaps an explanation for why he did not enact this lesson plan

_Linda:_

Linda envisioned curriculum that would provide inter-disciplinary opportunities for students to explore their careers through physics class. She also emphasized the importance of students having choice between and within classes. However, she did not enact most of the curriculum she envisioned. She only took on the role of an instructor when I specifically asked the class for volunteers to present their understanding of material they had learned in class. In these instances, she was able to leverage her epistemic authority to establish herself as a student with advanced understanding of complex ideas.

_Linda’s envisioned curriculum._

Linda envisioned advancing herself and other students interested in medicine towards their careers by re-structuring the way science was taught at the school. She wanted classes to be inter-disciplinary, rather than separated by discipline between biology, chemistry and physics, such that she could learn information relevant to medicine through each of her science classes. For physics, one way that she agreed this might happen was by focusing sections of the class on the study of devices that doctors might use. For example, she felt that learning about the physics related to the design of MRIs and X-Rays would help her better treat patients. In physics, she also wanted to mix more chemicals, similar to what she observed and did with the Gummy Bear combustion
and absorption activities, because she felt that experimentation with chemicals was pertinent to medicine.

Linda envisioned changing the structure of school by offering more choice to students across and within their coursework. Linda's sentiment echoed Grant's desire to create more of what he perceived as a "college" setting in high-school classrooms, where students chose their course and took classes with different students, rather than as a restricted cohort. Within class, Linda also wanted students to have choices - she felt that the room should be divided into different stations, so some students could study "chemicals" and others "electricity."

Relationships between Linda's authority and the design and enactment of curriculum.

The development of an inter-disciplinary science lesson and pursuing the option of having more choice in her courses overall would have given Linda an opportunity to acquire knowledge that would be, in her opinion, useful to her a practicing doctor. However, in contrast to Grant and Nicholas, she did not describe herself as acquiring this epistemic authority on her own, with respect to these topics, and returning to the class as a specialist who might in turn have an elevated positional authority. Linda was established strongly in the social dynamics of her classroom - students rarely made fun of her, and many of the more articulate girls were her friends. Several of her friends and the students with whom she worked in class were strong academic students. Linda was also a strong student in class and clearly grasped many of the main concepts we covered. In contrast with Nicholas and Grant who were doing poorly and struggling with
relationships in school, Linda expressed limited need and desire for additional knowledge and social status, given her existing authority in class.

The only time during which Linda acted on an idea to lead a lesson was when she could present her opinion to teach other students about what she had built or learned in class. She viewed these opportunities for presentation as contexts in which she could express her opinions and help other students better understand complex ideas. Linda’s decision to teach involved the intersection of both her epistemic and positional authority. She felt that she had specialized epistemic authority because she had grasped difficult or inaccessible concepts during a lesson, better than her peers did. From these presentations, Linda was able to expand her positional authority as someone, in addition to the teacher, who was responsible for student learning.

Kanisha:

The themes of Kanisha’s lesson were related to her beliefs that science could done by everybody with everyday materials. She also viewed lessons as springboards that students could use as preparation for different careers. Finally, she emphasized the need for options for advanced students to challenge themselves.

Kanisha’s envisioned curriculum.

Kanisha repeated in multiple interviews that she felt that all people had the capability of being scientists. She also wanted to convey to students the idea that science could be accomplished with everyday materials.

Kanisha’s wanted to communicate this philosophy about science through the lessons she envisioned. For example, Kanisha said that if she designed a lesson, she
would “have the class choose ordinary things you wouldn’t normally experiment on, candy, how it explodes, how it deteriorates.” Another lesson Kanisha proposed required students to act as police officers or detectives who were using science to respond to a crime scene. In a final lesson that she proposed, Kanisha suggested that students visit a broadcasting agency and design a weather report related to physics topics. The last two lessons suggest the theme that Kanisha emphasized of people using science in a variety of careers.

Kanisha, similar to Linda, wanted to change how physics was taught at the school so students could acquire inter-disciplinary knowledge, applicable to their careers. She said, “doctors can’t just learn physics – they need to know about machines, cat-scans, biology and the stuff that is going on.” To help students explore different careers, Kanisha envisioned a physics lesson in which students took field trip to sites of their choosing, where they could explore different careers. At these sites, in Kanisha’s mind, they would conduct research related to a physics topic. The physics content that students might acquire at these sites was almost an after-thought to career exposure. Her goal in these trips was to “allow students to test out their abilities in different fields, so you would know what you’re good at instead of taking a chance.”

Kanisha felt that a revised science program would allow advanced students to take high-level classes that would challenge them and move them forwards at a pace appropriate for them. Kanisha wanted advanced students to have more science available to them, particularly biology, so “when they are older, they can have more knowledge and get ahead.” She felt that advanced students might take “extra biology,” so they “knew more by 12th grade.”
Relationships between Kanisha's authority and the design and enactment of curriculum.

Kanisha chose not to enact any of the lessons she proposed. Similar to Linda, she did not express a strong need and desire for improvement in her positional and epistemic authority, as did Grant and Nicholas. Kanisha strong social bonds in school and her academic success may explain why she did not work actively to pursue her lesson ideas. Kanisha certainly expressed no specific way in which any of her lesson ideas might expand her positional and epistemic authority. Unlike Grant, Nicholas and Darlene who created lesson content and/or structures deeply tied to their funds of knowledge, particularly their career interests, Kanisha’s lesson only vaguely connected to her career interests in architecture and broadcast journalism.

Nicholas

Nicholas drew upon the portfolio process and access to internships and the KISS robotics competition, to design a robotics curriculum that he eventually enacted in the medicine-engineering academy at school. Through design and enactment of curriculum, Nicholas leveraged and expanded his epistemic authority and simultaneously altered his positional authority.

Nicholas’ envisioned curriculum.

Nicholas wanted to do more than just learn information about robots and computers; he was interested in communicating his understanding by teaching and displaying what he had learned at school. Nicholas wanted to share his knowledge of robotics with an entire class of students, so he proposed that he develop an in-school
robotics course that culminated with an in-school competition, as a way to affect curriculum at his school. Unlike other students, Nicholas tackled the idea of designing an entire unit, rather than just a single lesson.

In the unit he had in mind, Nicholas envisioned teaching students about how to build stable robots with legos, how to program robots, and how to attach and programs sensors so that the robots, to some degree, could respond to their environment.

For the lesson, Nicholas wanted to group students by motivation and their history of completing assignments. For example, he wanted the hard-working and advanced students in one group, the students who had catch-up work to complete in another, and a third, unmotivated (in Nicholas’ opinion) group to sit by the doorway. Also, Nicholas, at first, proposed that students in one class would all have to work on one robot, but he changed his mind when he found out that we could purchase multiple robots per class. Then he felt that students should work in small groups, because, in his opinion, this was a more effective way to learn.

To design his lesson, Nicholas created an outline of content and skills he wanted to teach. He discussed with me the types of materials we could acquire for a whole class competition. He also created a design for the competition gameboard, which he gave to his father to build – his father specialized in construction. We used the money that the robotics team gathered from donations to fund the construction of the game board.

Decisions to enact the lesson plan.

During interviews, I simply asked Nicholas to develop ideas for a lesson; Nicholas chose to actually enact his ideas. Nicholas’ his commitment to enacting the curriculum was evident through his initiative and perseverance. Over the course of the
year, Nicholas spoke with me several times about when and how he could build a game board, the kinds of equipment we could order for the competition he envisioned, and the kinds of funding we might have for materials. Often caught up in the many demands of students and school, I was unable to respond to his requests for time and materials right away. But if I told Nicholas to return to me a few days later to repeat his question or request, he invariably came back without further prompting from me. A year after Nicholas designed his unit, he and his team-mates had a chance to co-teach robotics with me as a unit of the medicine-engineering course offered to tenth-graders.

First, as co-teachers, Nicholas and his team-mates helped me preview and prepare the robotics materials for class. I chose the robotics kits we would use, primarily based on the budget that the school allocated for the class. However, Nicholas and team-mates previewed the robotics kit before it arrived. Then they prepared the materials we needed to run the robotics program in class: specifically, they unpacked equipment, figured out what types of batteries we needed, downloaded the software for programming onto ten laptops and sorted the robotics lego pieces for students to use.

Prior to a lesson, I would discuss with Nicholas and his team what we might do in class, for example, building different types of wheels, mounting the robot brain on the lego body or exploring the programming software. The topics of the lesson mostly aligned with what Nicholas had envisioned: constructing stable structures, exposing the students to various types of sensors, having them program and preparing them for an end-of-unit competition. In class, Nicholas, at first, worked with one group but then decided to move between different groups because he did not want to unfairly advantage his group in the competition. When he moved between groups, he helped students solve
building programs and become familiar with the software program. If during class, we struggled with programming or communication between the computer and robots, he came at lunch to try and sort out the problem, so next day’s class ran smoothly. Nicholas also helped with collecting and organizing materials at the end of class. At one point, Nicholas recognized that all of the robotics team members were in my section of the medicine-engineering academy and none were in the other teacher’s classroom. Nicholas felt comfortable enough in his expertise to volunteer to be a student teacher in the other classroom, where he would not have access to my supervision. Nicholas designed the final game board for the competition on his own; in this sense, he created the parameters for the final assessment of the unit.

