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Revitalizing science and technology studies: A Marxian critique of more-than-human geographies

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Abstract
This article revisits Marx's philosophy of history with respect to technological change, outlining some elements for the elaboration of a research agenda for materialist studies of science and technology. I argue that dominant thinking on the subject has been insufficiently attentive to relations of production and to the constitutive role of practical, transformative activity. The article suggests that a focus on class relations not only foregrounds the eminently open and contested nature of technology but also renders into view the multiplicity of actors and agencies involved in the making of natures. I draw from a subterranean strand of Marxist theorists of technology to develop a more-than-human approach to political agency through an interrogation of the complex interactions between human and machine in the everyday, experiential practicalities of the labor process. On this basis, the article contends that foregrounding the class preconditions for an alternative scientific praxis should assert itself as the starting point and horizon of a materialist Science and Technology Studies.

Keywords
Science and Technology Studies, Marx, posthuman turn, new materialisms

> . . . science it would seem . . . is neither sexless nor classless; she is a man, bourgeois, and infected too. (Rose, 2004 [1983]: 68)
> Natural science will in time subsume under itself the science of man, just as the science of man will subsume under itself natural science: there will be one science. (Marx, 2007 [1844]: 111)

Introduction

The idea that the technological application of modern science has reconfigured the biogeophysical composition of the planet to such an extent that humanity has entered

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a new geological epoch of its own making (i.e. the Anthropocene), gains increasing notoriety among the social sciences (see Castree, 2014; Moore, 2015; Parikka, 2015; Wark, 2015). Anthropogenic material flows from fossil fuel combustion, agriculture and metal ore smelting, as Bridge (2009: 1224) argues, now rival in scale those occurring independent of human activity, like volcanic emissions, rock weathering and water erosion on a planetary scale. From synthetic micro-organisms to complex infrastructural systems that stretch across whole continents, the process of socio-metabolic transformation that defines our current epoch is mediated by a staggering degree of technical sophistication and dynamism. In light of such massive transformations, Diana Coole and Samantha Frost (2010) argue in a programmatic statement of "new materialist" thinking that there needs to be a renewed emphasis on materiality. Indeed, ever since Sarah Whatmore observed in 2006 that cultural geographers were undergoing a turn toward materialist concerns, the field of Science and Technology Studies (STS) has become heavily influenced by Actor-Network Theory (ANT), new materialisms, speculative realism, and object-oriented ontologies.

Despite their differences, the tendency of these self-proclaimed materialist (or "material-semiotic") approaches to treat technical and scientific artifacts as ahistorical and external to relations of production, bears striking resemblance with the intellectual landscape that motivated older debates on the nature of materialism. In 1846, Marx and Engels wrote *The German Ideology* with the purpose of developing a materialist philosophy of history that stood in opposition to the idealism of Young Hegelians such as Bruno Bauer and Max Stirner, as well as to the "contemplative materialism" of Ludwig Feuerbach (see Marx and Engels, 1998 [1846]). For Marx, the unwillingness to systematically interrogate the history of industry and exchange made his contemporaries erroneously consider forces of production to be "a world for themselves, quite independent and divorced from the individuals" (95). Today, the influx of new materialisms on the fields of STS and geographical scholarship in general has engendered similar ideological visions. Plastic bags, surveillance systems, and electric grids, to cite a few examples, are often viewed as acquiring a seemingly autonomous existence, and this precludes a truly democratic engagement with technological change.

Interventions that either seek to establish a dialogue between new materialist thinking—especially ANT—and Marxism, or that criticize the former by means of a contrast with the latter, are abundant in the literature (see, for example, Brenner et al., 2011; Castree, 2002; Christophers, 2014; Holifield, 2009; Hornborg, 2014; Kirsch and Mitchell, 2004). The remit of this article is therefore different, because my core aim is not to seek a synthesis/synergy between approaches, or to point out flaws in a theoretical framework. Rather, it is to stress the urgency of reclaiming the field of STS as one that is fundamentally concerned with the critique and radical overturning of the variegated forms of racism, exploitation, social domination, and ecological destruction engendered by bourgeois science and technology. To do this, I show the potential of Marx's philosophy of history to *revitalize* the field. I deliberately stress the word revitalize to reassert the view that underpinned Marx's own doctoral dissertation on Epicurean vitalism and dissipate commonly held views of historical materialism as an irredeemably deterministic and anthropocentric framework (see Burns, 2000; Foster, 2000, chapter 4). In this early text, Marx drew much inspiration from Ancient Greek philosophies of nature as a means to emphasize the *vital*, contingent, and expressive attributes of the material world, and hence the infinite potentialities of human–nonhuman configurations to transform reality in myriad ways. Based on these insights, Marx (2007 [1844]) argued in a later text for a view of technical artifacts as potentially emancipatory, yet deeply inscribed in class relations and for that reason subject to democratic appropriation, repurposing, and political mediation.

