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Economy and STEM Education Policy: Towards a Bidirectional STEM Pipeline

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Abstract

Whether implicit or explicit, the purpose of K-12 education in the American mind is for (1) economic advancement of the individual and (2) the maintenance of the capitalist economic structure through the provision of a qualified labor force. As the disciplines of science, technology, engineering, and math (STEM) are seen as central to future economic activity, much attention in science education research is presently paid to how to best retain students in a unidirectional pipeline model towards STEM careers. I challenge the purely economic impetus for diverse participation in STEM education as necessarily reproducing historical inequities. Rather, I reconceptualize a bidirectional STEM pipeline which seeks to democratize the tools of science for the continued work of social justice. In this model, science takes on the role of one of a number of equally valuable funds of knowledge which students can appropriate to answer questions and address issues in their own community contexts. I draw on the work of John Dewey and Lev Vygotsky in discussing the dialectical relationship between identity and culture, to explain how democratizing the tools of science in this way will allow marginalized groups to (re)construct the very culture of science.

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Whether implicit or explicit, the purpose of K-12 education in the American mind is for (1) economic advancement of the individual and (2) the maintenance of the capitalist economic structure through the provision of a qualified labor force. As the disciplines of science, technology, engineering, and math (STEM) are seen as central to future economic activity, much attention in science education research is presently paid to how to best retain students in a unidirectional pipeline model towards STEM careers. I challenge the purely economic impetus for diverse participation in STEM education as necessarily reproducing historical inequities. Rather, I reconceptualize a bidirectional STEM pipeline which seeks to democratize the tools of science for the continued work of social justice. In this model, science takes on the role of one of a number of equally valuable funds of knowledge which students can appropriate to answer questions and address issues in their own community contexts. I draw on the work of John Dewey and Lev Vygotsky in discussing the dialectical relationship between identity and culture, to explain how democratizing the tools of science in this way will allow marginalized groups to (re)construct the very culture of science.

Keywords: Critical pedagogy | sociocultural theory | STEM education | science education | education policy | social justice | STEM pipeline | STEM

The Economic Purpose of Education

In his 1973 book, *Small is Beautiful*, German-born economist, E.F. Schumacher, outlined a Buddhist perspective of economics, the aim of which "should be to obtain the maximum well-being with the minimum of consumption" (Schumacher, 1973, p. 61). He contrasted this perspective with the traditional modern economic model which conceptualizes consumption as an end in and of itself. Schumacher lays at the feet of traditional economics the blame for entrenched social inequity and thoughtless environmental degradation. In dissecting its role in such ills, he explained that the formalizing of economics as a social science through its establishment in the university beginning in the early 19th-century, has legitimized its perspective as scientific and therefore allowed economic thought to pervade public policy. This pervasiveness is evident today in the ongoing discourse around the governmental response to the COVID-19 pandemic and the seeming inability to separate public health from market concerns.

As is the case for any field shaped by public policy, education is heavily influenced by economic considerations. At the institutional level, educational standards, curriculum, and pedagogy are shaped in a top-down fashion by a political impetus towards national economic competitiveness in an increasingly globalized world. This impetus is driven by a uniquely American ethos towards the pursuit of individual economic advancement (Sahlberg, 2006). The most recent 51st annual iteration of the PDK Poll of the Public's Attitudes Toward the Public Schools found that while just 18% of American parents describe the purpose of school as preparation for work, an additional 53% believe the primary role of school is to prepare students academically (PDK Poll, 2019). This fact begs the question, prepare students academically for what end? A similar 2017 poll of representative U.S. parents found that 67% of the public would want their child to complete a four-year college degree, a figure that increases by an additional 8% when respondents are supplied with information about the increase in lifetime earnings afforded by possessing such a degree (Education Week, 2018). Given the economic context of modern society, whether explicitly understood as preparation for work, or described as the pursuit of academic success, the vast majority of Americans perceive the purpose of education as securing a child's economic future. Schumacher (1973) argued as much, as he described our society, shaped as it is by an obsession with economics, as unable to evaluate an activity completely without consideration of its value to the market. Given this consideration, he explained, any activity that does not produce favorable economic outcomes is deemed uneconomic and dismissed:

> In the current vocabulary of condemnation there are few words as final and conclusive as the word "uneconomic." If an activity has been branded as uneconomic, its right to existence is not merely questioned but energetically denied. Anything that is found to be an impediment to economic growth is a shameful thing, and if people cling to it, they are thought of as either saboteurs or fools (Schumacher, 1973, p.44).

