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Develoing a framework for critical science agency through case study in a conceptual physics context

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Abstract In this manuscript we examine how two students develop and express agency in and through high school physics. We tell the stories of two youth from a low-income, urban community to elucidate the important components of critical science agency in a physics context, and to situate a set of claims about how youth develop and express this concept. This research is part of a larger multiyear study of democratic practice in middle- and high-school science. We present three claims: (a) that critical science agency is intimately related to the leveraging and development of identity, (b) that critical science agency involves the strategic deployment of resources , and (c) that developing critical science agency is an iterative and generative process. Two university researchers have co-written this paper with the two students whose experiences serve as the cases under investigation, to provide both an "emic" perspective and student-focused voices that complement and challenge the researchers' voices.

Keywords Agency · Critical · Generative · Identity · Iterative · Physics · Resources

In this paper, we extend Turner and Font's operationalization of critical mathematics agency to also include how students identify themselves within science in ways that advance their participation in community. This means that one both views the world with a critical mindset and envisions how to advance in the world or change the world into a more socially just and equitable place with and through science, while considering oneself as powerful scientific thinker and doer of science. In other words, critical science agency in a

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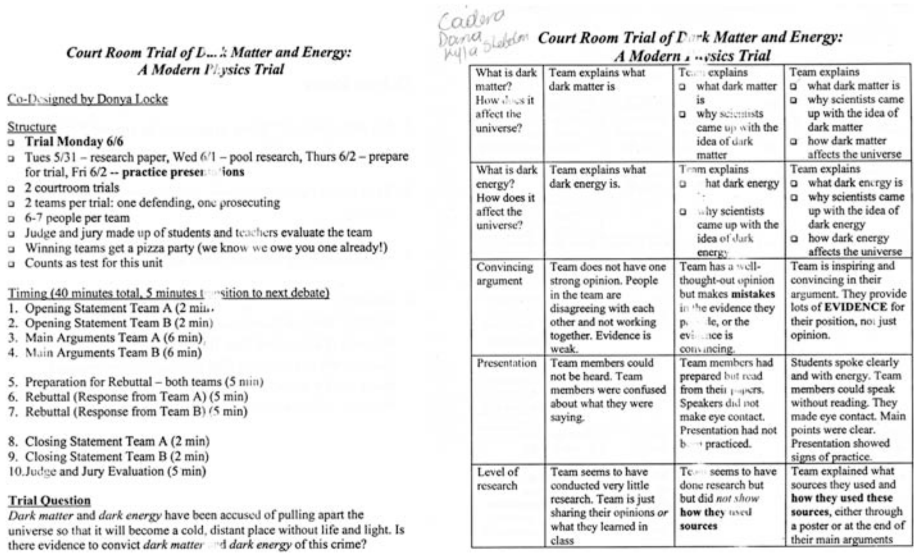
physics context implies that students: (a) gain deep understandings of physics and the processes, skills and modes of inquiry associated with this content, (b) identify themselves as experts in one or more realms associated with physics, (c) and use physics as a foundation for change, such that their identity develops, their position in the world advances, and/or they alter the world towards what they envision as more just.

Ninth grade conceptual physics

About half way through the school year, the students in Jhumki's ninth-grade conceptual physics course were presented with an opportunity to co-design a lesson for their class. The option was voluntary, but the teacher presented the opportunity to all of her students as one way to incorporate students' voices and experiences in her planning and teaching of physics. One student, Donya, took up the challenge because, as she described, she wanted to connect what she was learning in her physics class with her interest in becoming a lawyer, and she wanted her peers to be able to make similar connections. Donya initially told Jhumki that for her lesson plan she wanted her peers to engage in a class debate on the gravitational pull of black holes.

In describing her reasons for selecting the debate format and this topic, Donya cited a past experience from physics class, where she and her peers argued about the impact on the world of Einstein's $E = mc^2$ equation. Donya was excited by the idea that a high school science student could take a position on important scientific ideas and could argue about the impact of an idea developed by someone as famous as Einstein (See Fig. 1 in which Donya is describing her perspective on debate in science). She also liked the idea that debates on controversial topics in science do not necessarily have right and wrong answers but that they require students to develop and defend a stance. Donya thought that if she set up a debate then her peers would have a chance to think through ideas instead of repeating back what their teacher construed as the "right" answer. Donya thought that a debate would better prepare her for her future as a lawyer. She also engaged in a sophisticated view of science as tentative, rather than a canon of static truths.

Fig. 1 Donya discussing the role of debate in science



Court Room Trial of D... Matter and Energy:
A Modern P...ysics Trial

Co-Designed by Donya Locke

Structure
- **Trial Monday 6/6**
- Tues 5/31 – research paper, Wed 6/1 – pool research, Thurs 6/2 – prepare for trial, Fri 6/2 -- **practice prese... ions**
- 2 courtroom trials
- 2 teams per trial: one defending, one prosecuting
- 6-7 people per team
- Judge and jury made up of students and teachers evaluate the team
- Winning teams get a pizza party (we know we owe you one already!)
- Counts as test for this unit

Timing (40 minutes total, 5 minutes t... sition to next debate)
1. Opening Statement Team A (2 min)
2. Opening Statement Team B (2 min)
3. Main Arguments Team A (6 min)
4. Main Arguments Team B (6 min)

5. Preparation for Rebuttal – both teams (5 min)
6. Rebuttal (Response from Team A) (5 min)
7. Rebuttal (Response from Team B) (5 min)

8. Closing Statement Team A (2 min)
9. Closing Statement Team B (2 min)
10. Judge and Jury Evaluation (5 min)

Trial Question
Dark matter and *dark energy* have been accused of pulling apart the universe so that it will become a cold, distant place without life and light. Is there evidence to convict *dark matter* ...d *dark energy* of this crime?

Caiden Donya Kyla ...

Court Room Trial of D...k Matter and Energy:
A Modern ...ysics Trial

What is dark matter? How does it affect the universe?	Team explains what dark matter is	Te... explains - what dark matter is - why scientists came up with the idea of dark matter	Team explains - what dark matter is - why scientists came up with the idea of dark matter - how dark matter affects the universe
What is dark energy? How does it affect the universe?	Team explains what dark energy is.	T...m explains - ...hat dark energy ... - ...hy scientists came up with the idea of dark energy	Team explains - what dark energy is - why scientists came up with the idea of dark energy - how dark energy affects the universe
Convincing argument	Team does not have one strong opinion. People in the team are disagreeing with each other and not working together. Evidence is weak.	Team has a well-thought-out opinion but makes **mistakes** in the evidence they p... le, or the evi...nce is con...ncing.	Team is inspiring and convincing in their argument. They provide lots of **EVIDENCE** for their position, not just opinion.
Presentation	Team members could not be heard. Team members were confused about what they were saying.	Team members had prepared but read from their papers. Speakers did not make eye contact. Presentation had not b... practiced.	Students spoke clearly and with energy. Team members could speak without reading. They made eye contact. Main points were clear. Presentation showed signs of practice.
Level of research	Team seems to have conducted very little research. Team is just sharing their opinions *or* what they learned in class	Te... seems to have done research but but did *not show* **how they** used **sources**	Team explained what sources they used and **how they used these sources**, either through a poster or at the end of their main arguments

Fig. 2 Handouts for the debate created by Donya and Jhumki

With help from Jhumki, Donya expanded her debate from a focus on the gravitational pull of black holes to include the impact of dark matter and energy on the future of the universe. Donya wanted each student to take responsibility for understanding the material, so she instituted a requirement for each student to write a paper on the topics of dark matter and dark energy during the week leading up to the debate. See Fig. 2 for examples of material that Donya and Jhumki created together for the debate.

On the day of the debate, Donya acted as the facilitator and judge. Based on research they had conducted in response to questions such as: "What do scientists think dark matter is?" or "What is the evidence that the universe is accelerating apart? How convincing do you think this data is?," teams of students presented pro and con arguments for whether dark matter and dark energy were pulling apart the universe. Each team had 5 minutes to present an opening statement and then faced 5 minutes of questioning from the other team followed by a few minutes to respond to questions. At the end of debate, students voted on what they thought was the best answer to the debate question.

Donya created rules of conduct for the debate, for example: "No put downs such as 'Your argument is stupid'" and "You must raise your hand if it's not your time to speak." She also created a rubric for the debate, which she and Jhumki used to evaluate whether the groups participated in the debate, how respectful they were to other teams, and the level of detail and specificity of answers in their written report. For example, one criterion in the rubric was: "Team is inspiring and convincing in their argument. They provide lots of evidence for their position, not just opinion."