Writing in the 1970s, Alfred Sohn-Rethel (1978) claimed that in a genuinely post-capitalist society, the modern developments of science and technology should be made subservient to the common good and not to specific class interests. He thus considered the elaboration of a historical-materialist explanation of the origins of scientific thought and its technological application a key priority for critical social theory (Sohn-Rethel, 1978: 3). My aim with this article is then to argue that an insistence on mode of production and class struggle needs to be placed at the center of STS if the field is to be able to make any relevant contribution to the production of an emancipated science. I demonstrate that such an analytical move does not come at the expense of silencing the multiplicity of actors and agencies involved in the making of natures. I also wish to contribute to an already rich tradition of Marxist geographers developing powerful explorations of technological change under capitalism. Although such studies have provided key insights for understanding issues as diverse as territorial organization (Swyngedouw, 1992), real subsumption of nature (Labban, 2014; Moore, 2015; Smith, 2008 [1982]), logistics (Cowen, 2014), and the technical composition of capital (Harvey, 2006 [1982], chapter 4), the issue of technological change and the revolutionary consciousness of the working classes has not been substantially developed. Posing this latter question is of much relevance not only because of its self-evident political significance. Also, it problematizes the relation between the seemingly distinct spheres of life and science, henceforth revealing possible avenues for an alternative scientific practice.

In light of the above considerations, the article will be divided into four sections as follows: The first starts by outlining the main features of Marx's materialist conception of history concerning technology, most of which were forged in opposition with the views of Young Hegelian authors. I will argue that what Marx considered problematic about such strands of thought has been amplified in contemporary accounts of technology. Against the depoliticized and ahistorical approaches of new materialist thinking, I propose to shift the focus toward the critique of political economy, as well as toward alternative iterations of the field of STS, especially in its feminist variants. Feminist STS offers a fascinating springboard from which to rethink the field because it foregrounds embodied materiality and situated knowledge, while retaining an insistence on the dynamics of domination and exploitation that lie at the heart of capitalist society. The second section suggests that the value form of capital provides a crucial vantage point from which to understand technology's life-making capacities, as well as the political possibilities that are enabled by the expansion of large-scale industry across the world. The third section draws from a rich, yet largely overlooked tradition of Marxist philosophers of technology with the purpose of exploring the relation between science and political action, but from the standpoint of the worker. In revealing the inner transformations that the laborer undergoes as an agent of capital in its scientific-technological form, the article shows that the artificial cleft that separates organism and machine, human and nonhuman, becomes dismantled in the course of the labor process. In the remainder of the article, I discuss some common misconceptions about Marx's materialism regarding technological change, especially concerning claims on its supposed Promethean and techno-determinist outlook.

Materialism and technology

The analytical starting point in Marx's critique of political economy is the distinction between the vital capacities of human and nonhuman forms of life, and the repercussions this distinction brings for processes of metabolic exchange among socio-natural systems.[1]

Nonhumans adapt to their environment, while humans possess the capacity to transform the latter for themselves through sensuous practical activity (i.e. labor). In *The German Ideology*, Marx and Engels (1998 [1845]) set the foundations for this approach by claiming that the "first historical act" constitutes the production of the means to satisfy the needs of the human life process (47). In collectively and consciously regulating the process of social metabolism, humans not only produce tools but also cooperative arrangements, which in their aggregate form constitute the productive forces of society. It is for this reason, Marx and Engels (1998 [1845]) point out that "the 'history of humanity' must always be studied and treated in relation to the history of industry and exchange" (49).