As with the science fair, Nicholas’ relationship with other students altered substantially while he was enacting the robotics lesson. In the first semester of the course, when we were covering topics in medicine, Nicholas got into arguments with other students in class, sometimes threw paper across the room, and erratically completed his work. During the robotics unit, Nicholas no longer engaged in disruptive behavior and did not have conflict with other students. His peers started to call him over to solve problems, sometimes before they asked me for help. Nicholas also participated regularly in class discussion and worked outside of class on the robots, far more than any his peers, with the exception of his robotics team-mates.

*Relationships between Nicholas’ authority and design and enactment of curriculum.*

As I made plans with Nicholas to enact his (and my) ideas for a robotics curriculum, it became clear to me that Nicholas was able to leverage an increasing
impressive epistemic authority of robotics that I might not have witnessed had I not invited him to plan lessons with me. Nicholas' existing drew upon the expertise he had developed through the KISS Robotics competition, the science fair, presenting on robots during his ninth grade portfolio, working at the Brooklyn Library in the summer, and volunteering for the campus computer expert. These gains in epistemic authority were essential for him being able to envision an entire unit worth of curriculum -- because of his experience with robotics, he was able to figure out what students needed to learn to build a working robot, from start to finish. Also, he relied on his broad knowledge of robots to be a trouble-shooter for teams that were struggling during the unit. Nicholas, on his own, acknowledged his remarkable gains in epistemic authority, with respect to robots; in one conversation with me, he said: “I can’t believe I’ve learned so much about computers in such a short time.” Through co-planning, Nicholas was able to shape the figured world of his science classroom and express what he knew.

While Nicholas was co-teaching with me, he continued to expand his epistemic authority by working on the robots and software outside of class, so that, for the next class meeting, he could manage any problems that students were having that he was not able to tackle in class.

Nicholas also drew upon his epistemic authority to build other forms of authority that mattered in his physics classroom. By authoring new spaces for presenting his expertise in robotics and showing me how his ideas could be taken up in a physics-related science class, he also worked to alter his positional authority. Specifically, he advanced his positional authority amongst his peers by enacting his lesson plan in a way that positioned him as a classroom leader.
Table 6: Envisioning and Enacting Lesson Plans, Connections with Epistemic and Positional Authority

<table>
<thead>
<tr>
<th>Student</th>
<th>Description of Envisioned Curriculum</th>
<th>Enacted and, if so, How?</th>
<th>Changes to Student’s Epistemic and Positional Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nicholas</td>
<td>An in school robotics course in which students learned about building stable robots and programming them</td>
<td>Negotiated with me to be a unit during the second semester of the medical-engineering course</td>
<td>Nicholas leveraged his specialized epistemic and authority in areas related to the curriculum (the KISS robotics competition, work as computer intern and computer “expert” and apprentice at school, taking on the role of teacher through the internship and portfolio process)</td>
</tr>
<tr>
<td></td>
<td>Authentic assessment through an end-of-unit competition</td>
<td>Nicholas regularly asked for opportunities to discuss the curriculum, purchase materials</td>
<td>By being a co-planner and teacher, Nicholas was able to expand his epistemic and positional authority in his science class.</td>
</tr>
<tr>
<td></td>
<td>• Nicholas regularly asked for opportunities to discuss the curriculum, purchase materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grant</td>
<td>A brown-bag lunch on mechanical engineering</td>
<td>Grant presented his brown-bag lunch to teachers, students and administrators who chose to attend the talk based on publicity from word-of-mouth conversations and flyers that Grant posted</td>
<td>For the brown-bag lunch, Grant leveraged what he learned about mechanical engineering. He expanded his epistemic authority through research.</td>
</tr>
<tr>
<td></td>
<td>A building project, modeled on an assignment given by his math teacher</td>
<td>Grant did not pursue his ideas for the building project or the changes to classroom size and school structure.</td>
<td>Through the brown-bag lunch, Grant thought he could expand his positional authority and create a new identity for himself as a motivated and accomplished student.</td>
</tr>
<tr>
<td>Linda</td>
<td>Inter-disciplinary physics classes so students could learn information relevant to medicine</td>
<td>Linda took on the role of an instructor when I specifically called on volunteers to describe what they had learned.</td>
<td>When presenting work she had completed for class, Linda felt she understood complex and inaccessible ideas better than other students and, therefore, leveraged her epistemic authority.</td>
</tr>
<tr>
<td></td>
<td>Offering more choice to students between courses and within a physics course</td>
<td>Linda did not pursue any of her other envisioned lesson plans.</td>
<td>Linda had strong positional and epistemic authority in class, which may have reduced her incentive to develop her lesson plan.</td>
</tr>
<tr>
<td>Student</td>
<td>Description of Envisioned Curriculum</td>
<td>Enacted and, if so, How?</td>
<td>Changes to Student's Epistemic and Positional Authority</td>
</tr>
<tr>
<td>---------</td>
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<td>-------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Darlene | - Darlene originally developed a lesson structured around the model of debate and focused on the content of teaching students about the existence of black holes | - Darlene enacted and then reflected on a lesson on the nature and effects of dark matter and energy on the universe, also in the form of debate. | - Darlene's research for the debate allowed her to leverage her existing epistemic authority on black holes and advance it.  
- She also chose to engage in a lesson connected to her funds of knowledge, specifically how she envisioned herself in her professional future |
| Kanisha | - Kanisha proposed physics lessons that encouraged students to believe that “everybody is a scientist” and that science can be pursued with everyday materials  
- Kanisha also suggested lessons that, while unspecific regarding physics content, allowed students to explore their career interest  
- Finally, she wanted too create opportunities for advanced students to have more choices in what courses they could take | - Kanisha did not choose to pursue any of her lesson ideas | - Kanisha had strong positional and epistemic authority in class and the lessons did not connect deeply to her funds of knowledge, perhaps contributing to her lack of interest in developing the lessons. |
Comparing Findings on Transforming Curriculum and School Structures with the Literature on Agency and Expanding My Initial Model of Critical Physics Agency

Data from case study youth in this chapter both substantiates and adds to existing ideas on critical physics agency. In this section, I connect findings from the data on curriculum transformation with the literature on agency and to expand the model of critical physics agency that I initially generated, as a summary of the literature (Figure 3).

**Figure 10: Revised Model Based on Data Regarding Transformation of Curriculum**

Resources and Identity: What Students Relied On for Envisioning Lessons

Different case study youth relied in different resources to develop physics lessons and changes to classroom structure. In this section, I describe themes that emerge across students in terms of the types of resources they utilized. In comparison with the boys, the
three girls relied more on content and skills they had learned in class as sources to leverage for epistemic authority. Perhaps this is explained by the fact that the two boys were less academically-successful in class and, therefore, had less specialized expertise from class and needed opportunities outside class to cultivate this expertise.

Certain types of classroom experiences were foundational in how students thought of lessons for physics class. The classroom experiences that stimulated different students’ ideas for lesson plans were tied their funds of knowledge and critical goals. Linda said that studying the combustion and absorption of the gummy bear motivated her thinking about chemistry being taught in physics and, therefore, the possibility that science classes could be inter-disciplinary. This lesson plan was tied to her desire to better understand the how materials and objects in the world interacted. In designing the dark matter/dark energy debate, Darlene drew on her experience with the Einstein debate, which made her excited about the idea that science could include the sharing of opinion over controversial topics researched by experts. Her lesson plan connected to her desire to create learning environments that would cultivate the skills she thought she needed for a career in law. Kanisha’s experiments with the Gummy Bear confirmed her belief that science could be taught using everyday materials, and she built this idea into her envisioned lesson. Grant relied on the design of a math assignment that his teacher had created as a model for his building project. His lesson connected with his critical goal of improving his knowledge of and skill in building.

Access to opportunities outside of class, which connected to students’ funds of knowledge and/or critical goals, were also important in helping students generate ideas for lesson plans. Nicholas drew on his experience building and programming the robotics
competition for the Botball competition to structure his unit on robotics. Grant's experiences at Polytechnic, which exposed him to ways in which students might learn about how materials interact and how to build and fix devices, stimulated his thinking about science labs and classroom sizes at school.