Education is therefore a means to a primarily economic end, and to consider otherwise would be branded uneconomic and foolhardy.

The role of education as preparation for economic participation necessarily devalues the community context in which education takes place. Social and cultural concerns are demonstrably uneconomic, as students are shepherded towards disciplines and careers that have the greatest individual financial incentive and serve the perceived needs of employers. The economic impetus of education policy understandably makes challenging any attempts at institutional reform that seek to upset the existing capitalistic hegemony. In his lesser known 1967 anti-war speech, "Beyond Vietnam," Dr. Martin Luther King Jr. lamented the detrimental effect a preoccupation with markets and value has particularly on marginalized groups who exist on the outside or towards the bottom of the current economic hierarchy and are thus viewed as disposable. Ali and Buenavista (2018) explained how King challenged the commodification of bodies as it related to education, arguing that "learning is not [seen as] educational or valuable unless it is economically motivated to produce material outcomes for the expansion of markets" (p.10). They argue that the education system primarily functions to reproduce the existing economic hierarchy.

Modern social justice movements seek to address social and economic inequities, but often struggle to break from the economic concept of the purpose of education. Efforts to construct more culturally responsive curricula and pedagogy often list preparation for post-secondary education and work-place competitiveness as primary goals for marginalized students (Ladson-Billings, 2008; Saint-Hilaire, 2014). Schumacher might view such a foregrounding of economic goals as antithetical to his Buddhist economics, placing consumption before well-being. An alternative approach to education, that elevates the utility of institutional knowledge and tools in addressing the immediate social justice concerns of students' communities, would center student well-being and paradoxically, may ultimately lead to improved academic and thus, economic outcomes for marginalized students (Kutsyuruba et al., 2015).

The Leaky STEM Pipeline

The shaping of education by primarily economic considerations is perhaps most evident in the educational disciplines of science, technology, engineering, and math, collectively termed STEM. These fields are seen by most as foundational to the emerging 21st-century economy. The dominant American capitalist narrative perceives the purpose of science education, in particular, through what has been referred to as a *learn-to-earn* lens (Morales-Doyle & Gutstein, 2019), where the primary aim of coursework in science is future participation in science-related careers. Scholars in science education often reference a "STEM pipeline" employing terminology such as "increased production capacity" and "global competitiveness" (Allen-Ramdial & Campbell, 2014, p. 612) and conceptualizing students as "human capital" to be trained to meet the needs of corporate employers (Spring, 2015, p. 5). This dehumanizing language is indicative of a system that values economic over humanistic activity and outcomes. Even the introduction to the now-broadly adopted, often lauded Next Generation Science Standards states:

> Science is […] at the heart of this country's ability to continue to innovate, lead, and create the jobs of the future. All students—whether they become technicians in a hospital, workers in a high-tech manufacturing facility, or Ph.D. researchers—must have a solid K–12 science education (The National Academies Press, 2013, p. xiii).