Material production, according to Marx and Engels (1998 [1845]), is always interwoven with the production of ideas.[2] It is then as transformative and creative beings that humans, in their permanent relations with reality, produce not only material objects but also social institutions, relations, and conceptions of the world (Freire, 2000 [1970]; Sohn-Rethel, 1978). This intimate interfusion between material and subjective realities leads a more mature Marx (1976 [1867]) to argue that "instruments of labour not only supply a standard of the degree of development which human labour has attained, but they also indicate the social relations within which men work" (286). This is pertinently exemplified by Michael Hardt (2010) by arguing that the refrigerator and the automobile, besides being mere technical artifacts are also midpoints for the creation of labor and gender relations of the nuclear family (in the case of the former), and a mass society of individuals isolated but together (in the case of the latter). It is in this sense that Marx (1976 [1867]) famously contends that

> Technology reveals the active relation of man to nature, the direct process of the production of his life, and thereby it also lays bare the process of the production of the social relations of his life, and of the mental conceptions that flow from those relations. (493)

Technological inventions, Marx (2007 [1844]) argues in the *Paris Manuscripts*, are the "objectified essential powers of man in the form of sensuous, alien, useful objects..." (110). These technical objects, he suggested a few years later in the *Grundrisse*, are natural materials mobilized into "organs of the human will over nature, or of human participation in nature" (Marx, 1973 [1939]: 706). Just as leaves and organs sustain biological processes, Marx claims that mechanical tools and systems of machinery—and one might add, cybernetic systems as well as other recent products of human ingenuity—"are organs of the human brain, created by the human hand" to support an evolving, collective process of social metabolism (1973 [1939]: 706; 1976 [1867]: 493). Quite crucially—and this would constitute one of the fundamental hallmarks of the materialist conception of history—the divisions of labor that emerge from the collective mediation of such instruments of social production invariably lead to the formation of classes and to conflicts between them over their benefits and ownership (Marx and Engels, 1998 [1845], 2011 [1848]). Classes should not be understood as social structures, but as the concrete embodiments of socio-material formations that are produced and reproduced technically. The gendered relations of oppression and exploitation of the maquila manufacturing system, or the racialized relations of industrialized house cleaning, are as contingent and dynamic as the sociotechnical systems by which they are underpinned. Also, and quite crucially, the notion of class should not be confined to the wage relation exclusively, but should also encompass unpaid work.

The emergence of large-scale industry, argued Marx and Engels (1998 [1845]), "made natural science subservient to capital and took from the division of labor the last semblance of its natural character" (81). This is precisely why it is important to capture the historically specific nature of technology in capitalism, whereby equipments, expertise, and techniques

are mobilized exclusively for the endless pursuit of surplus value (Smith, 2010; Sohn-Rethel, 1978). In this social order, Tony Smith (2010) argues, technology is not a means for the fulfillment of human needs but first and foremost a means to capital's self-valorization. So-called "new materialist" thinking, which has become very influential in the field of STS and in geographical scholarship generally considered, tends to be oblivious toward these considerations. In treating technical and scientific arrangements as autonomous from relations of production, these strands of thought reproduce the "contemplative materialism" of Young Hegelians, which aroused fierce criticism from Marx and Engels in *The German Ideology* and other texts (see Marx and Engels, 1998 [1846]; Marx, 1998 [1888]). In a key intervention of new materialist thought, Jane Bennett (2010) suggests that inanimate objects have the capacity to "act as quasi agents or forces with trajectories, propensities, or tendencies of their own" (viii). These intellectual traditions usually depict everyday objects—garbage, food, an electric grid—as capable of *acting* autonomously from human mediation (i.e. social forms of labor).

Besides the tendency to consider things (organic, inorganic, technical, and so forth) as ahistorical, a further characteristic that cuts across the various new materialist intellectual traditions is an appeal to notions of "ethics" and "justice" as the solution to our current predicament. In a programmatic statement, Coole and Frost (2010) argue that new materialisms are directly concerned with what is viewed as the pressing *ethical* issues that accompany the scientific and technological advances predicated on new models of matter. As was the case with Young Hegelians, new materialist authors need to come to terms with the fact that the content of empty signifiers such as ethics and justice are, in actuality, dictated by those who wield power, especially economic power. As Iñigo Carrera (2013 [2003]) argues, the egalitarian and solidary spirit that embellishes transcendental notions of ethics and morality actually obfuscates the real historical determination. More than seeking normative "truths," post-foundational engagements with ethics demand attention to the embodied realities of social action, and the ways in which they perform political equality and transform power relations (for a critique of liberal conceptions of ethics and justice, see also Buck-Morss, 2013; Velicu and Kaika, 2015). Worker empowerment, not appeals to normative ideals of ethics, should constitute the political horizon of an STS that takes materiality seriously.