Despite what Donya and Jhumki considered to be detailed planning, Donya felt that the debate was unsuccessful. In her particular ninth-grade section, she felt that the students were not as actively engaged as she had hoped. Within groups, there was confusion as to who was speaking and in what order. Students did not seem to understand how to link the content they had learned on dark matter and energy to an evidence-based stance on how these shape the universe. Donya's observations of these problems inspired her to envision ways in which class could be altered to better support students in learning to make arguments. For example, she felt that the ninth-graders might benefit from public-speaking lessons. Also, Donya thought that students needed practice with small group debates before engaging in a full-class debate.

The following year, Jhumki incorporated Donya's debate in her ninth-grade physics class. When she prepared students for the debate, she used Donya's suggestions. She had students discuss what it means to speak well in public and had them practice presenting their stances to each other, prior to the final debate. The students also took on personas of religious leaders and physicists, which helped them engage in the idea of interpreting information from different perspectives. Far more students participated successfully in the debate that year, as a result of Donya's reflections on how to support students in debating complex, controversial science topics.

Donya's experiences helping to set up a class debate on dark matter and energy are a glimpse into how she helped to create a place of engagement in school science that supported who she was and wanted to be. Donya made use of the opportunity to plan a lesson in collaboration with her teacher to experiment with the idea that learning science was not always about right and wrong answers, but could also be about arguing science ideas, in evidence-based and reflective ways.

The vignette about Donya suggests that she was an agent of change in how her physics class was structured. A primary purpose of education is to support students in becoming agents of change (Freire 1970). Change is an interesting concept because it could mean larger social change or smaller incremental change. In the case of Donya's experiences crafting a debate on dark matter, we see, if for a moment, a young woman who begins to understand what it means to think and know scientifically and to use the opportunity of lesson planning to help her peers to see that too. Given that school science for many youth is an experience in getting right (or wrong) answers, Donya sought out significant changes in how science is learned, albeit on a small scale in her personal classroom context. Donya certainly experienced challenges in enacting her lesson—things did not turn out in the ways she had planned. But her reflections on what went wrong moved her and her teacher to better understand how students learn and what supports they needed to engage in debates.

For Donya, and for other students in our larger study, their experiences in physics simultaneously engaged them in content knowledge and education for change, or what we refer to as "critical science agency." In this study, we investigate when and how students developed "critical science agency" in a physics context and what this meant for their deeper engagement in physics learning. Our research is framed around the following questions:

- What does critical science agency look like in a ninth-grade conceptual physics classroom?
- What key processes and structures are involved in the development of critical science agency in a physics context?

Talking/writing about agency from multiple perspectives

To make sense of how or why youth might engage in critical science agency in a high school physics class is a complex endeavor—and one that requires us to interrogate activity from multiple angles. Thus, in our stories about critical science agency, which follow, we work to incorporate at least three perspectives: (1) Teacher-researcher (with the lens of teacher research methodologies), (2) student-researcher, and (3) traditional university-based researcher (with the lens of critical ethnography). We do this not only to try to bring to the fore both an "emic" and "etic" perspectives to a teacher and her students' experiences learning and taking action in high school physics, but also to allow our subjectivities to be exposed and interrogated (Kincheloe and Steinberg 1998). We also wanted to employ methodologies of change. By involving multiple players in unpacking critical science agency in the process of teaching and learning physics, then we believed we would be able to engage in a generative process, allowing the research/researched nexus to collapse in order to advance the concerns of the research participants. Furthermore, we could help to surface the voices of the research participants—the teacher and the students—in order to challenge traditional power differential in science classrooms and keep our stories from propagating the status quo (Elmesky and Tobin 2005). Finally, we felt our attempt to balance these multiple perspectives through the deployment of critical ethnographic research practices would help us to document, analyze and act on the discriminatory practices supported by schooling. In our study, we drew upon critical ethnography as a foundation from which to build analysis focused on how students challenged traditional classroom power structures through the design and enactment of curriculum, with a focus on agency and authority.

To further make sense of the stories we tell, we want to step back for a moment to highlight the different forms of data we draw upon to tell these stories. We do so because we want to foreground that while our stories are subjective—they are grounded in our lived experiences that frame our participation in high school physics—they are also thoughtfully crafted. We have purposefully sought out forms of data (and data acquisition) that would challenge the assumptions we brought to bear in our study.

Thus, it was during the 2004–2005 school year that Jhumki, the teacher-researcher in this study, kept careful notes of her classroom practice. Jhumki is a teacher-researcher who had taught high-school physics and biology for four years at the time when the research began. She kept a teaching journal with weekly reflections on how she felt students responded to curriculum and any particular challenges or successes that stood out from the week. She also engaged in sustained dialog with a group of student-researchers in an effort to further unpack their experiences and to allow their voices to frame the next steps. These dialogs took the form of semi-structured interviews with five students in her class who represented a range of interests, abilities, and levels of participation in the school's ninth-grade conceptual physics classes, which served eighty-five students. These five student researchers also engaged in "think-alouds" in which they envisioned original experiments and lesson plans connected to the unit they were studying. They also talked about about what they most liked about their physics class and the types of changes and additions they would make to the class to make it more engaging and relevant to their lives. Jhumki also talked with family members of the student researchers to examine the importance of family in students' decision-making. Jhumki also collected student work from the five students who were interviewed, which included their projects, class work, homework, journals, labs and assessment as well as materials that students chose for their inter-disciplinary end-of-year portfolios. She also gained access to grades, attendance and lateness records. She gathered archival material including written records of conversations with individual and groups of students, observations of students, and student journals, class work, homework, projects and assessments. She also relied upon her own and other teachers' records and planning notes about school practices such as advisory, town halls and ninth-grade-level teacher planning.

Furthermore the student researchers participated in a series of metalogues about the course; they were invited to write reflections about their life histories, their experiences with science in school, what they learned in physics, their long-term and short-term goals, and their ideas for improving physics education. These students also participated in how we analyzed the data by providing reactions to key claims as they emerged in the analysis.

To help bring additional perspectives to Jhumki's and the students' work, Angie participated as an analyst and story teller, engaging both the data and with Jhumki and her students in a dialog about the results (noting however, that Angie's participation took place electrically, given her physical distance from the students). Angie is a researcher who did not teach in Jhumki's school, but worked closely with her on the research conducted at her school. As an urban educator who embraces critical methodologies, she persisted in helping to locate ways for participants (teacher and students) to gain and express voice in this study. She brought a critical ethnographic analytic framework that we used to help us expand the range of data and analysis techniques available to us, and to help us see things from an outsider's point of view (although we admit she was not a complete outsider!). While Jhumki was concerned with looking across the data sources to the types of goals the students had for themselves, their communities and world and how this intersected with youth identity and agency development, Angie was concerned with the students' life histories and the dialectic relationship between how youth sought to express these histories with the resources they purposefully sought to access and activate. Of course there is overlap between these two approaches, and we used these points of overlap as well as contradiction to flesh out our stories. The student researchers, too, contributed to our data analysis and writing, however, we did not "give" them an analytic framework to use. Instead, we wanted their raw feedback and insights so that their stance on the data could be as authentic and reflective to their standpoints as possible.

One could argue that this process helped our data to be more reliable, given that it abides by triangulation of data sources. More importantly, however, we feel this process allows us to work towards a greater objectivity by allowing us to circle a set of ideas, claims, and assumptions, from multiple standpoints (Harding 1993). However one chooses to reflect upon this point, we believe that working to tell a story about youth's critical science agency only truly responds to and builds upon their agency if authentic approaches to student voice are incorporated in how we worked with and wrote about our data. Furthermore student authorship challenges notions of youth as objects of research and instead honors their deep, rich knowledge of their own lives and school setting.

Situating critical science agency

Our stories are located in The School for Social Change, a small public school that opened in the Sunnyside Park neighborhood of New York City in September 2004, as part of a wave of small new schools authorized by the city in the context of school reform. The school opened with sixth-graders and ninth-graders; the school now serves 525 students, ranging from grades six to twelve. The school, with the exception of a start-up grant from the Gates Foundation, received regular public education funds. It was designed to attract all ranges of neighborhood students. Most students at the School for Social Change were from the Caribbean diaspora. Approximately ninety-five percent of the high-school students at the School for Social Change were black. Almost all spoke English as a first language, though many recent immigrants spoke English with a different accent and structure than their teachers and peers in the United States. Approximately six percent of high-school students had Individualized Education Plans, an indicator of some form of legally-mandated special education.