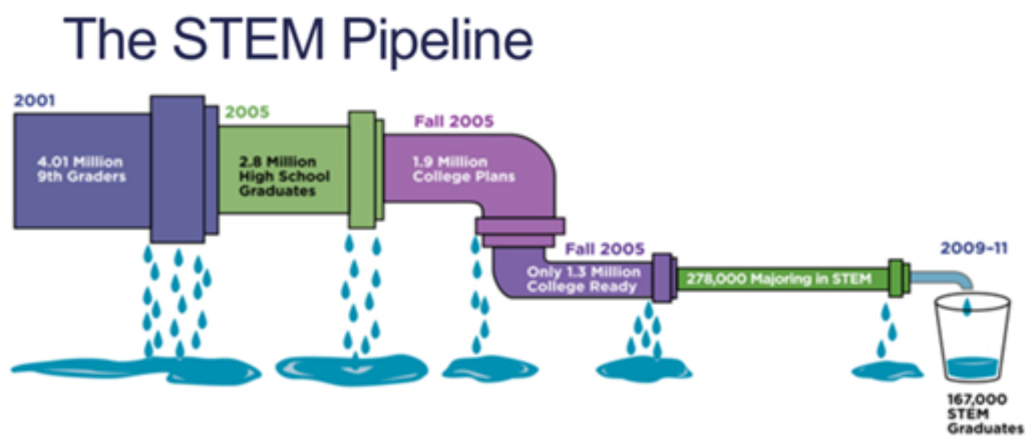
As discussed above, regarding education more generally, science education policy primarily shaped by such an economic impetus is likely to undervalue the more immediate uneconomic concern for student and community well-being. Advocates for improving participation by students from marginalized backgrounds in science majors and careers highlight the importance of a diverse science workforce both for the physical and economic security of the nation and for the economic competitiveness of the individual. In the modern era, shaped by national defense needs and rapid technological advancement, this impetus shapes a culture of science that is increasingly technological and oriented towards technical career training; hence the inclusion of technology and engineering in the STEM acronym (Vossoughi & Vakil, 2008).

This pipeline model of progression through secondary STEM courses towards economically viable STEM careers is often described as leaking (Figure 1). Despite initial interest in STEM, particularly science, women and many ethnic and racial minorities drop out of the pipeline as they move through secondary and higher education (Bianchini & Solomon, 2003; Costa, 1995; Norman et al., 2001; Seymour 1995). Aikenhead (2006) described how marginalized students "experience school science as a foreign culture" (p. 1) due to its increasingly technical orientation and lack of community-level applicability. These students often feel that they have to assimilate into the culture of science where they "learn the canonical content of school science, which clashes with their worldview in some way, by replacing or marginalizing their own ideas and values with scientific ones" (p. 19). Students from more privileged background may be more likely to know and interact people in their communities who would work within this technological culture of science and thus encounter less of a culture shock (Aikenhead, 2006).

Again considering Schumacher's (1973) concept of Buddhist economics, the problem of inequitable representation in STEM appears driven by the prioritization of consumption over well-being, of preparation for competition in the market over immediate community social justice concerns. An approach to science education more in line with Schumacher's philosophy is one that "celebrates science as a human endeavor, embedded within a social milieu of society and constructed by various social communities of scientists" (Aikenhead, 2006, p. 1). Presenting science as a culture into which students must assimilate by traversing a unidirectional STEM pipeline is antithetical to this more humanistic approach. I therefore believe it is important to draw a distinction between what I have referred and will continue to refer to as the culture and tools of science. The *culture of canonical science* that I refer to here is the conception of the economic purpose of science that pervades American education policy and its resulting technological-professional orientation towards science, as described above.

Figure 1

The Leaky STEM Pipeline



Note. Adapted from (Dubois, 2014).

The *tools of science* refer to the historically accumulated content and methods used by scientists, what Layton et al. (1993) considered "a repository to be raided for what it can contribute to the achievement of practical ends" (p. 135). I do not wish to deny the utility of the tools of science. As Morales-Doyle and Frausto (2020) note, although a history of epistemic oppression has shaped science and scientific ways of knowing, this reality does not diminish the value of scientific objectivity as a tool that can be appropriated for the ongoing work of social improvement. This distinction between culture and tools of science provides a simple framework which we can use to begin to interrogate science standards, curriculum, and pedagogy to determine if a particular facet presupposes cultural assimilation or empowers the democratization of the discipline's tools for culturally diverse ends. Below, I will elaborate on how the latter not only allows for equitable access to science for the work of social justice in students' communities but also empowers marginalized groups to construct their own culturally-relevant understanding of the utility of the tools of science, a step towards the (re)construction of a new more humanistic institutional culture of science.