Fundamental to students developing lessons was my belief, shared by several experienced teachers at the school, that youth should be co-planners of curriculum and school structure. An important foundation for students thinking about lesson plans was the dialogue they had on this topic during interviews. For example, a three-way conversation between Kanisha, Linda and me, encouraged Linda to consider the possibility that she might connect physics, which felt disconnected from her career goals, to her interest in medicine.

Learning settings that contrasted the case study youth's everyday classroom environment were a resource for their ideas for lesson planning. The portfolio, required of all students at our school, was an important background for students to develop the skills and ideas they needed for enacting their lessons. Through the portfolio process, Nicholas had an opportunity to practice teaching a small group about robotics for about 15 minutes before he tackled a full classroom of students and a several day curriculum. When Darlene decided that the debate she had planned had failed in many regards, she thought back to the success of almost every student in the intimate setting of the portfolio presentations. She proposed the structure of the portfolio presentations as a stepping stone towards students participating in a larger debate. Grant referred to the small learning environments at Eugene Lang as a model for how he wanted to change his classrooms at school, so that students could receive more personalized attention. Kanisha
and Grant referred to how they envisioned college classes as a structure they wanted to bring to their school, particularly, that students might have choice in the classes for which they enrolled.

Finally, the simple experience of enacting curriculum was a resource for students in envisioning curriculum. Once Darlene enacted her lesson, she had several ideas about how she might structure school and the classroom differently to achieve the types of student learning she desired. What cross-cutting themes with respect to choice in resources?

Below, I have added key resources into my developing model of critical physics agency.
Transforming Curriculum: Designing and Enacting Student Lesson Plans

- An in school robotics course and competition in which students learned about building robots and programming robots
- A brown-bag lunch on mechanical engineering
- A building project, modeled on a math assignment, and emphasizing creativity and easy success for all students
- Inter-disciplinary physics classes so students could learn information relevant to their career interests
- A lesson structured around the model of debate and focused on the content of teaching students about the existence of black holes and later dark matter/dark energy
- Physics lessons that encouraged students to believe that "everybody is a scientist" and that science can be pursued with everyday materials
- Offering more choice to students between courses, in particular for advanced students

Figure 11: Revised Model of Agency Including Resources for Curricular Transformation

An Intersection between Positional and Epistemic Authority: Moving from Envisioning to Enacting Lessons

As part of their interviews, I asked each case study youth to envision a lesson for physics class. The case study youth were likely to enact the lesson they had designed when their ideas for curriculum leveraged their epistemic authority. Key features of whether students enacted lessons, thereby exerting agency to shape their figured world, were the following: 1) youth enacted lessons that allowed them to leverage epistemic authority that distinguished them from their peers, 2) youth were able to alter their
positional authority with respect to their peers, and 3) youth were able to connect their lessons with their funds of knowledge.

*Connections between Enacting Lessons and the Student Leveraging Epistemic Authority.* When students could leverage and enhance their epistemic authority, they were more likely to enact lessons and, therefore, through a process of agency, shape their figured worlds. Darlene’s plan for a lesson required her to gain and use advanced epistemic authority on black holes and dark matter/energy, in comparison with her peers. Grant chose a topic for the brown-bag presentation, mechanical engineering, which students had not formally studied. So, through his research (and what he learned through his field trip to Polytechnic), he was in a position to be an expert. Linda used her deep understanding of topics in class to act as a student leader. Through use of her specialized authority, she was able to establish herself as a smart, articulate student. Nicholas’ lesson was in a domain about which students, besides the robotics team-members knew very little. So, in the field of robotics, Nicholas was able to use his expertise to create and enact lesson and be a student leader in the classroom. Nicholas also, through this opportunity, was able to further expand his epistemic authority in matters related to robotics.

The absence of a clear connection between envisioned lesson plans and the acquisition of authority marked situations in which case study youth did not enact their lesson plans. Grant did not express that the building project lesson plan did not would help him cultivate authority. Both Linda and Kanisha were strong students who comprehended major concepts in physics class. They did not express a need or desire, as
did Grant and Nicholas, to acquire additional epistemic authority, perhaps explaining their limited attempts to enact curriculum.

*Connections between enacting lessons and students' positional authority.*

The case study youth were likely to enact a lesson when their ideas for curriculum intersected with the expansion of their positional authority. When students had limited need to acquire additional positional authority, they seemed less likely to seek out opportunities to enact lessons.

Similar to his experience with the science fair, Nicholas found that he could enhance his positional authority with his peers by taking on the role of a teacher in the classroom, because he was an expert from whom other students could learn. Grant believed that he could expand his positional authority by pursuing the brown-bag lunch: this presentation would establish him as an academic leader, in the eyes of his peers and teachers. He also saw the brown-bag lunch as a source of math and science credit, another way in which he could alter his positional authority, from being a student with a history of incarceration with no credits to a student who took the initiative to fill this gap.

Darlene, Linda and Kanisha were less concerned with acquiring positional authority. The girls were more socially-established in their classrooms. (Each had several friends in class and was able to select partners who helped her succeed. Each was comfortable asking for help from teachers, participating in class, and finding partners for projects.) Darlene did enact her curriculum, but her motivations were more focused on personal epistemic authority and exploration of topics related to her funds of knowledge. Kanisha and Linda did not seek me out for academic support or science opportunities.
that would gain them epistemic and positional authority, except that Linda sometimes acted as a teacher when she presented her understanding of a physics topic.

*Other Key Themes in Designing and Enacting Lessons*

_The importance of teacher commitment to student co-planning._

The data on case study youth provides evidence of the importance of teacher commitment to students being co-planners of curriculum and school structure. Only with extended teacher support were Darlene, Nicholas and Grant able to access the extra materials and feedback they needed to enact their lessons. The enactment of lessons was fundamentally a collaboration between teacher and student. The students certainly had ideas for how they wanted to structure their lessons. However, I, as the teacher, could tackle structural constraints, such finding out about the school’s budget for materials and considering the relationship between students’ individual lessons and larger scope and sequence for the class. Other teachers and I needed to provide the students with ongoing feedback for them to be successful with their lesson plans. All of this required time and creativity on my part, which I would not have extended given the wide variety of tasks I had to complete each day, if I had not been committed to idea of students co-planning.
Teachers and schools as boundary-setters.

For my school, my students and for me, student co-planning was a new endeavor. I had little idea of what students might and how I might affect their decisions. But in several instances I clearly influenced how they envisioned and enacted lesson plans.

Darlene altered the content focus of her lesson plan from black holes to dark matter/energy because of pressure from me. I was nervous about repeating a topic that some students had chosen to pursue and might be bored with and that other students had not wanted to engage in. In retrospect, the existing knowledge and interest of some students in Darlene's class with respect to black holes might have helped groups had ideas for the debate, but, regardless, I influenced how Darlene enacted her curriculum.

In Linda's case, she took on the role of teacher when I explicitly asked for volunteers who felt comfortable explaining their understanding of nuclear fission and fusion to describe their models to the class. Both she and Kanisha were strong students who tended to carefully follow explicit instructions. She did not take on a teaching role from her envisioned lesson plans, nor did Kanisha. It is possible that these students, who tended to follow the expectations of a classroom as guidelines for behavior and were successful in this context, needed explicit classroom instructions from me if they were to enact lesson plans of their choice, in pursuit of agency.

None of the case study youth pursued their ideas of structural change to classrooms and the school. For example, Linda and Kanisha discussed but did not enact the idea of students being able to choose their classes and have choice within their classes to acquire knowledge related to careers that interested them. The same held true for Grant who wanted to reduce classroom size and provide more materials for science labs at the
school. Though I recorded their ideas related to structural change, I rarely followed-up in interviews on these topics, perhaps implicitly setting boundaries on what was realistic to enact.

In the figure below, I have built in my findings about the relationship between positional authority, epistemic authority and the enactment of lessons into my developing model of critical physics agency.

**Figure 12:** Summative Model Showing Curricular Transformation as An Example of Critical Physics Agency
Chapter 8

Conclusions and Implications for Teaching and Research

Conclusions from Research

Access and Engagement

In urban settings, such as New York City, minority, low-income youth are greatly disenfranchised from a physics education. The existence of magnet schools (Metz, 2003), the high-school science sequence and tracking (Neuschatz, 1999) limit their access to physics. Kelly (2004) reports that only 5.2% of all high-school students in New York City currently enroll in physics and that schools with black and Hispanic and low-income populations had less access to physics than schools with a higher percentage of white and middle-class students. In contrast, the approach to physics documented in this study provided access to all students entering our school, almost all of whom were from underserved minority and low-income backgrounds.