The school's mission emphasized student activism and leadership, in the context of college preparation for all students. All ninth-grade students at the school enrolled in conceptual physics, a course that Jhumki planned with one other teacher. The decision to offer physics to *all* students early in their high-school careers is unusual and innovative for both New York City and the country at large (Kelly 2004). In the next section we discuss why this commitment to physics literacy for all is important.

Why pursue physics literacy for all?

A number of authors explore the idea of scientific literacy, producing various definitions of this concept (Laugksch 2000). Recently, there have been growing debates on whether the science education community's focus on science literacy should also explicitly incorporate notions of citizenship and democratic participation (Hobson 2003). For example, schools could be more centrally concerned with "civic" science literacy (Miller 2002), which focuses on (1) scientific understandings of basic foundational ideas like matter and molecules as well as on the nature of scientific inquiry, and (2) the development of a regular practice of consuming science information through reading about and evaluating scientific ideas as they relate to the public sphere. This view of science literacy is not drastically different from those ideas put forth by Project 2061 (Benchmarks for Scientific Literacy 2003) when this project first introduced "science literacy" to the science education community's lexicon in the 1980's. However, the emphasis (or balance) between "what" one should know and "why" this knowledge ought to be taken up in daily life differs in civic science literacy, with more emphasis on how and why public consumption of science ought to take place.

Despite calls for science literacy or even civic science literacy, it has become common knowledge that most pupils in the US school system fall short of this goal. Nowhere is this more profound than in the domain of physics. Physics, in particular, has historically been reserved for "elite" students, such that most students graduate from high school without any exposure to this discipline. A recent study revealed that only 23% of all students in public schools in New York City enroll in high school physics (Kelly 2004). Girls, minorities, students with disabilities, and youth from rural settings are even less likely to have access to and experience success in physics (Gollub and Spital 2002).

Whereas physics has a reputation for sitting on top of the school science hierarchy, with complex and abstract explanations for the physical world, in reality, physics is a foundation for a diverse range of understandings across scientific domains. For example, how we explain the structure of the universe, weapons and global politics, energy sources, digital technologies, and biomedical devices, all depend upon physics, to some extent. Furthermore, millions of dollars of federal research money are regularly allocated for research in physics and associated fields—approximately $5 billion per year for engineering and $4 billion for physical sciences (National Research Council 2001). Given the ubiquitous influence of physics in our lives and the resources devoted to this discipline, it is important that students learn physics content and understand how reliable this content is, by exploring the processes by which physicists arrive at different conclusions.

Analytic choices: a study in contrasts

We offered the option of participating in the study to all seventy-five ninth-grade students at the research site. Ten students submitted consent forms. Five of these students opted to participate in group interviews rather than the longer individual interviews. So, our final group of case study youth included two male and three female students. Four were students who described themselves as of Caribbean origin; the other identified herself as of Puerto Rican origin. The five youth achieved a range of grades in physics. The two boys struggled to pass their first semester of physics and were sometimes suspended; one of the boys often came to class late and skipped class approximately once per week or frequently left the room mid-class. Two of the girls frequently achieved assignment grades of As and Bs on assignments; one girl received an A in physics throughout the year and was on honor roll for her grade each quarter.

Choosing "opposites" is important in presenting case studies that contribute to the development of theory (Yin 1994). So, in this paper, we chose to focus on the stories of two of our student-researchers, a boy, Neil, and a girl, Donya, who were contrasts to each other in several areas. Neil was a very recent immigrant to the United States, having moved from St. Lucia at 14 years old (at the beginning of the school year in which he participated in this study). He struggled to pass his ninth-grade courses, was interested in a career in science, was often suspended and penalized for disruptive behavior, and worked with Jhumki practically everyday on robotics development. Jhumki met Neil's father approximately once a week over the course of his ninth-grade year, to discuss academic and behavioral issues that arose at school or Neil's progress and interest in robotics. At the beginning of the school year Neil was particularly disruptive in class, and his peers were openly critical about how he contributed to their learning environment.

Donya had lived in the United States for several years, was on honor roll, expressed an interest in a career in law, and received high praise from her teachers on her progress reports regarding her learning and behavior. For example, a history teacher described her as: "a hard-worker, a top student, highly-intelligent, energetic, eager." She was largely independent in her regular academic work, rarely coming in for physics help. During the study, Jhumki met Donya's guardian only once (at parent-teacher conference). Donya got along with most of her peers and participated in many of the school's extracurricular activities, with her favorite activities being track-and-field and GlobalKids, an after-school activity that helped students be activists in the larger world.

Stories of developing critical science agency in a physics context

We begin this section with Donya's and Neil's stories of critical science agency. For both students, the story is their own personal narrative, which they wrote themselves. For authenticity purposes we leave their narratives in the first person, but italicize them to offset them from the rest of the text. The purpose of these stories is to introduce the readers to the participants, as they describe themselves in their own words. Following the vignettes we reflect upon their stories to unpack what critical science agency can look like in a high school ninth-grade conceptual physics classroom.

Neil's story

My name is Neil, and I attend the School for Social Change, which is located in Brooklyn, New York. I am an eleventh-grader. During my freshman year of high school at the School for Social Change I met this wonderful teacher named Jhumki. She taught me science for 2 years in both ninth- and tenth-grade. Jhumki came to me one day and asked me if I would be interested in robotics and the New York/New Jersey Robotics tournament. My first response was "No. I won't be able to build a robot. It's too hard" Then after 2–3 weeks I told her "Yes, I would love to learn about robots." And from there my future and goals were to build robots for the military and Homeland Security. My main goals were protecting soldiers and finding terrorists. Robots can improve the life of my fellow comrades dying in the combat field. My cousin served in Iraq for 1 year which was very painful not only for him but for his parents. However after high school I plan to join the army. "Hooahhh!!!"

Besides joining the army I have many other goals I want to achieve in the near future. I am a student who is very interested in robots. I have participated in the New York/New Jersey Robotics tournament for 3 years now. My teammates and I came up in the top 10 in the competition where we had a big challenge to face ahead of us.

I also learned about robots through the ninth-grade science fair. The ninth-grade science fair was something I will never forget because the science fair showed and taught me a lot about how seriously I take robotics. For the science fair I built a robot that went back and forth (see Fig. 3) with a mechanical claw attached to it, without any remote control—just in response to its surroundings, based on a program I downloaded from a computer into the robot's brain. The skills I have learned with regard to robots are to build a powerful robot that will be able to move around and is aware of its surroundings. I have learned to attach sensors so that the robot can be alert regarding what's in its sight and programming in Virtual C, which is a very difficult thing to do. The reason why it's difficult to do is because you must write the correct program in order to have a very successful mission for the robot. (Any slight error will cause the robot to fail its mission.) I increased my programming skills by taking a two-day workshop that introduced me to the robot before the first year I started the competition and by reading a manual on programming and playing around with the programs.

Donya's story

My name is Donya Locke, and I am about to become a senior this year at the School for Social Change. I am the type of student who likes to be challenged and I find no joy in doing work that is fairly easy. I tend to get very frustrated when I know right off the top of my head what I am supposed to do. I like to think of myself as a strong and intelligent person. Therefore I often try to go beyond my ability. I set certain goals for myself that I try my hardest to accomplish. I also love to get involved in many different activities. I feel that my brain takes me beyond where I should be and that's a good thing.

Since I was in Junior High School, I have never been a big fan of science. However, I try to get involved with various aspects of it because you can really realize that it's very

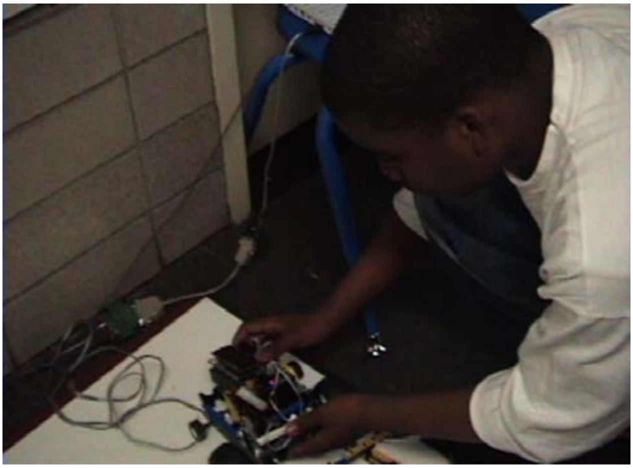


Fig. 3 Neil and his robot at the ninth-grade science fair

interesting. At this point, I am linking even more because it's growing on me, which helps me understand it better.