Patching the Unmalleable Unidirectional STEM Pipeline

The Dialectical Nature of Identity and Culture

The STEM pipeline is conceptualized as unidirectional, and thus, the literature in science education research focuses on interventions for retention of groups underrepresented in STEM majors and careers, patching the pipeline's leaks, so to speak. This unidirectionality presupposes a construction of identity, whereby simply traversing the pipeline, experiencing and internalizing science education, the student's identity is reshaped towards membership in the monolithic culture of science. However, the construction of identity is necessarily dialectical. Describing the interplay of identity and culture, as understood by Vygotsky and other sociocultural theorists, Roth and Lee (2008) explained, "Identity is evidently a dialectical feature: It is continuously produced and reproduced in practical activity, which both presupposes and produces identity" (p. 216). Put more simply, the development of the individual through learning, as described by Vygotsky, depends on the culture in which that learning is situated and contributes to the continued re-creation of that very culture. Students bring to the classroom a preformed identity that continues to evolve as it interacts with the content of the course and with the social milieu of the learning environment. Conversely, students' unique identities shape the culture of the classroom and ultimately the culture of the domain of science itself (Elbers, 2008). This dialectical relationship continues as students traverse the pipeline, the individual shaping the social and the social shaping the individual.

Existing models of science education disregard this dialectical relationship between identity and culture. The culture of science is treated as monolithic and unchanging. Students are expected to assimilate into this culture, rather than contributing to its continued (re)construction. For many, "moving from home to school is itself an act of cultural change and […] entails culture shock. That which is taken to signify competence in one culture may signify incompetence in another or irrelevance in a third" (Daniels, 2008, p. 66). This is particularly true for students of marginalized cultural identities, whose home culture, social life, and related funds of knowledge prove incongruous with the culture of science, and who subsequently drop out of the pipeline at a higher rate. Attempts at retention of these students, need to reconceptualize the culture of science as flexible and able to be (re)constructed when encountered by individuals of diverse identities. I posit that this can best be achieved by situating science as fund of knowledge, the tools of which can be appropriated to serve the work of social progress in the authentic community context.

Funds of Knowledge

The idea of situating the utility of the tools of science in cultural contexts familiar to students, as a means to engage culturally and linguistically diverse learners in science education, is by no means a novel idea. Moll et al. (1992) acknowledged that students enter the classroom with a diverse array of experiences that have and continue to shape their identity. Experience in different cultural contexts provides students with understandings and skills that may or may not be congruous with the content of the course being taught. Moll et al. (1992) described these socially and culturally situated resources as funds of knowledge. Students' funds of knowledge provide resources that can inform the teaching of science content and skills. Engaging these funds provides a starting point for building deep understanding of how science can be used to explain real world phenomena (Lee, 2001; National Research Council, 2018). Connecting students' existing knowledge and skills to academic contexts allows them to construct a personally relevant understanding of domain content. Ideally, this allows students to see science less as a monolithic culture into which they must assimilate and more as a fund of knowledge, itself, from which they can appropriate the tools of science to solve real world problems. Engaging students' existing cultural and linguistic funds of knowledge in this manner is seen as an effective way of improving retention of diverse learners within the existing STEM pipeline model (Hogg, 2011).