Nevertheless, simply getting students into a physics class is not enough to ensure their engaged participation in and ongoing pursuit of physics (Redish & Steinberg, 1999). There is almost no physics education literature that documents the role of student voice
and agency in learning physics, and physics classroom are rarely spaces for innovative pedagogy (Christian & Belloni, 1999). But for the case study youth in this study, a curricular focus on critical physics agency allowed them learn about topics and take action on issues of importance to them and shape the figured world of their physics classroom, as they acquired a deep and broad understanding of physics. Based on this research, I propose that critical physics agency, a fundamental philosophical change in how physics is currently taught, is a means by which a greater diversity of students can access and engage in physics, thereby becoming more informed about and powerful in how they can shape the world.

My original model of agency (see Figure 3), derived from literature, referred to conscious and unconscious goal-setting, enhancing one's repertoire of knowledge and skills and exploration of identity. The data from this research have allowed me to expand this model such that it is more specific to critical agency in physics (see Figure 13). The model provides insight into the relationships among critical goals and associated mechanisms, envisioning and enactment of curriculum, youth identity and utilization of resources, development of understanding and rigor, and use of physics as a context and tool for agency.
Critical Goals

Youth in this expressed critical physics agency in three key ways: 1) articulating critical goals, b) progressing towards their critical goals, and 3) envisioning and enacting ways to transform curriculum in physics. The critical goals that youth articulated resonated with ideas in the original model of agency I created, specifically: “Setting conscious and unconscious goals based on identity. However the data from this study provided more detailed insight into the critical goals of youth, specifically, the students expressed: a) Learning goals, b) Engaging in opportunities to express voice, c) Altering participation in relationships, d) Participating in the world as activists. These goals were critical because youth either, through these goals, tackled the problems they saw as unjust or unsolved in society or, through these goals, unconsciously challenged stereotypes about poor minority youth (Merry, 2005).

The critical goals that emerge from my research mirror some of the existing literature on agency. In this study, through their learning goals, case study youth expressed an idea similar to Jackson’s (2003) notion of “academic identity” – an understanding of self that involves “intellectual activity.” In this study, students articulated different ways in which they wanted to express voice. The literature supports the idea of voice as an important aspect of agency (Lensmire, 1998; Holland, 1998). McCallister (2004), Sizer (1992) and Zembylas (2004) discuss the importance of social context to student motivation – this idea emerges from my data as the desire of each case study student to alter his/her participation in relationships. Finally, several authors such as Dann (2002) and Butler (2004) take up the idea of students trying to enact large-scale
social change, which is reflected in the data on case study youth. None of the case study youth achieved their ambitious goals for participation in the world. But literature also supports this finding that pursuing agency does not guarantee a particular outcome but rather is an exercise in risk-taking (Holland, 1998; Sizer, 1992).

The data on case study youth supports literature on agency that discusses the importance of success with small acts of agency before students take on the world (Holland, 1998). Nicholas’ and Grant’s experience with the science fair allowed them to gain hands-on skills and knowledge relevant to their ambitious ideas for participating in the world as activists. Their success in these small steps helped them build confidence towards their larger goal. For example, at the end of the robotics competition, Nicholas created a proposal for his military robot and submitted it to his mentor.

Since 1899, when the Committee on College Entrance Requirements developed a credit system, making physics and chemistry into advanced electives in the United States, (Sheppard and Robbins, 2003), physics has been a discipline for the elite. Consequently, youth of minority, low-income backgrounds have been marginalized from physics as lacking ability and motivation. Aspects of the idea of “critical goals” are clearly well-established in the general literature about agency. However, the idea that youth might bring well-formulated critical thoughts about their own learning and schooling, based in their funds of knowledge, to their classrooms is a new contribution to the literature in physics education. An exploration and valuing of students’ participation in relationships is also new territory in physics education. Generally, physics education has taken an objective position towards student learning; in other words, the position in this field is

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that physics and the learning of physics stand-alone -- they are not connected with student identity, context and relationships.

Two cross-cutting themes emerge from the data on critical goals. First, each case study youth wanted to establish a physics presence, a way in which he/she could, in an individualized way stand out from his/her peers in physics. Second, in this study, I found that critical goals were shaped by and helped to shape the students' figured worlds.

Mechanisms for Advancing towards Critical Goals

Youth used three mechanisms (ways in which they leveraged and constructed their figured worlds) to pursue their critical goals. These mechanisms were: 1) pursuit of physics-related careers, 2) engaging in and creating opportunities to learn physics content and skills, 3) taking on the role of a scientist. The two boys in this case study were able to state in more detail how they envisioned themselves in physics-related careers. These boys were also interested in creating working technologies, as part of their learning goals, and struggled more in school than the three girls with respect to academic success and social integration. Further research might explore whether and how boys and girls articulate and pursue physics-related careers in different ways.

Mechanism 2 – engaging and even creating opportunities to learn physics content and skills -- reflects an idea in the original model -- enhancing one's repertoire of
knowledge and skills. However, this research provides a more detailed understanding of what resources students leveraged in physics and how their individual funds of knowledge shaped this utilization of this mechanism. For example, youth specifically stated that they most engaged with demonstrations and activities that taught them new ideas or encouraged them to think about materials in new ways, particularly when these experiences connected to their funds of knowledge. Youth in this study, through this mechanism, conveyed a "science identity" — they wanted to do more than read, hear about, or solve problems on topics with which they were familiar. Instead, they wanted to see evidence for new ideas that explained principles and materials in the universe; they even created opportunities on their own to engage in this sort of exploration. Students also articulated the importance of choice, teacher availability outside of class and access to specialized equipment as key resources in using this mechanism to pursue their critical goals.

All students engaged in Mechanism 3 — taking on the role of scientist through the vehicle of their science fair project. The science fair was an assigned project and, therefore, required of students, but unlike several other assignments (such as the Einstein debate), students expressed a deep level of commitment to this inquiry-based activity. Once again, how youth took on the role of scientist connected with their "funds of knowledge" and advanced them towards their "critical goals." For this mechanism, students relied on opportunities to design their own hands-on experiments about questions to which they personally sought answers, flexibility in the materials they used and the partners with whom they worked, and positional authority to shape the requirements of the project to match what work they considered to be scientific.
Holland (1998) refers to the idea of a “socially-constructed self,” in that “our communications with one another not only convey messages but also always make claims about who we are relative to one another and the nature of our relationships” (p. 26). From this standpoint, the critical goals of case study youth as articulated through their interviews and actions make claims about their identity. Through the expression of agency, using the three mechanisms articulated above, youth were able to advance towards their critical goals and, thereby, transform their identities. Contexts in which students were able to pursue their learning goals were evidence for change in “intellectual identity” (Jackson, 2003). Contexts in which students were able to cultivate their voice provided opportunities for growth in their epistemic and positional authority and, therefore, in intellectual and social identity. Altering participation in relationships also allowed youth to affect their social identities. Finally, youth were able to expand their participation in the larger world and, thereby, deepen their identity as activists. Dewey (1938) describes one purpose of education as giving students power and freedom to exert power over their own lives. An education that allowed students to express critical physics agency allowed youth to transform their own identities and, thereby, access the power and freedom that Dewey describes.
Transforming Curriculum as an Expression of Critical Physics Agency

All youth in this study, based on my request, envisioned ways in which they might alter or add to the existing physics curriculum of their classroom. The curriculum they envisioned, once again, connected to their funds of knowledge and critical goals. For envisioning their curriculum, youth who were successful in class, primarily the girls, drew on in class demonstrations and activities. The boys, who were less academically-successful, relied on some out-of-class experiences and alternate learning settings to envision their lesson plans.

Students who enacted their curriculum found some way to leverage or cultivate specialized epistemic authority to enhance their epistemic and positional authority. Grant read a text on mechanical engineering to become an “expert” on this topic, Nicholas channeled his knowledge of robotics, and Darlene used her research on black holes and knowledge of a career in law to enact curriculum. Through the enactment of curriculum Darlene was able to learn more about a topic about which she wanted to cultivate more in-depth knowledge; Nicholas expanded his understanding of robotics and computers, and Grant explored a career in mechanical engineering. All three expanded their epistemic authority, as related to their critical goals. Also, each student enhanced his/her positional authority; for example, Nicholas established himself as a computer expert; a year after Nicholas first engaged in robotics, teachers and students asked him for help setting up their computers at school and at home respectively.

To enact curriculum, youth relied on my commitment to co-planning, which reflected my personal values but also that of our school context. Without my questions
regarding the envisioning of curriculum, students would not have engaged in this activity. Without my support (both dialogue and access to resources), students could not have converted a brown-bag lunch into a student-centered activity, structured the physics curriculum for a day or helped teach a unit in the medicine-engineering academy.

My identity also created boundaries for how students could enact curriculum. Though Darlene wanted to do a debate on black holes, based on my assessment of what would interest and motivate students and my belief about needing to cover new material, I decided that we should alter the debate to focus on a different topic (dark matter and dark energy). Enacting curriculum also seemed to be a resource for envisioning revised curriculum. In reflecting on her debate, Darlene had much to say about she might the structure the debate differently in the future: ideas for a round-table and a public-speaking class or training came from her discussion of problems with the debate.