In my ninth-grade year I created a science lesson for my peers. For extra credit I helped my physics teacher plan a lesson on black holes. The purpose of this lesson was for the students to learn more about dark matter and more specifically black holes. It was also an opportunity for them to be able to argue for and against the topic. At first I did not know what I was doing but I used my career goals to help get through it. When I grow up, I want to become a lawyer so what I decided to do was have a debate. One question was "If any object ever gets sucked into a black hole will it be able to get out?" So we split the classroom into two groups, one side said no and the other said yes and they had to use research to prove why they are correct. In this lesson, my role was the facilitator and the judge.

The classes did very well however they had trouble using the information they had as arguments for the other side. Another set-back was that students chose not to participate but instead kept their heads down and were quiet after entering the room.

The relationship between learning, agency, and physics literacy

The stories include references to a range of physics topics and nature of science processes. But before we analyze their stories from the lens of critical science agency, we need to define what learning in physics means and what does it, or should it, mean to become "physics literate?" How ought this relate to the goals of civic science literacy that we have described previously, if at all?

Both Project 2061 and National Science Education Standards (National Research Council 1996) argue for a stance on literacy and physics that combine content, inquiry skills, and habits of mind but do not necessarily offer insights into how a powerful combination of these three critical areas ought to frame participation in a democratic society. While both of these major policy documents carefully state the importance of conceptual understandings in making sense of human action and interaction, little attention is given to what this might mean or look like. In addition to content areas and inquiry skills, physics literacy also ought to take into account how and why physics is taught. Physics courses should be taught in a manner that "inspires student understanding and enthusiasm, and is relevant to the cultural and social needs of students and society" (Hobson 2003, p. 110). We believe Hobson advances how we ought to be thinking about science literacy; his point, however, stops short of engaging the idea that learning is about agency, about transforming one's world.

Our own critical reflection upon physics literacy has led us to wonder about the relationship between learning and knowing science and using that knowledge to take action in one's everyday life. More specifically, we have come to wonder about the relationship between science literacy (or in our case physics literacy) and agency.

The idea of agency as an integral part of learning

Socially-situated approaches to learning

Learning, thinking and knowing involve "relations among people in activity with, in, and arising from the socially and culturally structured world" (Lave and Wenger 1991, p. 51). Such situated approaches to learning offer a powerful break from more deterministic approaches, which suggest that knowledge and learning are cerebral only, leaving the nature and context of the learner and his/her world unexplored. Yet, critical and feminist perspectives also remind us that not all situations—and those individuals, cultures, discourses, and histories that make up those situations—are equally valued. When we describe learning as situated, we must also describe how "situations are themselves confluences of widely distributed streams of activity" (Nespor 1997, p.169). To unpack this point, we construe education as ideally a process of developing a critical consciousness with respect to context, with the power to transform reality, positioning the learner as a growing member of a community, with expanding roles and responsibilities (Freire 1970).

Thus, if learning is reflected in one's changing participation in social activity, then we must also consider as part of learning: (a) the roles that youth generate or accept for themselves within science-related communities, (b) their reasons for participating in particular ways, and (c) the relationship they perceive these roles have to the knowledge and practice of science. Here we view these articulations of what it means to be successfully engaged in science (i.e., successful science learners) as both products of and contributions to one's location in the world.

The importance of agency

This take on learning underscores the importance of *agency*. When individuals or groups act upon, modify, and give significance to the world in purposeful ways, with the aim of creating, impacting and/or transforming themselves and/or the conditions of their lives, we think of this as agency (Holland 1998). Some have argued for a much more political orientation to agency and the importance of people taking some action to topple oppression, to bring about justice-oriented change, or to make some kind of difference in their lives (Freire 1970). Vital to this awareness-action cycle is the process of resisting social norms by locating them as cultural rather than normative as well as learning how to enact resources to uncover oppression and recover from it (Butler 2004). Learning to work against oppression involves a process of understanding the effects of oppression and leveraging resources to act against it. One study depicts a student's efforts to rely upon social supports at his school for gay and queer youth, so he could change his trajectory from a student who originally chose not attend school to one who engaged in school in ways that allowed him to graduate (Blackburn 2004). Developing agency for this student involved choosing goals he hoped to achieve in his community (tolerance education and personal academic success), and enhancing the repertoire of knowledge and skills he had to enact his goals.

Critical science agency as an iterative and generative process linked to identity and the strategic deployment of resources

Defining critical subject agency

Critical agency has taken up an important place in educational research framed around research on issues of equity and social justice. Whereas the vast majority of research on critical agency tends to focus generally on students' abilities to build critical awareness and engage in acts of social transformation, a subset of this work is more deeply grounded in how participation in *subject matter communities* frames one's enactments of critical agency. For example, urban sixth grade mathematics students have developed a sense of *critical mathematics agency*, or of viewing the world with a critical mindset and engaging in action aimed at personal and social transformation through developing deep and rigorous understandings in mathematics, through participation in a novel mathematics program focused both on standards and on real world concerns (Turner and Font 2003).

Next we look across both stories to describe how critical science agency in a physics context emerged as the expression of identity and the strategic deployment of resources and identity. In addition, we discuss how this process was iterative and generative. A summary of the findings regarding Neil and Donya's critical science agency is expressed in Table 1.

Critical science agency is intimately related to the leveraging and development of identity

Neil

Neil's story in this study begins with him arriving from St. Lucia and struggling academically and socially in his school. It unfolds with him taking on ever-expanding challenges in physics, computer science and engineering, building relationships with teachers and students and establishing himself as an expert and agent of change at his school.

Neil's story suggests that the expression of critical science agency—Neil identifying himself as powerful science thinker and doer in ways that advanced his participation in his community—was connected to the expansion of his identity (taking on the roles of expert and teacher and building social networks with peers and adults). In Neil's story, we begin to see how a young man worked with his teacher to create opportunities to expand his knowledge of robotics, and have that knowledge mean something for his conceptual physics class. In the process of doing so, he was afforded opportunities to draw upon his deep understanding of robotics, electricity and forces and motion, to build a new identity in his science class as an expert in robotics, and to use that knowledge and identity to transform some aspects of his own life and his physics classroom.

Neil—an expert in robotics

In the weeks before the science fair, Neil sat at the back of class at a table separate from his peers. Each day, he spread out across the table the parts of his robot and a dedicated laptop and worked on either building the physical structure of the robot or programming its movement. Students visited his construction area/design site during these weeks to look at his robot as it developed and to ask him questions about his next task. He rarely spoke in class except to ask his teacher for help with his work. This was in sharp contrast with Neil's usual behavior—prior to the science fair unit, he often moved about the room, participated in name-calling and arguments with his peers and his teachers, sometimes stared and rolled his eyes at students, burped loudly in class, and called out unexpected and often rude comments. In an interview, Neil described his behavior as a purposeful decision to "act dumb."

Learning programming required Neil to develop expertise. He had to read from manuals, test out sample programs, and spend hours trouble-shooting with his physics teacher and with mentors at the local university that sponsored the robotics competition in which he was involved. Revising his robot time and again taught Neil to build a strong, self-contained robot.

Table 1 Development of Neil's and Donya's critical science agency in a physics context

	Neil	Donya
Identity development	Developed as:	Developed as:
	Robotics expert	Expert scholar and student who cultvited depth of knowledge regarding black holes and dark matter/energy
	Expert teacher	Scientific process expert with focus on originality and inquiry
	Socially-networked with peers and adults	A student who challenged social stereotypes about the abilities of urban black youth in science
Leveraging resources	In- and out-of-school opportunities to develop nontraditional knowledge (how to build and fix robots and computers)	Strong academic ability and work ethic
	Adult and peer networks related to robotics	Sense of self as a future lawyer
		Opportunity for dialogue with her teacher
		Experiences with physics (debate) non-science opportunities (end-of-year exit project) and out-of-school opportunities (local college visit)
Iterative & generative nature of critical science agency	Iterative:	Iterative:
	Regularly tested and modified robotics programs based on his results	Expanded her knowledge of black holes based on examining the extent of her understanding
	Worked with his peers to test their and his programming ideas	Improved teaching techniques for constructing a debate by evaluating her debate experience
	Generative:	Generative:
	Built his internships and his choice to teach robotics on his science fair experience and robotics competitions	Used her expanded knowledge to establish herself as a teacher for one lesson as well as an expert and judge
		Drew on her debate experience to consider science as a possible career option

Neil's experience with robotics also helped to reinforce some of the concepts covered in his conceptual physics class. As he constructed his robot, Jhumki observed Neil review and enact schematics that involved concepts about electricity such as charge, current, voltage, resistance, diodes and more. For example, he studied the circuit board associated with his robot and identified parts of electronic circuits. He had to find batteries of different voltages for different appliances. In his science fair poster, Neil displayed his attempts to craft the kinds programs he had wanted to create for his robot and the challenges that he faced in this process. He provided this information as an example of hypothesis-testing through data collection in that he tested programs he thought would work and modified them based on his results. In this sense, Neil gained literacy not just in physics content but in the open-ended inquiry aspect of being a scientist.