Theoretically, engagement of funds of knowledge is an effective method of valuing the cultural identities of diverse learners in order to allow them to construct personally relevant understandings of the utility of the tools of science. In practice, the economic impetus shaping educational standards, curricula, and pedagogy means that the engagement of funds of knowledge rarely goes beyond a method to aid in assimilation (Sherfinski et al., 2020; Sleeter, 2008), of enticing students to enter the relatively unmalleable unidirectional STEM pipeline (Hogg, 2011). Science teachers often struggle to move beyond this perception of funds of knowledge as a "hook," which they use to gain initial student interest in the canonical science topic at hand (McLaughlin & Calabrese Barton, 2013). Likewise, socially or culturally relevant phenomena are typically discussed in the context of introducing units of study, either explicitly or implicitly taking on the "Engage" role in the so-called 5E instructional model (Duran & Duran, 2004). Engage is the first step in this instructional approach, whereby the teacher uses a phenomenon to pique students' interest in the content or skills learned through the further steps, Explore, Explain, Elaborate, Evaluate (Bybee et al., 2006). In this sense, community or cultural phenomena are utilized superficially, providing a familiar touchstone for students that can be explained by canonical science content. Such an approach keeps intact the unidirectional nature of the STEM pipeline. Student social and cultural identity are primarily used as a means of introducing students to explanations made available by assimilation into the culture of science, rather than providing a context in which the tools of science can be democratized to address community issues in harmony with social and cultural identity. I contend that this discontinuity between the theory and practice of how funds of knowledge are leveraged by science teachers follows from the pipeline ideology that implicitly or explicitly undergirds science education policy.

A Bidirectional STEM Pipeline

Cannady et al. (2014) have argued that the pipeline model is an overly simplistic representation of the trajectory that students take from post-secondary science to careers in STEM fields. They argue that the linearity of the model with its single terminus implies a uniform educational experience for all who ultimately attain careers in a scientific discipline. Rather, the experiences and courses of study that shape future scientists are as varied as the disciplines and sub-disciplines that make up the professional fields that compose the STEM acronym. In addition, Cannady et al. problematize the linear pipeline model for its assumption that students who "leak" out become removed from science altogether. They point out that not all careers in science require terminal degrees, as the pipeline model suggests, and even those students who fail to go on to work in science fields should be expected to retain something from their education for use in other fields or in their future lives. Rather than portraying leakage, the pipeline should branch from its beginning with secondary science enrollment along countless possible valid trajectories.

While I agree with the argument presented by Cannady et al. (2014), I find their reconceptualization of the pipeline model still places undue emphasis on forward progress through science education. That is to say, even this multi-trajectory model remains unidirectional in time and primarily retains the learn-to-earn concept of the purpose of science education. Critical educational theorists argue that school should not just engage in social reproduction, but also in social transformation (Bourdieu & Passeron, 1990; hooks, 1994). Science should not only be treated as something students learn now that they will use in their future lives and/or work.

Rather, as I will explain below, students should learn science through use in the authentic context of their home communities, appropriating the knowledge and tools of canonical science to understand and address community social issues. Such an approach to science education prioritizes a social justice orientation towards the purpose of teaching and learning science, rather than an economic one, and implies a bidirectional pipeline model whereby the utility of science to the project of social justice today is of equal or greater importance to the student's progress towards future career or personal utility. By conceptualizing the purpose of science education as first and foremost to democratize the tools of science for use in students' communities today, we also allow for a forward directionality that empowers students to (re)create the culture of canonical science itself.

The concern that science is presented as a monolithic culture, unique from students' daily lives, and thus necessitating an act of cultural assimilation is not a new one. Over 120 years ago educational theorist, Dewey, identified much the same issue as can be observed in the modern science classroom, positing that curriculum often treats science as a "new peculiar kind of experience" (Dewey, 1897, p. 5). He argued that, instead, science should be treated as a set of tools complementary to and useful for addressing social experience. Dewey's thinking on science education epitomized his broader educational philosophy. He believed that the content of curriculum should both arise from the social context of students' lives and provide relevant training for the work of social progress. In *Democracy and Education* Dewey wrote:

> The place of communication in personal doing supplies us with a criterion for estimating the value of informational material in school. Does it grow naturally out of some question with which the student is concerned? Does it fit into his more direct acquaintance so as to increase its efficacy and deepen its meaning? If it meets these two requirements, it is educative. The amount heard or read is of no importance—the more the better, provided the student has a need for it and can apply it in some situation of his own [….] A curriculum which acknowledges the social responsibilities of education must present situations where problems are relevant to the problems of living together, and where observation and information are calculated to develop social insight and interest (Dewey, 1916, 2008, pp. 365-372).