"Teacher Research as a Pedagogical Tool to Fostering Critical Physics Agency"

Key resources that students relied on in this study with respect to expression of agency included:

- in-class experiences, particularly curriculum providing access to new ideas and new ways of thinking about materials

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• out-of-class experiences (advisory field trip, robotics competition)
• inquiry-based hands-on curriculum, particularly the science fair
• choice in topics, texts, materials and partners
• positional authority to shape assessment

However, an essential component of students exploring and expressing critical physics agency was my teacher-action research as a vehicle for dialogue that allowed students to:

• identify and discuss their critical goals
• discuss ways to leverage epistemic authority and enhance epistemic and positional authority
• access available resources and specialized materials
• have time out-of-class to be guided through the knowledge and skills essential for their pursuit of critical goals and their ideas for enacting curriculum
• create a space for reflection, self-evaluation and revised planning.

When I designed this study, I saw my research as a way to explore student ideas of critical agency in physics and to search for ways in which to include more low-income, minority youth in the study of and careers in physics. I did not anticipate finding that the actual research itself would be one of the most important resources on which students would rely to explore their ideas about how their identities and goals could connect with physics. The interviews associated with the action research allowed case study youth to express critical physics agency with a richness and level of accomplishment that set them apart from their peers. For example, I asked other non-case-study youth in my class, after the success of Darlene’s lesson, to consider envisioning and enacting curriculum. But
none of these followed through on their initial excitement about this idea. The dialogue about critical goals, funds of knowledge and curricular change, seemed to provide case study youth with powerful tools and resources to direct their action towards their goals.
1. Articulating Critical Goals:
   a) Learning goals
   b) Engaging in opportunities to express voice
   c) Altering participation in relationships
   d) Participating in the world as activists

3. Transforming Curriculum
   (envisioned v. enacted)

   Resources:
   1: In Class Experiences Connected to Funds of Knowledge
   2: Out-of-Class Experiences Connected to Funds of Knowledge
   3: Exposure to Alternate Learning Settings
   4: The Experience of Enacting Curriculum
   5: Teacher Commitment to Students Co-Planning
   6: Opportunity for Youth to Expand Positional Authority
   7: Possibility and Opportunities for Youth to Leverage and Expand Epistemic Authority
   8. Teacher Action Research

   TEACHER BELIEFS & CURRICULAR CONSTRAINTS

Figure 13: Final Model for Critical Physics Agency
Understanding, and other classroom and curricular goals

A key goal of this classroom and this research was to ensure that a physics classroom focused on agency did not turn into physics “light” – by this I mean, a non-rigorous exploration of physics. My conceptual framework was adapted from Turner’s (2003) ideas regarding critical math agency, which emphasized that students acquire deeply understanding of the discipline they were studying.

Several pieces of evidence from this research suggest that students developed a rigorous understanding of physics content and skills. Within the cohort of 9th graders who took the conceptual physics class at our school, several felt comfortable enough to attempt the physics regents, despite the fact that only 9% of students in the city pass the regents exam, primarily at magnet schools and during their senior year (City Council of New York, 2004). Of these students, a few came close to passing, and one passed the regents, a monumental achievement for a 9th grade student in an under-resourced school.

Specifically, of the case study youth, Kanisha, Linda and Darlene achieved high grades on assessments of standards-based curriculum and accepted physics texts (NSES, Project 2061, New York State Standards and Hewitt, Giancoli, Arons). Nicholas transitioned from weak grades at the beginning of the year to exceptional work by the end of the year, as reflected by his grades. All students explored topics in the nature of science and investigated technologies associated with everyday devices such as LEDs, with which they were previous unfamiliar.
The learning goals of the case study youth often high for learning content and skills in physics. Kanisha wanted to engage in the highest-quality academic work of which she was capable and was willing to revise her work time and again and select appropriate partners to achieve this goal. Darlene went beyond the basic requirements of class – she sought out the most challenging projects and set herself a standard of being original and independent, in comparison with her peers. Linda wanted to develop an understanding of the world to a degree that she could teach others. Both Nicholas and Grant sought expertise in their respective fields of robotics and mechanical engineering.

In his interview transcripts, Grant’s comments suggested that his experience with critical physics agency in my classroom did not correspond with his developing a strong understanding of many physics concepts that we discussed in class. Nevertheless, the curriculum did provide him with an entry-point into physics, such that he was able to articulate key topics in physics and how these connected to issues in the larger world.

In contrast to what happens in New York City and across the country, through a physics-first, critical agency approach, an entire grade of low-income, minority students gained traditionally restricted access to the following topics: measurement, motion, energy, electricity, the nature of science and modern physics. They also practiced skills such as graphing, data collection and analysis, problem-solving and inquiry. The case study youth, in particular, developed deep understanding of various topics in physics and the nature of science. Each was invested enough in physics to cultivate a “physics presence” – a way to distinguish oneself from one’s peers by standing out as exceptional in physics class. None of the students, during interviews, expressed sentiments that physics was “too difficult” or “for the elite” (Sheppard & Robbins, 2003) Instead, the two
boys actively described themselves pursuing careers in physics; Kanisha had a well-developed set of beliefs about science that she wanted to communicate. Darlene rose to the challenges she met while conducting her science fair and wanted to pursue more advanced courses in physics, and Linda was comfortable enough with physics to share her opinion about content in most units. Much of student thinking about physics required them to engage in higher-order thinking skills (Bloom, 1984). For example, Nicholas had to apply ideas he was learning about electricity to the development of a robot. Darlene was able to teach her ideas about dark matter to other students. In short, this critical agency approach to physics pedagogy appeared to engage a diversity of generally marginalized students in rigorous physics thinking. Even Grant, who continued to articulate misconceptions about physics, could discuss complex topics that most low-income, minority youth in the city have no opportunities to explore: fusion and fission, storage of energy in capacitors and problem-solving in mechanical engineering.

Despite successes with cultivating understanding and rigor in class and with case study youth, a sizeable number of students continued to be marginalized from learning physics content and skills—nine out of twenty-six students in my section failed physics for the year (though none of the case study youth failed). As I suggested in the methodology section, several of the students who failed physics were what I would categorize as “resistant”—not willing to follow instructions in class and often in conflict with me and other students. These actions of resistance may, nevertheless, played an important for these youth to develop “autonomy and self-determination (Brayboy, 2005). The case study youth with whom I engaged in a discussion about critical physics agency each had some positive connection with me. I did not succeed in exploring these ideas
through my action research with students who disliked being in my class or avoided working and conversing individually with me. In light of these findings, future research on critical physics agency should explore how to create connections around academic success and agency with students most at the periphery of and most resistant to functioning within the norms of physics classrooms.

With respect to how our course contributed to students being learners in our school at-large, I have only anecdotal and observational evidence, since this was not a question on which my study focused systematically. Students did engage in problem-solving (identifying key information, breaking down the steps of a problem) and literacy work in our classroom (word walls, guided reading, etc.). But the degree to which this built their overall, inter-disciplinary and long-term skills as literate, analytically-strong students is unclear. In our class, students, as a cohort, seemed progressive more confident making review sheets for tests and using their class materials efficiently for open note assignments – but we more thoughtfully focused on cultivating these types of study skills the year after I completed the study. Overall, the ninth-grade students did seem to move forward in terms of public-speaking skills, structuring and pursuing their own questions for inquiry and engaging in activism work for themselves and their school. However, once again, my data on this topic is not systematically-collected, and some fraction of our students failed to advance in one or more of the skills I have listed above.

*Physics as Context and Tool*
In some instances, youth progressed towards their critical goals by relying on their physics classroom and curriculum as a *context*. In contrast, youth also actively and consciously chose to use physics in specific ways to achieve their goals – in these scenarios, physics was a *tool* for agency.

For example, physics was a context through which Linda, Darlene and Kanisha pursued their learning goals; they met the expectations I had of students in class and, in turn, achieved some of their critical goals such as seeking out challenge, understanding the world better and exploring how everyday materials interact. The science fair also provided a context by which students were able to learn new ideas and engage in investigation of everyday materials – a context for case study youth to pursue their individual critical goals.

With respect to the mechanism of exploring physics-related careers, case study youth saw physics as a tool for moving in the direction of their long-term career aspirations. For example, Linda saw learning physics as a stepping stone to a career in medicine. Nicholas and Grant, when they worked on projects outside of class, beyond what was expected from them in the curriculum, used physics as a tool for agency. They specifically chose these projects so that they could achieve their learning goals of creating hands-on working technologies that advanced them towards their envisioned careers and goals for activism. Darlene and Kanisha consciously utilized the choice they had in selecting partner in physics as a tool to improve their chances of academic success.