On the day of the science fair, Neil placed his robot in the hallway on top of a game board he had drawn on a portable white board. When Jhumki came to look at his project, there was a crowd of students around him watching him run the robot as it collected colored plastic pieces and pushed them into the "trash." Neil noticed the buzz he created. He said of the science fair: "a whole bunch of people came over to my group and wanted to see bunch of things… They wanted to see the robot move." Two scientists who acted as judges during the competition later told Jhumki that they felt his project was of a quality distinctly higher than those of any of his peers. Neil won first prize in the science fair competition, based on the evaluations of several ninth-grade judges. When he told Jhumki about his feelings about winning the prize, he said: "The day of the awards they [the students] were like, 'Neil, Neil, Neil.' I know it's me. The students say 'We all know it's Neil getting awards.' I was like, 'Yeah it's me, why not?'"

Neil had profound interest in computers and robotics, fueled in part by his desire to invent new technologies to save the lives of soldiers in war. These interests, in many ways, propelled Neil into the role of capable physics student and expert. Not only were these changes reflected in his grades in the course but also in his developing identity as a capable school science expert. What is interesting is that despite the expertise Neil demonstrated in robotics and computing, he was not initially viewed by his peers or teacher as a good science student or an expert in physics. This is important because it suggests how easy it is to underestimate a student's potential, based on his/her behavior in class, and how exploring a student's interests and talents is an essential part of developing a young person's critical agency.

Neil—a robotics teacher

A powerful aspect of Neil's story is the way in which he cultivated and drew deeply upon his physics knowledge to position himself, over time, as an expert *teacher* who acted as a learning resource for his peers. Through physics, Neil altered how his peers viewed him, by presenting himself as a knowledgeable and serious student who could help them make connections between their lives and physics class.

During interviews for this study, Jhumki asked Neil to develop ideas for a lesson. Neil also chose to enact his ideas for teaching robotics with the whole class. He based his lesson on his experience with the robotics competition at a local university for which he had prepared and in which he enjoyed participating. He said of the competition: "I met a lot of people at the tournament, teams that came over and helped us with programming. The people at the tournament, I liked them 'cause they respected me."

Over the course of the year during which this study was conducted, Neil spoke with his teacher several times about when and how he could build a game board, the kinds of equipment the school could order for the in-school robotics competition he envisioned, and the kinds of funding the school might acquire for materials. A year after Neil designed his unit, he and his team-mates had a chance to co-teach robotics with Jhumki as a unit of the "Medicine-Engineering" course offered to tenth-graders.

Jhumki chose the robotics kits the students would use, primarily based on the budget that the school allocated for the class. However, Neil and team-mates previewed the robotics kit before it arrived. Then they prepared the materials needed to run the robotics class: they unpacked equipment, figured out what types of batteries were needed, downloaded the software for programming onto ten laptops and sorted the Lego pieces for students to use.

Prior to each lesson, Jhumki would discuss with Neil and his team what they might do in class. The topics of the lesson mostly aligned with what Neil envisioned: constructing stable structures, exposing the students to various types of sensors, programming and preparing students for an end-of-unit competition. In describing what he taught, Neil said:

> The lesson was teaching students about robots because I did robotics. I liked it and I think all the students will. The first thing I be doing is introduce the topic, talk to the students about what robots means, what different things robots can do, what different parts of a robot are useful—touch sensor, light sensor—to start the robot. I tell them what it is used for. Then they write an evaluation—if Neil was a good teacher for the day or not. [I tell them] what different hydraulics can do, open and close, how to build claws.

In class, Neil moved between groups to help students solve building problems and become familiar with the software program. If during class, students 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. Neil also helped collect and organize materials at the end of class. At one point, Neil recognized that all of the robotics team members were in one section of the medicine-engineering academy and none were in the second teacher's classroom. Neil felt comfortable enough in his expertise to volunteer to be a student teacher in the other classroom, where he would not have access to Jhumki's supervision. Neil 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.

Neil's interest in robotics and experience in physics allowed him to take on a new identity as a teacher in his classroom.

Neil—building social networks with peers and adults

Neil's participation robotics afforded him more than knowledge of how to build and operate robots. This experience put him in contact with other students and adults who either shared this interest or wanted to see him succeed with it. Figure 4 depicts the strength of relationships Neil developed through robotics. The image captures the photographs from his university robotics competition that he considered important enough to gather together for presentation at the science fair. In the pictures, you can see that Neil has shown his team-mates working and posing together as well as a photograph of him with his father in which he describes his father as proud of him.

Building a strong social support network was important as Neil struggled with the transition to high school. He struggled with his grades and to cultivate positive relationships with his peers and teachers. The context of science provided Neil an opportunity to cultivate new relationships. Both the science fair and the co-teaching experience led Neil to expand his network of resources, including new adult relationships and new knowledge, upon which he could draw for doing robotics and computers. He regularly worked with and e-mailed two mentors at the local technical university sponsoring the robotics competition and found a summer internship at a robotics lab through materials he acquired from these mentors. He continued working with Jhumki over the next 2 years on his robot, setting and achieving goals for expanding his robotics skills until the 11th grade science fair. In 11th grade he even met with Jhumki's husband and father, both of whom were computer programmers, to discuss programming his robot and to design business cards that captured his ability and desire to fix his classmates' home computers.

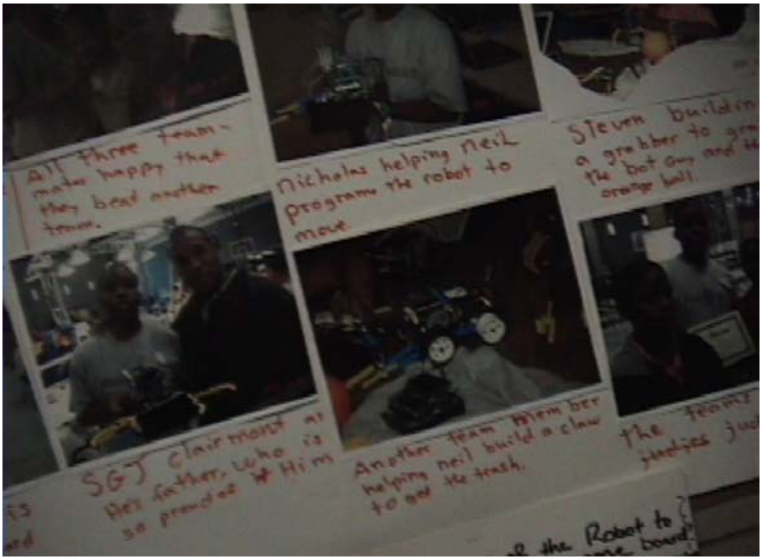


Fig. 4 Neil with team-mates and his father at the university robotics competition

Seeking out this adult help and mentoring reflected what was may have been a turning point for Neil. Despite Neil's initial struggle with classroom behavior, he began to find spaces through physics to build a network for success. He also began to project an identity as someone who was smart in this area rather than as someone who "acted dumb." In physics class, Neil noticed the stature 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." Neil also expressed his appreciation of the friendships he built through robotics.

The cohort of "friends" Neil made on the robotics team provided him with a social network that he maintained for the next 3 years. He organized a "going-away" party for one of his team members when this friend left for Trinidad at the end of Neil's junior year. He also could be found meeting regularly with these friends and Jhumki to discuss how to improve science teaching and learning for urban youth, even when Jhumki was not his teacher.