Dewey made clear the bidirectional nature of successful curriculum growing out of students' prior social experiences and serving the purpose of continued social (re)construction. Applying this idea to the leaky STEM pipeline, we begin to see how current efforts to engage students' funds of knowledge fail to adequately inspire students to persist in STEM fields throughout secondary and higher education. Students' social context is used solely as a gateway into the pipeline, which then carries them away from the social reality of their immediate communities and cultures. This is particularly true for students from marginalized backgrounds who do not see their communities or cultures represented in the technological-professional culture of science (Aikenhead, 2006). Rather, Dewey might argue, the social should not just act as an entry point to the pipeline but should be the context in which the entire pipeline is situated, in which all science is presented and understood. Science apart from its role as a tool democratized for social progress fails to inspire interest and ultimately leads to the reproduction of the existing socioeconomic reality.

Despite his argument for the importance of grounding curriculum in the practical social context of students, Dewey (1916, 2008) saw this as only the starting point for deeper understanding of more abstract scientific generalization. To advocate for the bidirectionality of science education from social experience, for social activity, does not negate the value of building a deeper understanding of scientific laws and constants. Dewey saw this higher, scientific thinking as a natural continuation of the social nature of learning, as students gained insight from more experienced others, peers, teachers, and members of the community at large:

> [T]he young begin with active occupations having a social origin and use, and proceed to a scientific insight in the materials and laws involved, through assimilating into their more direct experience the ideas and facts communicated by others who have had a larger experience (Dewey, 1916, 2008, p. 372).

This philosophy of the development of scientific thinking bears a strong resemblance to the thinking of Russian psychologist Vygotsky (1986) on the relationship between so-called spontaneous and scientific concepts. Vygotsky's description of the bidirectional development of concepts arising from everyday experience, spontaneous, on one end and canonical, or scientific, on the other is even more explicit than that described by Dewey. In *Thought and Language*, Vygotsky described how the upward progression of spontaneous concepts, from the specific lived experience toward generalization, and the downward progression of scientific concepts, from taught laws and generalizations toward specific examples, simultaneously clear a path for one another as development proceeds:

> In working its slow way upward, an everyday concept clears a path for the scientific concept and its downward development. It creates a series of structures necessary for the evolution of a concept's more primitive, elementary aspects, which give it body and vitality. Scientific concepts, in turn, supply structures for the upward development of the child's spontaneous concepts towards consciousness and deliberate use. Scientific concepts grow downward through spontaneous concepts; spontaneous concepts grow upward through scientific concepts (Vygotsky, 1986, p. 194).

Previously, Vygotsky had rejected the idea of learning by imitating alone (Vygotsky, 1978). Imitation, he argued, does not further an individual's development because it is impossible to imitate that which is beyond one's actual developmental level, as determined by prior social experiences.

Imitation, as antithetical to the bidirectional development of concepts, can be seen as akin to Aikenhead's (2006) description of assimilation. Rather than replacing one's own socially constructed identity with the identity of a scientist, students must actively participate in the (re)construction of their own identities and of the culture of science itself. Aikenhead (2006) described these processes respectively as acculturation and enculturation. It is important to note that Aikenhead intended assimilation, acculturation, and enculturation to describe distinct interactions between identity and culture depending on whether a given student sees their identity reflected in the culture of science. I believe acculturation and enculturation can be interpreted as dialectical processes. Through acculturation, students' appropriate canonical science as a set of understandings, skills, and tools to be used to solve problems and explain phenomena in the everyday social context. Through this process, borrowed scientific concepts move downward, as described by Vygotsky (1986), and are added to or replace spontaneous concepts, (re)constructing identity. Through enculturation, scientific concepts enhance everyday spontaneous concepts as they move upwards and students' identities contribute to the continued (re)construction of the culture of science.