Nicholas’ conception of physics with respect to participation in relationships changed from physics being a context to the discipline being a tool for agency. Over the course of the robotic competition he went from appreciating the relationships he built as a
side-product of robotics to consciously seeking friends and mentors through robotics. When youth are able to consciously direct their knowledge towards their goals, Holland (1998) touches on these forms of agency writing that the “space of authoring” identity can either be “automatic” or “a matter of great variability and most significant to a single person’s address (p. 272). In my study, using physics as a context for agency falls under the category of an automatic response that fortuitously connects with students’ critical goals. Shaping physics to be a tool for agency connects to the idea of sorting through a variety of choices such that the action taken connects to a “single person’s address.” Further research might explore how this transition in viewing physics occurs, such that more students might consciously direct their actions towards what they value. Nevertheless, this exploration of physics as a context and tool for agency is new in the physics education literature.
Implications for Teaching

What does it take to set-up critical physics agency?

Low-income minority youth, particularly in New York, have limited options for agency because of the curriculum imposed upon under-resourced schools. This study suggests that what teachers believe about student needs and curriculum as well as what they expect students shapes how youth express agency. Given the constraints that student experience in expressing agency, what insight does this research provide about how educators might cultivate critical agency while maintaining an academically-rigorous curriculum?

First, critical agency can take place within the context of a standards-based curriculum. Subject-specific critical agency, by definition, requires attention to rigor, understanding, content and skills. In fact, a focus on agency may provide entry-points for a larger group of diverse learners to access content knowledge and skills in physics. In designing my curriculum at the School for Social Action, I relied upon NSES standards, NY State standards, Project 2061 guidelines and a wealth of textbooks and curricula (Hewitt, Giancoli, Arons, etc.) I also depended on exposure, through graduate school and research for my dissertation, to physics education and science education as well as professional development opportunities at museums, schools and workshops and co-planning with teachers at each of the high schools where I have worked.
However, a teacher committed to ideas of critical agency needs to do more than teach a standards-based curriculum with attention to existing “incremental” best practices in physics pedagogy. Crucial for students to develop critical physics agency is that teachers reserve space in their curriculum for students to articulate their funds of knowledge and develop their critical goals. In practice, this means that teachers must design lessons in which students describe their backgrounds, beliefs and values and then shape these into goals for learning, participation in relationships and participation in the larger world. Then teacher and students can work together to shape and expand a standards-based body of physics content and skills around what students value. Ideally, from a Freirian standpoint, youth would develop these goals identifying unsolved problems and injustices in their own lives and larger community that they hope to tackle through their goals.

Of course, it is not realistic that teachers spend as much time with each student around questions of agency as I did in my research. Cultivating “co-generative dialogue” (Milne, 2005) might take place more efficiently through structured protocols directing discussions about agency between students, focus groups involving multiple youth and the teacher, regular and descriptive unit evaluations with a focus on critical agency and short one-on-one discussions between students and teacher, over the course of the year. These are all strategies through which teachers might support the development of critical agency with a whole classroom of physics students.

As a teacher-researcher, I was lucky to have the mission of my school support development of student agency. Not all schools are set-up in this fashion. However, as physics teachers, we often do not look to the space outside our classroom as providing
resources for students. Finding spaces in which to plan across disciplines, with a focus on agency, might help youth develop stronger skills for pursuing agency overall, which would then play out specifically in what students achieved in this area in physics. For example, if youth engaged in activism in social studies for a unit project, the physics and social studies teachers might agree upon common strategies to reinforce in their classrooms around activism, with the hope that youth could leverage these skills in both classes better because of shared curricular emphasis.

This study suggests that the contexts of teacher identity, youth identity and school mission and structure are essential features of how critical physics agency takes shape in a classroom. Hence the importance of particular students expressing their funds of knowledge and developing their personalized critical goals. However, some common resources and practices are important for development of critical physics agency:

- Without a teacher belief in cultivating agency, development of agency is unlikely to take place in a physics classroom. Because the teacher has substantial positional authority in a classroom, he/she shapes the focus of what takes place in this shape in this space.

- All youth in this study leveraged and cultivated specialized epistemic authority -- something other youth did not know or could not do, so the student in question could bring something to the class that felt special and distinct. Providing this type of opportunity might be a key feature of a classroom that supports students’ exploration of agency and a rigorous engagement in physics.
• Though academically-successful youth could leverage and expand in-class experiences tied to new knowledge and new understandings of materials, youth less successful in the classroom needed choices of out-of-school learning settings and experiences to draw upon as resources in the pursuit of agency. Hence the importance of youth choosing field trips and competitions that connect to their critical goals.

To structure agency into the curriculum, teachers might require certain projects that cultivate agency but offer youth choices in partners, topics and materials as well as the positional authority to shape how the project is assessed. For example, an inquiry-based, hands-on science fair was an important setting through which youth in this study expressed agency. The debates allowed youth to develop and share their opinions on controversial topics, an opportunity to express voice. Also the process of envisioning and enacting curriculum gave students a chance to enhance their epistemic and positional authority. Requiring the enactment of curriculum, not just its envisioning, might encourage academically-successful youth such as Linda and Kanisha to engage in this practice, if the teacher values this form of agency. Because Kanisha and Linda strived to meet explicit classroom expectations and had less need than Grant and Nicholas for enhancing their positional authority, they may have also been less likely to pursue enactment of their lessons based on their own volition, without direct requirements. Because Kanisha and Linda responded to grade-based incentives, if I had really valued enactment of lesson, I would have built this assessment into how I graded the class. Once again, attention to student identity is important in setting up structures for agency in class.
A final resource in expanding student agency is the cultivation of a relationship between student and teacher by which youth receive the mentoring they need to advance towards their critical goals and have access to time and specialized materials beyond class to pursue projects about which they feel passionate. One might expect that teachers simply volunteer their time for this mentoring to occur. But for systematic change to occur, structural reform must occur in teacher compensation (NCMST, *Before It’s Too Late*, 2000), schedules, training and support. For one, teachers must have more flexible time in their schedules to support student agency. Second, teacher education programs must provide physics teacher with the tools they need to cultivate agency.

*What Are the Implications of This Study for Teacher Education?*

Because critical physics agency emphasizes standards-based rigor, teacher education programs must provide pre-service teachers with substantive content and skill knowledge and physics. University departments can be collaborators in this process, providing expertise in physics, through standards-specific coursework, to teachers (Gollub & Spital, 2002). This training should be ongoing once teachers are practicing in schools. Through ongoing training, teachers could keep up with what is happening in physics – for example, what topics might be controversial and relevant for students to investigate through inquiry and debate – and in physics pedagogy – for example, new

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best practices for including a diversity of students in rigorous physics (AIP Report, 2003).

In addition to providing content and skill knowledge in physics, teacher education programs in this discipline should provide exposure to tools for structuring co-generative dialogues (Milne, 2005). This training should begin with a philosophical exploration about one’s belief as a teacher about who physics is for and why, particularly because one’s experience in school was likely in tracked math and science program (Vanfossen, Jones & Spade, 1997). Exploration of critical physics agency cannot take place without teachers combating the fundamental belief that physics is reserved for an elite group of students. Next, teacher should develop tools for exploring students’ fund of knowledge. One way that Calabrese Barton and Vora (2004) have pursued this idea is to have pre-service teachers identify and discuss students’ fund of knowledge through a video-based tool presenting case studies of youth. From this point, teacher education programs might provide teachers with training and tools in action, for example, structures for designing focus groups, co-generative dialogue between students around issues of agency, descriptive, agency-focused unit evaluations and one-on-one interviews of students.

The literature reviewed for this study argues that low-income, minority youth lack access to physics. But the results of the study suggest that the case study youth were capable of engaging in physics not only at a rigorous level but also with the purpose of transforming their identities and their physics curriculum. It is my belief that teacher education focused on co-generative dialogue, funds of knowledge and critical goals is essential training for professors at the university level if this realm of physics is to meet the AAPT standard of “physics for all” and move away from marginalizing particular
groups of under-served, under-represented young people. For me, exploring the idea of critical physics agency both intellectually and for practice in my classroom has been a process of ongoing learning, revision and synthesis. This support the idea that teacher education must be ongoing rather than limited to a short period before one arrives in a classroom.

Implications for Research

Though this research provides insight into how critical physics agency took shape in my particular research context, it also raises several questions about critical physics agency that might be topics by future research. For example:

- If, as this study argues, development of critical physics agency is context-specific, how does critical physics agency take shape in different schools contexts and classroom settings? How does critical agency reflect the identities of other teachers and students? What other types of classroom practices are an expression of critical physics agency? What other resources do students leverage in their pursuit of critical physics agency?
- How is resistance to participation in a physics classroom linked with agency? How do and how can youth who are angry in and absent from class engage in critical physics agency?
• Do students who are exposed to a classroom focused on critical physics agency perform differently on standards-based, project-based, inquiry-based and authentic assessments?