Agency and identity

Because engaging in agency involves reflection and the development of awareness, it necessitates that individuals continually examine their identities—who they are and how they change. Issues of identity—and how one positions oneself (or is positioned) through practice and identity building—are central to making sense of how one seeks to pursue one's goals. In our use of the term identity, we align ourselves with those who view identity as fluid and constructed socially within communities of practice. Upon entering a community of practice such as the science classroom, students develop identities through engaging with the tasks of the science class. Learning science becomes "a process of coming to be, of forging identities in activity" or "identities-in-practice" (Lave and Wenger 1991, p. 3). For example, how novice members of a community negotiate their relationships with the official authority, that is the science teacher or the recognized good science students, shape not only the goals students may choose to pursue but also how they identify with that community and its goals.

Bringing this framing of identity to bear on agency, we take the stance that the process of *coming to be* is rich with agentic possibility. Based on their particular "imaginings of self" (Holland 1998, p. 5), individuals, as part of a process of agency, set particular goals towards which they want to direct their action. Evolving identities-in-practice can be inferred from the way students choose to interact with other members, the decisions they make with regards to the assigned tasks in the science classroom, the opinions and questions they raise and also their reticence and silence, should they choose not to participate. Agency is as a form of "semiotic mediation—modifying one's environment with the aim, but not the certainty, of affecting behavior" (Holland 1998, p. 39). Embedded within is the idea that pursuing agency does not guarantee a particular outcome but, instead, requires risk-taking, through which one might expend energy but not achieve one's goal.

The relationship between Neil's identity and agency

In physics, Neil leveraged the aspects of his identity that compelled him to pursue robotics such that he could build a new social identity for himself with respect to peers and adults. He expressed agency in that he used his experience in physics to change his life. Specifically, he positioned himself as a socially-connected expert and modified the world of his school by instructing other students in robotics. Overall, Neil's critical science agency was deeply connected to leveraging and expanding his identity. He drew on his passion for computers and robotics to develop as an expert, teacher and socially-networked young man.

Donya

Donya's story in this study begins with her as a strong, motivated student interested in a career in law. During the student she explores challenging topics in physics such as black holes and dark matter and energy. She also tackles a unique, difficult science fair project. By the end of the study she positions herself as a scholar and expert who can guide her peers and as a young woman who challenges stereotypes about urban minority youth in science. She also says that she is more open to the possibility of a career in science.

Donya's story suggests that the expression of critical science agency—expressing herself as powerful physics and scientific thinker in ways—was connected to her identity as a student and helped her expand her identity (such that she established herself as an expert student and scholar challenging what she saw as stereotypes about black students).

Donya—an expert student and scholar

Donya was a student who wanted to challenge herself. She applied these qualities in physics to expand her knowledge and scholarship, further developing her intellectual identity.

With regard to black holes, Donya began her investigation of this topic by intentionally choosing the most difficult of three topics for a first semester project on motion: how a moving object might avoid being drawn into a black hole. However, she did not feel that she had "learned everything" about black holes through her first semester project, so she decided to do more research on this topic in designing the lesson she chose to enact in Jhumki's class. For her lesson, she studied topics as diverse as the density of white dwarves, the process of fusion, the formation of collapsed stars and the speed of light.

Clearly, Donya sought out a depth of physics knowledge through the design of her lesson. Because Jhumki wanted students to learn about a topic other than black holes, since some of them had already encountered this idea for their first-semester motion project, Donya went a step further in her research by agreeing to conduct research on the topic of dark matter and energy, a new topic for all students. She established a scholarly identity in this area by writing a paper on this subject, based on research, which provided the foundation for questions students should research for the debate. Donya also drew on her identity as a future lawyer to bring debate into her physics class.

By leveraging her desire for challenge and innovation, Donya also expanded her identity in the realm of scientific inquiry. She wanted to pursue an "original" project for the science fair, "something different" from what her peers were examining. She arrived at the idea of exploring how objects float, and she chose as her partner someone whom she thought would work hard, despite the fact that this student was not her regular partner and best friend. She viewed this partner as "someone who will really commit to doing this project with me and really complete it."

In agreement with how Donya said she normally sought out challenge, she described how she struggled with the number of hypotheses she was expected to generate for the science fair but enjoyed the new experience of conducting her own experiment. She said she liked "getting to check the results and test ideas in different ways." During the science fair, Donya enjoyed being independent. She liked knowing where she was going with her work, to the extent that she could start work right away without waiting for her teacher's instructions. She said, "In the 3 weeks, we knew what we were doing, we would just go to it."

During the science fair, Donya and her friend displayed a detailed poster describing their experiments with floating different objects of different shapes and sizes in different types of liquids (oil, water, soda, etc.). They presented their findings on a detailed poster board documenting their scientific process. About the science fair, Donya said that she felt "really good, I felt we were doing something really extraordinary. 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.

Based on her experience with the science fair, Donya decided to further explore science. She said: "All in all, this experience has taught me a lot and I feel that I have started a new beginning because now I'm starting to think that I may like to pursue a field of science in college which is something I never thought I'd do." The summer after her sophomore year, Donya enrolled in a nanotechnology course for high school students at a local university while also attending a pre-law program.

Donya—challenging stereotypes about black students

Donya relied upon this physics context to critically thwart the negative stereotypes that abound about black youth and the economic discrimination often seen in black communities. While Neil began to see a different future for himself through physics—one that allowed him to safely step out from "acting dumb," Donya used physics to shield her aspirations from and challenge a racialized world. Donya's involvement in physics demonstrated critical dimensions in that she explicitly challenged, through her actions as a science student, stereotypes about low-income, minority youth in science. As she states: "My name is Donya, I think the reason that most areas, black areas lack funding because…they think black people are just going to be the ones who work at McDonald's, that's why they don't give us funding. They think it's a waste of their money." Through her decisions to challenge herself with the toughest science projects and as evidenced by her position on her school's honor roll for every semester that Jhumki has known her—by leveraging her identity as a strong, capable student—Donya purposefully demonstrated that urban black students could be in a position to be excellent science students.

The relationship between Donya's identity and agency

Donya expressed agency in that she changed her own life by positioning herself as a scholar and guide to other students and modified her world by creating a space in which students could debate scientific ideas. Donya's critical science agency was related to the development and expansion of her identity. Her commitment to challenge and innovation allowed her to expand her identity as a scholar, science inquirer and someone who challenged stereotypes about urban minority students.

Critical science agency and students envisioning their futures

Neil's and Donya's experiences with critical science agency indicate that this process was deeply connected with the leveraging and expansion of identity. In metalogues on this topic, Donya and Neil raised the point about identity but in a way that connected not only to who they are but who they want to be. This looking ahead on the part of students further emphasizes how taking action toward shaping identity is important to how these students frame their participation in science.

> Donya: Science is more exciting to me and the whole class when the teacher structures a class around who the students are, or want to be.
> Jhumki: Like wanting to be a lawyer.
> Donya: Like being a lawyer. What is in science for me is that with the lawyer thing, there were a lot of topics that you could discuss that would be practice for being a lawyer. It's not just how you might argue your point, even though that matters. It's also about seeking out good evidence, and making it fit together to make a point. And it is also about asking hard questions that do not have obvious answers.
> Angie: Donya and Neil, your stories about becoming a lawyer and a robot expert are telling me that part of what is important in helping you learn science is being open to how science intersects with not only who you are now but also your futures. In other words, developing a critical science agency is about developing an identity with and in science.
> Neil: I think it is important for teachers to remember that students have goals that science can help us achieve, and that these goals are not always the same as getting a good test score. Sometimes these goals are really connected to the science we might learn. For the class I taught, it related to robots, which I want to do for Homeland Security. That class I taught also helped me how to understand how to program the robot, also open up my mind and set me on the correct path of what I want to achieve. But sometimes these goals are not really connected to the science directly. Like the science fair reflects on me, because I came in first place, and through the science fair, it shows what I can achieve. It helped me realize the goal that I want to achieve.
> Donya: Learning science for me is about doing something. I mean its just not doing hands-on stuff because the debate is also doing something. I mean that learning science is also when you can do things that you develop yourself, like Neil said.

Jhumki: And so I need to see your learning, or at least part of your learning, in my class as about how you are able to build your future?
Neil: You know, it is not just how things directly tie to my future. I enjoyed learning about black holes even it wasn't my topic. I learned a lot about black holes and I also learned about what Donya wants to be in the future. Why did she care about that? How did science class help her? If she wants to achieve in science to help her be a lawyer maybe that is something that I haven't thought about. This is different than just learning what an atom is.