Bidirectionality in Action

A Heuristic for Critical Analysis

Schumacher's concept of Buddhist economics sought to separate our understanding of well-being from that of consumption. Applying this lens to science education, we can begin to disentangle policy, curriculum, and pedagogy from the learn-to-earn purpose that has historically guided it in order to reimagine practical approaches that prioritize individual and community well-being. Vossoughi and Vakil (2018) provided a simple examination of meanings attached to the word "diversity," drawing on work at the intersection of race and mathematics education by Martin (2009). This tool acts as a heuristic with which we may begin to critically analyze existing policy and practice that seeks to increase "diversity" of representation in STEM majors and careers. Table 1 is adapted from Vossoughi and Vakil (2018), where the left-hand column illustrates meanings of "diversity" rooted in capitalistic competitiveness and economic hegemony, and the right-hand column illustrates meanings of "diversity" rooted in student and community well-being. Vossoughi and Vakil (2018) argued that curriculum and pedagogy decisions that apply motivations for promoting diversity from the column of the right side of Table 1 will help shape science education in which science can primarily be appropriated as a tool for community development and social transformation (p. 134). They add that the right side of the table emphasizes "the need to imagine ways of broadening and deepening participation in STEM education without simultaneously increasing participation in the kinds of scientific knowledge production that contributes to the oppression of young people and communities of

Table 1

Contrasting motivations for diversity in STEM

Diversity as rooted in competitiveness and hegemony	Diversity as rooted in student and community well-being
Culturally and linguistically diverse STEM workers as tied to expanding markets	Culturally and linguistically diverse knowledge producers as tied to expanding and democratizing the meanings, values, and purposes of STEM education
Token representation as tied to perceptions of multicultural democracy	Substantive representation as tied to the redistribution of power and the struggle for social, racial, and educational justice
Expanding the pool of qualified domestic labor so that U.S. technological innovation can dominate markets	For some, expanding the pool of qualified domestic labor as tied to economic/social mobility and community development. For others, diversifying STEM education tied to building a future free of racial hierarchy and economic exploitation.
Closing the "achievement gap" as tied to improving international measures of STEM excellence	Reimagining and transforming education such that all students (in the U.S. and around the world) have access to intellectually respectful learning experiences and the resources to fulfill their individual and collective potential

Note. Adapted from Vossoughi & Vakil, 2018, p. 134.

color around the world" (p.133). Superficial use of funds of knowledge of culturally and linguistically diverse learners conceived solely to "hook" or "Engage" students into an otherwise unmalleable curriculum, as discussed above, represents a practice that this heuristic would problematize. Recognizing such superficiality would then allow policymakers, institutions and/or teachers to correct their practice so as to incorporate an understanding of diversity rooted in student and community well-being.

Youth Participatory Science

Beyond problematizing policy, curriculum, and pedagogy, it is helpful to acknowledge existing frameworks that exist that adopt a concept of the bidirectionality of the purpose of science education. One such framework is Youth Participatory Science (YPS), as outlined by Morales-Doyle and Frausto (2020). YPS draws on the critical pedagogy of Youth Participatory Action Research (YPAR), which "stress[es] the production of knowledge by those who do not hold formal positions as intellectuals and thus position youth as transformative intellectuals" (p. 528), traditionally utilized in social sciences education. YPAR, and subsequently YPS, embrace and seek to foreground the diversity of cultural and linguistic perspectives that marginalized students bring to the classroom. YPS marries this appreciation for other ways of knowing with the democratization of the tools of science of the movement known as "citizen science." Morales-Doyle and Frausto (2020) explained, "YPS can be conceived as a specific form of street science, which democratizes the tools of science in a way that values the wisdom and understandings that exist within communities marginalized by racism and economic dispossession" (p. 526). That is to say, rather than engaging community social issues as a means of introducing students to canonical science content, YPS situated the entirety of the science curriculum in the community context. In this case, Youth actively Participate in applying the tools of Science to understand and address social issues relevant to their lives.