• Through what processes do students transition from using physics as a context to using physics as a tool for agency?

• Are there gender differences between how girls and boys pursue critical physics agency? Are these gender differences mediated by other factors such as academic success and social standing?

• What does it mean for a classroom of students to exhibit collective physics agency? What are the similarities and differences in how collective and individual agency (the focus of this study) are expressed?

• In this study, my focus on envisioning and enacting lesson plans directed students to express critical physics agency through this practice. How do other types of co-generative dialogue (Milne, 2005) result affect the development of critical physics agency?

• How do various types of training, support, scheduling, and compensation affect how teachers articulate and cultivate critical physics agency in their classrooms?
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Appendix A: Interview Protocols

Protocols for Student Case Studies

Interview 1: Knowledge and Skills

1. What do you think are the main topics of this unit? What are you learning about?
2. Follow-up to Question #1 by asking student to describe, in detail, what he or she is learning about the main topics of the unit.
3. What are some things you learned how to do in this unit? What skills that have you acquired or improved?
4. Follow-up to Question #3 by asking student to describe, in detail, the skills he/she is learning in the unit.
5. What grades do you think you are getting for this unit for class work, homework, projects and tests?
6. Why do you think you are getting these grades? What are you doing well, and what could you improve?
7. What parts of this unit do you consider important to learn? Explain your answer.

Interview 2: Conceptual Understanding of Course Material, Nature of Science and Collaboration

1. What are some examples of ideas in this unit that you understood? How do you know that you understood each of these ideas?
2. Follow-up to Question #1 by asking student to describe, in detail, what he/she understood.
3. From this unit, what did you learn about how the universe works or what the universe is made up of? Examples would help!
4. From this unit, what did you learn about inventing or making technology? The more specific you can be, the better!
5. How do you define science? The more examples you provide the better an idea I will have of what you mean!
6. Explain how you imagine a scientist to be and what a scientist does.
7. Give some examples of when you have been a scientist. Try to be as specific as possible – create a picture, in your reader’s mind, of what it was like to be a scientist.
8. From this unit, what did you learn about what it means to do science? Explain your answer.
9. Give an example of a time during this unit when you considered a new idea or changed your mind about something you believed.
10. Give an example of a time during this unit during which you talked about a question that was controversial or to which science does not give a complete answer.
11. Describe a time during this unit when you worked and had a problem. Maybe you disagreed about what to do. Maybe someone wasn’t doing his/her work. It can be something small or big. How did your group resolve this problem?
**Interview 3: Engagement**

1. Did you enjoy completing this unit?
2. Follow-up by asking student to explain his/her answer in Question #1.
3. What was your favorite part of this unit, and why?
4. What parts of the unit did you not want to do? What did you try to avoid or postpone? Explain why you felt this way.
5. Has this unit made you want to study more physics? Why or why not?
6. What have you done in this unit that has made you want to pursue a career in physics?
7. What have you done in this unit that has made you not so interested in being a physicist. Explain your answer!

**Interview 4: Agency**

1. What are some things in your life that you believe? What are some of the things you care about the most?
2. What are your most important goals right now?
3. How does what you did in physics in this unit connect to the ideas you described in Questions #1 and 2? For example, how might this physics unit contribute to what you want to achieve or affect what you care about?
4. How do you think physics has affected the world in which you live?
5. If you were to be a physicist, what kinds of things would you do and what kinds of mysteries would you solve? What would you decide to study and explore?
6. How would you solve the mysteries that you wrote about in Question #7? What steps would you take? What research would you?
7. In our most recent group project, in what ways did you feel that your work went well? In what ways could your work been better?
8. How will your choose your group members differently next time you do a group project? Why will you make these choices?
9. How will you change how your group works together next time you do a group project? Why will you make these choices? How might your group work together better?
10. What did you choose as your topic for your most recent project? In what ways did you feel that your choice was a good one? In what ways could your choice have been better?
11. What choices were you able to make for your most recent projects and unit?
12. Did you get to make any guesses or hypotheses in this unit? Talk about these guesses – were they “correct”? Was it important that they be “correct”?
13. Did you design any original experiments in this unit? Why do you consider these experiments to be “original”?
14. How did you feel about these experiments? What was difficult? What was easy? What was interesting?
15. In what ways would you like to decide what happens in your physics classroom?
Protocols for Families of Students Participating in Case Studies

1. What topics in science interest you?
2. What does it mean, in your opinion, to be informed about science? in physics? Do you consider yourself to be informed about science and physics? In what ways?
4. What types of science do you think your child should learn in school? Why?
5. What do you think about your child pursuing a career in physics? Is this a worthwhile goal?
6. What could you imagine your child doing as a physicist? Why would this work be important?
7. How important is it for your child to do well in physics? Perhaps compare the importance of success in physics to the importance of your child succeeding in English and math. Please explain your answer.
8. What do you think your child is learning by taking physics? What does he/she understand better than before?
9. What can your child do better since he/she started taking physics? How have his/her skills improved?
10. What have you heard from your child about his/her physics class? What does your child like? What does your child not like?
11. Do you think your child is interested in physics? How do you know? The more specific you can be, the better!
12. What do you think are your child’s goals? What does he/she consider most important?
13. Does your child ever connect physics homework or what happened in physics class to anything at home? For example, does your child think about or understand electricity differently? Energy? What things are made of? How technologies are designed and created?
14. How, if at all, does physics connect to your child’s life, values and goals?
15. Does your child have a better sense of his/her goals as a result of the physics he/she is learning? Is he/she better able to achieve these goals? The more examples you can provide, the better!

Protocols for Teachers Participating in Study

Protocol for Co-Planning Physics Teacher

Interview 1: How Teacher Believes Critical Physics Agency Takes Shape in a Classroom

1. What specific knowledge, skills and understanding were you trying to build, through this unit?
2. How do the knowledge, skills and understanding you described connect to the standards in physics set by other organizations?
3. Did you hope to teach anything about the “nature of science” during this unit? In what ways did you try to do this?
4. In your opinion, what were the most engaging parts of this unit? What did you think would catch and keep students’ interest? Were you successful in your predictions?
5. In my dissertation, I have defined agency in the following way: “The process by which youth purposefully enact change, based on their beliefs, whether or not these align with the goals of schooling and socialization.” What do you think of this idea? Is it a focus of your teaching? Could you modify what I have written to reflect your pedagogical values?
6. Are there portions of this unit that emphasize collaborative learning? How do you think these opportunities for collaborative work affect student learning, engagement and agency in physics?
7. Do parents and families participate in the physics unit you are teaching? If so, how has their participation influenced student learning, engagement and agency in physics?
8. What have been the goals of the assessment you have crafted? How successful do you feel you have been in planning assessment that meets your goals? How has the assessment you have designed contributed to student learning, engagement and agency?
9. In your classroom, in what ways do youth explore their identities, particularly their identities as scientists? Examples from unit would be helpful. How does the opportunity for exploring identity in a physics classroom affect student learning, engagement and agency?
10. In your classroom, do the opinions and voices of youth matter? In what way? Examples from unit would be helpful. How does incorporating student voice and opinion into a physics classroom affect student learning, engagement and agency? Examples would be helpful.
11. In your classroom, what types of choices can youth make? Examples from unit would be helpful. How does having choice in a physics classroom affect student learning, engagement and agency? Examples would be helpful.
12. What types of reflection do you emphasize in your classroom? How do these emphases affect student learning, engagement and the ability for youth to make change based on their beliefs? Examples would be helpful.
13. Zacharias and Calabrese Barton (2003) argue that curriculum should be structured with the needs, beliefs and interests of students in mind. In what ways, is this belief related to your teaching and curriculum?
14. Freire describes a process of reflection and action, through education – “learning to perceive social, political and economic contradictions, and to take action against the oppressive elements of reality” (Freire, 1970, 35). In what ways, if any, have you emphasized this idea in this past physics unit? Examples would be helpful.
15. How has an emphasis on Freire’s philosophies affected student learning, engagement and agency in your classroom, if at all?

Interview 2: School Organization/Community and Critical Physics Agency

2. What would say is the mission of the school at which you teach?
3. How is the mission of the school enacted (or not enacted) in the practices of the school?
4. How do the mission and practices of the school affect student learning, engagement and agency in physics?
5. What would say is the culture of the school at which you teach physics?
6. How does the culture of the school, in your opinion, affect student learning, engagement and agency in physics?
7. What would say is the leadership structure of the school at which you teach physics?
8. How does the leadership structure of the school, in your opinion, affect student learning, engagement and agency in physics?
9. How do you feel that the 9th grade Conceptual Physics course at your school has affected student learning, engagement and agency in physics?