Critical science agency involves the strategic deployment of resources

Neil's strategic deployment of resources

Neil's initial interest in robotics was related to his concern for the well-being of American soldiers in Iraq. (See Fig. 5, which documents the connection he made between building his robot and helping soldiers). Throughout the year, he drew on resources inside and outside of school to expand his knowledge and experience and pursue his goals with respect to robotics. These experiences include his participation in an inter-school competition at a local technical university, choosing a robotics project for his science fair and participating in internships with the school computer expert and as a computer-use advisor to patrons at a local library.

Neil also drew on human resources to pursue his critical goals. For example, during the science fair, he came to school early, worked in Jhumki's office at lunch and stayed late to build and program his robot. The week before the robotics competition, to improve his robot, Neil visited his mentors at the local technical university everyday after school for several hours. He relied on his peers as a resource in establishing himself as a robotics expert, relying on their help to co-teach his robotics unit with Jhumki.

We consider Neil's deployment of resources to be *strategic* because he purposefully drew upon both traditional and non traditional resources in ways that positioned him with voice and authority, and in ways that challenged and even transformed normative and stereotypical rules for participation in science by urban youth. In our metalogues with Donya and Neil, Neil stresses how this strategic leveraging of resources is really a negotiation of who can participate and how that participation is made to matter to the larger community.

Neil: I think we have to include the other students in this negotiation, too. The kind of help I needed was a game board, which was a really big game board that my father built. And the robots competed against each other. And another help I needed was my friends gave me ideas, of where to put the different pieces on the game board—not this way but the other way, and they gave me feedback on where to put the different objects. I also got help from you on how to make the unit more organized so students know what they're doing and would like it and could learn something from it even it wasn't their topic. Cheef and Darius helped me because the programming was too hard to make the robot go forward, backwards, sideways. I needed help to make a claw, to put the pieces together to make a strong and powerful robot. They helped me a lot.
Jhumki: In addition to students, the larger context shapes this negotiation. Neil, do you think you would have been so involved in robotics if there hadn't been that New York Robotics competition?

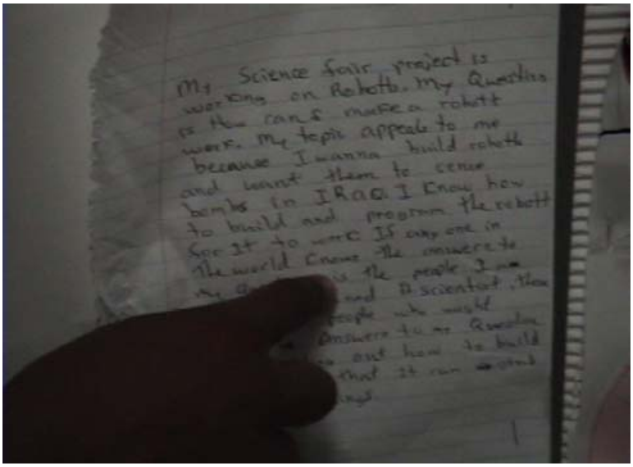


Fig. 5 Neil explains in writing how his robot is a first step to building a robot that senses bombs that might hurt soldiers in Iraq

> Neil: Yes, it was important. Because I met people and got to see what new people can do. Such thinking was very brainy, and I got to see it, the other students at the competition. The mentors they also gave you feedback, this part is right, this part is wrong, the program.
>
> Angie: It seems to me then, that central to any negotiation—whether it be about identities, futures, content, or context—is a process of opening up and coming to know.

Donya's strategic deployment of resources

Donya drew upon the context of physics to expand the repertoire of resources she could access and activate towards her own goals. We can see her goals coming into sharper focus as a result of her deployment of these resources. Donya's expressions of and reflections on agency were dialectically related to context, rather than being limited to her own individualized experience. In her assessment of her dark matter/dark energy lesson, Donya suggested structuring debates based on her experience with the $E = mc^2$ debate and on classroom formats she had seen in end-of-year exit projects and during her visit to a local college. In choosing how to improve the debate the following year, she drew on the experiences and attitudes of her fellow students. In reflecting on her science fair, she drew on the comments of the scientists who had come to her school to judge her project. We consider Donya's deployment of resources to be *strategic* because she purposefully drew upon both classroom and beyond-school resources in ways that positioned her as a scholar and expert and in ways that challenged traditional stereotypes about urban black youth in science.

Teacher as resource in critical science agency

Donya and Neil pointed out in their metalogue that they also significantly relied upon dialogue with their teacher as an important resource in this negotiation.

> Neil: From my opinion, teachers should speak to the students and have their voices heard, have the kids say how they think class should be organized, how it should go

along. Teachers should listen to what students have to say—students are the ones who are learning, not the teachers! As a teacher, you tried help me achieve me my goals by having me, as a student, come and teach in the classroom. It helped me learn new things I never knew about and learn more ideas about how to help people."
Donya: Jhumki, you gave me the idea of being the lawyer.
Jhumki: I did? I thought you were thinking of being a lawyer?
D: I mean, you helped me connect being a lawyer to black holes and to doing the debate. You helped me see how science class can help me achieve my goals.
Jhumki: So it sounds like our conversation one-on-one was helpful.
D: Well, I could not have done it on my own because what you told me to do was to make a list, write down what I needed to get this done. Having this in front of me made me see, yah, that is me. That is what I want to do. But then to think that black holes could help? I mean that is really true.
Jhumki: So you could lead class when I didn't just tell you to lead class or I just decided to do class. It was that you had your ideas, and I knew some things, and we worked together. I could help you make a list.

Developing critical science agency is an iterative and generative process

We use the term *iterative* in this paper to mean that a person constantly re-evaluates and modifies her knowledge and identity. By *generative* we mean that as a person expands his/her knowledge, his sphere of interaction, and his/her influence grow, allowing him to further access and activate new forms of capital.

Neil's critical science agency as iterative and generative

Neil's experience with critical science agency was iterative. He regularly wrote, tested and then modified programs to get his robot to perform in the ways that he desired. For example, Fig. 6 shows his conclusions about how to make a robot turn, a conclusion he developed from a series of trial and error steps with robot motors. He taught his peers new

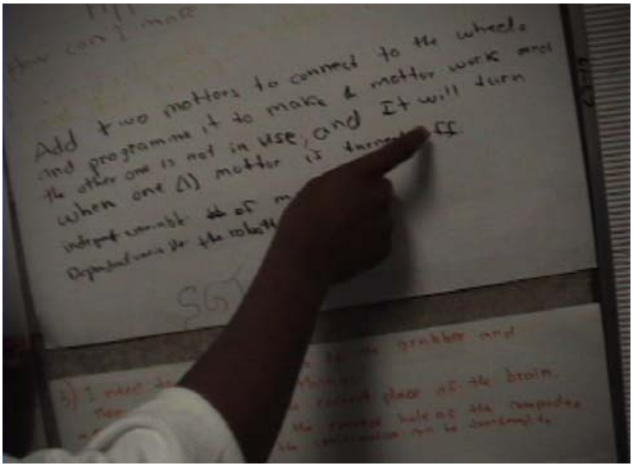


Fig. 6 Neil shows his conclusions about how to make a robot turn

ideas for building and programming, and had them test those ideas while he was there to help them.

Neil's experience with critical science agency was also generative. His success with the science fair helped him develop his understanding of robotics while expanding his stature as a serious, smart student. His presentation on robotics during his end-of-year portfolio project established himself as a teacher of robotics. Both these experiences expanded his confidence and supported him in feeling excited and assured about teaching a full robotics unit to other students. These also inspired him to seek out internships in computer science and robotics outside the familiarity of his school setting, which in turn encouraged him to develop his robotics project further for the ninth-grade science fair. Over time, his behavior in physics class improved as did his willingness to rely on Jhumki in situations where he needed academic, personal or professional support, for example, seeking out Jhumki's father in designing business cards or Jhumki's husband for fixing his computer and developing a theory of programming.

Donya's critical science agency as iterative and generative

Donya and Jhumki engaged in an iterative process when Donya developed her debate lesson. Jhumki asked Donya what kind of lesson she wanted to create; Donya discussed how she very much enjoyed the Einstein debate, in light of her interest in law, and said she wanted to pursue a debate. She chose a debate topic that appealed to her desire for challenge and originality, tapped on her experiences with her peers (particularly what she saw as their tendency to rely on one group member for completing work), and helped her fill gaps in her knowledge of black holes. Donya also suggested new teaching practices that were very useful to Jhumki in designing debates by evaluating her experience with the debate she crafted. So, in Donya's experience with critical science agency, Donya re-evaluated and modified both her knowledge and identity. She even expanded her career aspirations to include science.