In addition to outlining the YPS framework, Morael-Doyle and Frausto (2020) provided a case study of the framework in action. The authors emphasized that unlike professional development around the use of the 5-E instructional model (Bybee et al., 2006), which encourages a backwards design process of lesson planning, working from NGSS standard to the community issue that will be used for initial student "Engagement," lesson planning with YPS should begin with a community "social justice scientific issue*"* (p. 531) to be addressed. In their case study, Morales-Doyle and Frausto centered their unit in this way around urban lead contamination. After identifying this issue in cooperation with their students, they "[applied] a scientific lens" (p. 532) to the issue. At this stage of the framework, the teachers sought to democratize the knowledge and tools of science that can be used to understand and address the issue of lead contamination. The authors emphasized democratization rather than traditional conceptions of teaching, weary of "suggesting that science alone is capable of solving problems that are facing the community" (Morales-Doyle & Frausto, 2020, p. 532) and subsequently denigrating or silencing community funds of knowledge. Students apply this democratized knowledge to "plan and conduct an investigation" (p. 534) and "analyze data and assess learning" (p. 535). Through these steps of the YPS framework, the students gathered samples of paint, soil, and water from their community, which Morale-Doyle and Frausto, through their affiliation with a university are able to have analyzed by sophisticated equipment. In the final, and perhaps most impactful step of the framework, students "reflect[ed], disseminate[d], and act[ed]" (p. 536), some presenting their findings to the city council to lobby for cleanup of urban lead contamination. This final step of the case study emphasized the bidirectionality inherent to the YPS framework. Through the democratization of the tools of science in a manner that is sensitive to students' socially constructed identities and existing ways of knowing, science education in this case fulfilled the dual purpose of immediate individual and community well-being and preparation of students for a future where they may continue to use the tools of science in their lives and/or careers.

Discussion and Future Research

In his treatise against what he sees as the modern infatuation with economic growth and material consumption, Schumacher (1973) deemed education "the most vital of all resources" (p. 84), but warned that "[m]ore education can help us only if it produces more wisdom" (p. 86). He elaborated,

> Science [produces] "know-how": but "know-how" is nothing by itself; it is a means without an end, a mere potentiality, an unfinished sentence. "Know-how" is no more a culture than a piano is music. Can education help us to finish the sentence, to turn the potentiality into a reality to the benefit of man? (p. 86).

Schumacher viewed science as a set of powerful tools, that in the wrong hands breeds environmental destruction and social exploitation. He viewed education a means by which to humanize science for the work of social progress. As I have argued, by conceptualizing the purpose of science education as first and foremost to democratize the tools of science in order to empower and equip students with the means to understand and address social justice issues, we empower those very students to (re)create the future culture of the discipline of science itself. I have called this relationship between democratization of the tools of science and the (re)construction of the culture of science a bidirectional STEM pipeline. By grounding policy aimed at increasing diversity in STEM in this decided uneconomic model, we might hope to build a science that is more responsive to the well-being of marginalized students and communities.

Future work may look at how K-12 science education can work in a bidirectional manner, serving students' future applications of science in life and career as well as democratizing the tools of science to serve students' current lives and communities. The YPS framework outlined above represents one such emerging approach. The case study of YPS in action provided by Morales-Doyle and Frausto (2020) was a single isolated classroom curriculum in a course taught by the authors. More work needs to be done to understand whether and YPS would be scalable to institutions or districts where standardization of assessment continues to be politically necessary.

Moving beyond the linearity implied by a simple bidirectional pipeline, future research may also look at how science education can prepare students for a more diverse array of future applications of science skills and content as argued by Cannady et al. (2014). The existing leaky pipeline and the bidirectional model suggested here both conceptualize traditional science majors and careers as the ultimate endpoint of an institutional science education trajectory. Rather, than focusing solely on retention within the pipeline along this trajectory, educators might be better served to treat each "leakage" as an equally viable and important life and career trajectory. It becomes easier to see the value in these novel trajectories when we decouple science education from the economic motivations that have traditionally guided our policy and research.

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