Non-Physics Teacher Protocol

Interview 1: How Non-Physics Teachers Believe Critical Physics Agency Takes Shape in a Classroom

1. What is your relationship with the physics teachers at the school? How do you find out about what they teach?
2. What specific knowledge, skills and understanding do you think teachers were trying to build, through the most recent physics unit?
3. Do you think that the physics teachers hoped to teach anything about the “nature of science” during this unit?
4. What do you think most engaged physics students during this unit?
5. In my dissertation, I have defined agency in the following way: “The process by which youth purposefully enact change, based on their beliefs, whether or not these align with the goals of schooling and socialization.” What do you think of this idea? Is it a focus of the physics curriculum at the school? How do you know?
6. Did parents and families participate in the most recent physics unit? If so, how did their participation influence student learning, engagement and agency in physics?
7. Zacharias and Calabrese Barton (2003) argue that curriculum should be structured with the needs, beliefs and interests of students in mind. In what ways, is this belief related to teaching and curriculum in the physics classroom at the school?
8. Freire describes a process of reflection and action, through education – “learning to perceive social, political and economic contradictions, and to take action against the oppressive elements of reality” (Freire, 1970, 35). In what ways, if any, do you think the physics classroom at the school emphasizes this idea? Examples would be helpful.
9. How has an emphasis on Freire’s philosophies affected student learning, engagement and agency in the physics classroom, if at all?

Interview 2: School Organization/Community and Critical Physics Agency

2. What would say is the mission of the school at which you teach?
3. How does the mission of the school, in your opinion, affect student learning, engagement and agency in physics?
4. How is the mission of the school enacted (or not enacted) in the practices of the school?
5. How do practices connected with the mission of the school affect student learning, engagement and agency in physics?
6. What would say is the culture of the school at which you teach physics?
7. How does the culture of the school, in your opinion, affect student learning, engagement and agency in physics?
8. What would you say is the leadership structure of the school at which you teach?
9. How does the leadership structure of the school, in your opinion, affect student learning, engagement and agency in physics?
10. How do you feel that the 9th grade Conceptual Physics course at your school has affected student learning, engagement and agency in physics? Examples, to demonstrate your larger points, would be helpful.
Appendix B: Coding Tree

1. Funds of Knowledge
   1. Description of Types of Goals Students Have
      1. Critical Reflections and Beliefs
         1. Personal
         2. Community
            1. Having choice in how class and school are structured
            2. Affecting Physical Space of Classroom
      3. World
      4. Forced upon them
   2. Academic and Intellectual Goals
      1. Being an expert or resource or seen as intelligent
      2. Exploring curiosity or figuring things out
         1. How physics and biological worlds work
         2. Mixing things and exploring material
         3. Making meaning, seeing why concept is useful
      3. Being challenged or ambitious
      4. Definitions of, beliefs about and goals in science
         1. Being a scientist
         2. Learning science knowledge or reviewing what you know
         3. Belief that science can be done by everybody and or with everyday objects
         4. Belief that science is collaborative or social or involves synthesis
         5. Belief that science is a process of revision and relearning
         6. Belief that science can be used to enact change
7. Understanding
5. Improving in beyond physics classes and skills
6. Do the work according to teacher expectations and time frame specified and structure provided
7. Get the help you want or need to do better
8. Contrarian
9. Being focused or working hard or having a plan
10. Students wants particular grades
11. Being original or learning something new or bigger than usual
12. Being intellectual in and of itself or having this opportunity

3. Social
1. Being heard and participating and being respected
2. Creating or working with and reinforcing group
3. Being seen as a leader or expert or role model
4. Connection with a teacher or adult or school
5. Having an orderly classroom
6. Helping friend or self understand and succeed academically through working together
7. Being focused even when peers are distracted
8. Justice and Fairness in Consequences
9. Helping struggling or younger
10. Having or almost having fight
11. Not being taken advantage of

4. What is Personal and What Kid Envisions for Future
1. College and future education
2. Career
3. Hobbies
4. Staying out of recovering from being in jail or negative behaviors as defined by self

5. Financial or Resources or what Money can buy

6. Maintaining home or building

7. Developing independence, being treated in age appropriate ways

8. Religion

2. Background

1. Family

   1. Description of Family and Culture including values
   2. Connection between family culture values and personal goals
   3. Appreciation of family sacrifice

2. Prior experiences in school and view of school

   1. Academic Success
   2. Desire for small school and personal setting
   3. Influence of prior teachers
   4. Prior social interactions with peers

2. Instances of Critical Physics Agency

   1. Individual Critical Physics Agency

      1. Making Meaning and Enacting Change

      1. Science as Context Venue through which Action Happens

         1. Science as setting to think about reflect or act on identity

            1. Academic Goals
            2. Career and Life Goals
            3. Critical Beliefs
            4. Intellectual Goals
2. Science as setting from which to think about act on school classroom
   1. Classroom Structures
   2. Relationships
   3. Curriculum

2. Science as Tool -- conscious active use of science
   1. Actively consciously use science to explore shape identity
      1. Academic Goals
      2. Career and Life Goals
      3. Critical Beliefs
      4. Intellectual Goals
   2. Actively consciously use science to explore shape school
      1. Classroom Structures
      2. Relationships
      3. Curriculum

2. Having Voice
   1. What Students do in class is real or authentic
   2. Can express their opinions (heard)
   3. Opinions result in change (listened)
   4. Equitable Voice

2. Collective Critical Physics Agency
   1. Relationships with peers mediate physics experience and actions
      1. Social
         1. Being heard and participating and being respected
         2. Creating or working with and reinforcing group
         3. Being seen as a leader or expert or role model
4. Science as a context relationships
5. Science as a Tool Relationships
6. Helping friend or self understand and succeed academically through working together
7. Being focused even when peers are distracted
8. Justice and Fairness in Consequences
9. Helping struggling or younger
10. Having or almost having fight
11. Not being taken advantage of

2. Contrarian
   1. Not buying mission of school
   2. Resistance to effort
   3. Resistance to or discomfort with inquiry
   4. Resis School Class Rules or Structure
   5. Resistance to interdisciplinary

2. Experience with adult mediates physics experience and actions
   1. Do the work according to teacher expectations and time frame specified and structure provided
   2. Get the help you want or need to do better
   3. Connection with a teacher or adult or school
   4. Having an orderly classroom

3. Critical Reflections and Beliefs
   1. Personal
   2. Community
      1. Having choice in how class and school are structured
      2. Affecting Physical Space of Classroom
   3. World
4. Forced upon them

3. Self-Reflection
   1. Critical goals and Reflect on Action Research
   2. Managing Team Teaching and Collaboration
   3. Time Management
   4. Envisioned v Actual Curriculum
      1. Different
      2. As envisioned (aligned)
         1. Being challenged or ambitious
         2. Being a scientist
         3. Being original or learning something new or bigger than usual
         4. Being intellectual in and of itself or having this opportunity
         5. Science as context connection to career life goals
         6. Science as tool connection to career life goals
         7. Being engaged or interested or having fun or proactive in education

4. Physics Classroom and School Context Resources
   1. Physics classroom resources
      1. Knowledge Understanding
         1. Making meaning, seeing why concept is useful
         2. Being challenged or ambitious
         3. Learning science knowledge or reviewing what you know
         4. Understanding
         5. Being original or learning something new or bigger than usual
      2. Skills
         1. Definitions of, beliefs about and goals in science
1. Being a scientist
2. Learning science knowledge or reviewing what you know
3. Belief that science can be done by everybody and or with everyday objects
4. Belief that science is collaborative or social or involves synthesis
5. Belief that science is a process of revision and relearning
6. Belief that science can be used to enact change
7. Understanding

2. Improving in beyond physics classes and skills

2. School Resources Students Acquire Use Experience
   1. School Vision and Culture
   2. Rigour
      1. Higher Order Thinking Skills
      2. What Students do in class is real or authentic
Endnotes

1 www.nsf.gov


4 http://nces.ed.gov/

5 http://www.nycteachingfellows.org/

6 http://webphysics.iupui.edu/jitt/jitt.html

7 http://www.colorado.edu/physics/2000/index.pl

8 http://web.phys.ksu.edu/vqm/

9 http://www.slac.stanford.edu/gen/edu/education.html

10 http://cfa-www.harvard.edu/cfa/sed/projects.html

11 http://einstein.stanford.edu

12 www.lawrencehallofscience.org

13 http://www.amnh.org/education/child_youth_fam/?src=k_b

14 http://www.smith.edu/summerprograms/ssep/


16 http://nces.ed.gov/

17 http://www.schoolfunding.info/states/ny/lit_ny.php3

18 Botball was a robotics competition sponsored by the KISS (Keep It Simple Stupid) robotics organization. The tournament involved students from across the United States who used legos, interactive C and two robot brains to complete tasks on a gameboard (see www.botball.org for more details).