Donya's critical science agency was generative in that she developed new expertise about black holes, dark matter and dark energy. She also expanded her sphere of influence by working in a partnership with Jhumki, rather than simply being a recipient of the pedagogy Jhumki crafted. For example, Jhumki and Donya worked together to streamline the debate topic and traded rubrics, debate instructions and research questions for students back-and-forth, in designing the lesson. Eventually they debriefed about the success of the lesson, and Jhumki used Donya's suggestions in her class the following year. Donya also established herself as a leader (teacher and judge) with respect to her peers, a social position that was important to her.

Donya's and Neil's metalogue reflections on how critical science agency was iterative and generative for them

We end this section on the generative and iterative nature of critical science agency with a brief metalogue with Donya and Neil because they summarize for us how learning to participate in physics and to use such participation to bring about change is transformative not only of their identities, but also of what it means to be successful in high school physics. Their actions changed their positioning in school science because they took on new roles and because we learned to respond to them in productive ways.

Neil: Well, what I know is that she did care, and my life is different now. I can be brainy and that is OK. I really don't know how I would have been if Jhumki did not care. I would still be doing robotics, but it would not be in my physics class. Maybe I would still be skipping class.

Donya: At the beginning of ninth-grade, I didn't like science, but I learned new things about science. Now, I'm even thinking of becoming a scientist. I'm a person who likes to be challenged, and I don't like to know the answer right off the top of my head. I like to do research and have a scientific experience. Like with the debate. It gave me a different aspect of science. I didn't know science had something that could go both ways. And I liked that part. But, it has changed me, and that matters for me both inside and outside the classroom.

Jhumki: And that change has taken place and makes sense in both of your worlds inside and outside the classroom.

Neil: And in the future. In ninth-grade, I did my first robotics competition and I went off to do it in class, and then I went off to doing an after-school program at New York College, and then I went off to doing a robot program at NY Technical School, making a robot that works underwater, and then I got second place at the eleventh-grade science fair. And I couldn't do the programming, and I kept getting better and better. Like in my spare time, I would work on programming and then it would work, but back then I just got started. You know, I did not try to become a better student on purpose. I acted dumb because it was part of me. But robotics has a purpose to me, and having that taken seriously gives me a place to be who I am and who I want to be. Being a good student is not following classroom rules. We shouldn't talk about good students or even good teachers, but good science learning because that is how it happened for me.

In Donya's and Neil's stories we see two valuable points about critical science agency that both parallel and challenge each other. First, Donya used the context of physics to develop an identity as an expert physics *student*, who was both original and hardworking, whereas Neil used the context of physics to develop an identity more so as a specialized robotics expert and a *teacher*. Donya used her good social standing and school smarts, her hard work ethic, a sophisticated view of science, and confidence in taking risks to challenge stereotypical images of who can be successful and what it means to be successful in science. This differed from Neil, who drew more from adult networks, non-traditional knowledge, and a shared interest in robots to support his identity development.

Despite the difference in how their critical science agency played out in light of Donya's and Neil's different identities, our findings suggest that the expression of critical science agency for both youth was connected with their intellectual and social identities and the strategic deployment of resources. In addition, for both, the expression of critical science agency was an iterative and generative process.

A key implication of the study is that agency and subject knowledge are not at odds. In fact, an important aspect of expressing agency for both youth was the development of their physics knowledge in the context of their identity. Donya conducted research on a controversial topic in modern physics and applied it to her aspirations for a career in law and her quest for challenge and originality in her education. Neil became a robotics expert, and through this, established himself as a potential robotics developer and a scholar and teacher at his school. In their metalogue, Donya and Neil associated a positive physics experience with the development of knowledge. Donya felt that choice gave students the incentive and opportunity to better understand a topic. Neil felt that exposure to a robotics competition gave him "smart" ideas; this was a way to build his repertoire of robotics knowledge.

This finding aligns with research on critical subject agency in mathematics, where youth leveraged subject expertise to make changes in their lives and world (Turner and Font 2003). We argue that both youth made gains in physics literacy (Hobson 2003), in that they displayed engagement with physics and science and felt that what they learned was relevant to their lives. Both youth also expressed agency in that youth used science to modify and impact their lives and world (Holland 1998). Donya stood out as having a "critical" lens in that she was cognizant of the stereotypes in society made about urban black youth and challenged these with active, successful involvement in science.

While Angie and Jhumki felt that we could claim that critical science agency is *related* to identity development, both Donya and Neil emphasized critical science agency *as* identity development. It was important that physics be connected to Donya's identity as a developing lawyer—when this connection was made, she felt that class became more exciting to her and her peers. Neil felt that it was essential that his class connected to the future he envisioned in robotics and also showed his potential to his peers, thereby strengthening his social identity.

The iterative, generative nature of critical science agency was an important finding in this study. In an accountability climate, there is a sense of immediacy for urban minority youth to perform. For example, students and schools are often considering to be failing if test scores do not show a specific kind of progress. But the findings of this study suggest that the development of science expertise and engagement with science take time and ongoing human interactions. Neil became an expert by revising his work over time and building one opportunity in robotics upon another. Donya worked in conjunction with Jhumki to revise the plan for the following year. So the study suggests the need for longer-term metrics for understanding how low-income, minority youth learn science, with attention to their human interactions and the resources they leverage.

While Jhumki and Angie talked about the process as being both iterative and generative, there is something to their point that is worth expanding upon here. Donya described Jhumki as helping her connect her interest in law with physics, while Neil relied on similar guidance in light of his passion for robotics. Yet both students indicated that *they* also guided their teacher and mentors into understanding their worlds and strengths better.

Key resources for the two youth in this study were in-class (physics curriculum such as the Einstein debate), out-of-class (end-of-year portfolio presentation), beyond-school (local university competitions and field trips), material (game board and robotics equipment) and human (teacher-student dialogue) resources. Donya and Neil, in their metalogue, also emphasized the importance of one-on-one teacher student dialogue in pursuing critical science agency. The findings suggest the importance of youth being exposed to a diverse world of opportunities that allowed them to create networks and mentoring connections in- and beyond- school.

Critical science agency, we believe, is an important construct in advancing our understanding of science literacy and even of the learning sciences. Clearly, the boundaries used to frame what it means to be literate in science are too narrow to fully grasp how both Neil and Donya grew as science scholars and youth who make a difference. The relationship between knowing and doing was not limited by traditional classroom activity, but was made more intense by the inclusion of out of classroom and out of school activity and an eye towards the future. If we had used traditional measures to make sense of either Donya or Neil, we would have a deficient view of their experiences in 9th grade physics. We may see Donya as a superior student—straight A's in physics, good attendance and class participation. But Donya, in a sense, is at once more astute and fragile than her report card suggests. She worried deeply that her lesson plan failed, yet wanted her peers to know that science doesn't always have answers. We may see Neil as a student on the verge of either passing or failing—skipping class, disruptive behavior intermingled with moments of success in the science fair. But Neil is much more cerebral and committed to his future than we might otherwise know. A framework of critical science agency, which requires us to understand that what students know is intertwined with who they are and want to be, has pushed us to develop more complex understanding of both youth.

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Neil Clairmont was born in a wonderful country by the name of St. Lucia. He migrated here to the United States to get a free and better education. He is a 12th grader at the School for Social Change and soon to attend college. He applied to Polytechnic University where he is hoping to get accepted. He is very interested in joining the U.S army in the near future. (HOOOOAAAHHH!). He has a high interest in building robots. He builds them for competitions and for the fun of it. He has this invention that he wants to bring out to the military, it is a robot that can help decrease the deaths of soldiers out there being killed in the battle field.

Donya Locke is a senior at the School for Social Change, hoping to attend Lehman College to major in political science. In college she would also like to continue track and field along with dancing. She feels like she has been a successful student and an active participant in various things. She took law and nanotechnology courses at Columbia University, worked at the CORO New York Leadership center and used that to become a civic leader. Through that she made positive changes on educational issues. She also interned at the Children's Aid society in Harlem where she assisted at the summer camp. She also had the opportunity to assist Ms. Jhumki in obtaining her Ph.D. which was an honor to be a part of. For this project, Donya and some other students also got the opportunity to go to California to experience another state while doing something productive (present their research). Outside of school Donya is a part of a youth program called Youth of Unity (Y.O.U). In this program the volunteers are very active in their community. They go to nursing homes, soup kitchens, fundraise and send the profits to Africa.