Foucauldian studies of governmentality have also gradually been drawn into the umbrella of neo-materialist thinking (see Braun and Whatmore, 2010; Lemke, 2015; Wakefield and Braun, 2014). Research in this tradition reveals with increasing sophistication the variegated technical mechanisms of power, or *dispositifs*, that shape the dynamics of modern cities, warfare, ecology, gender relations, and the modern home, among others. *Dispositifs* of governmental reason are viewed as autonomous forces that typically exert top-down, actuarial regulation of populations, and the very possibility to make things different is thwarted from the outset and considered external to the dynamics of technological and organizational arrangements (Hardt and Negri, 2009: 59). In the *Theses on Feuerbach*, Marx (1998 [1888]; *thesis III*) argued that Feuerbach's materialism failed to account for the fact that all human practice bears within itself the possibility to transform an existing state of things (570). Foucault's fixation with "total institutions" and "panoptic machines," Marshall Berman (1988 [1982]: 34) suggests, made him unable to grasp the significance of revolutionary practice and hence view modern life as a mere variation of the Weberian iron cage. This, naturally, percolates into the ways governmentality scholarship construes technological change.

Actor-Network Theory (ANT), possibly one of the most influential traditions of new materialist thinking, is perhaps even more problematic and in certain ways more

reminiscent of old debates on the perils of "contemplative materialism." Although ANT has developed several iterations since its inception with the foundational works *Laboratory Life* by Bruno Latour and Steve Woolgar (1986), and *We Have Never Been Modern* by Latour (1993), its defining features have remained relatively unchanged (for a programmatic statement, see Latour, 2007). ANT's fundamental contributions consist, first, on showing how scientific facts are intrinsically co-produced in routinely laboratory practice, and therefore independent from broader social context(s) (Farías, 2015). Second, ANT purports to show the constitutive role of nonhuman agencies in the production of science and technology, an approach that was later condensed by Michel Callon—one of ANT's key proponents—into the principle of *generalized symmetry* (Farías, 2015). It is this insistence on non-mediated social practice and materiality that makes ANT an inherently materialist approach—or "material-semiotic," more specifically (see Law, 2009).

Contemporary renderings of ANT have radicalized these assumptions—especially the agency of nonhumans—leading to an "ontology of naïve objectivism" (Brenner et al., 2011) that fetishizes full-blown immediacy while overlooking the context in which it is embedded. These scholarly discussions usually offer a contemplative stance toward the sheer complexity of sociotechnical arrangements that frequently blends into hair-splitting discussions on ontology and depoliticized description. For that reason, and despite his lifelong interest in the study of the microprocesses unfolding in the context of everyday life, Henri Lefebvre (2008 [1961]) warned about the dangers implicit in remaining attached to immediacy. When isolated from total social reality, he argued, the "hyperconcrete" can be as abstract as any other philosophical generality (Lefebvre, 2008 [1961]: 181) and as a result becomes stripped of any explanatory potential. Such object-oriented ontologies cannot but be reminiscent of Marx's own indictment of non-historical materialisms. Thus, in *Thesis 1*, he notes how the chief defect of all hitherto existing materialism was that things were conceived only in the form of the *object*, or of contemplation, but not as sensuous productive activity (Marx, 1998 [1888]: 569). In *The German Ideology*, Marx and Engels (1998 [1845]) are critical of Feuerbach's approach to science by its lack of attentiveness to relations of production in a statement that could have easily been aimed at neo-materialists as well. Feuerbach, they argue,

> ... speaks in particular of the perception of natural science ... but where would natural science be without industry and commerce? Even this "pure" natural science is provided with an aim, as with its material, only through trade and industry, through the sensuous activity of men. (Marx and Engels, 1998 [1845]: 46)

It is difficult to not feel a sense of frustration toward the current state of STS, especially when considered against the backdrop of earlier iterations of the field, and especially in its feminist variants (for an overview, see Suchman, 2007). In a now classic intervention, Hilary Rose (2004 [1983]) paraphrases Virginia Woolf to argue that, far from being classless and sexless, science "... is a man, bourgeois, and infected too" (68). Feminist STS authors denounce a regime of scientific production that is premised upon a sexual division of labor where women are relegated to reproductive work and therefore excluded from science. Authors in this tradition argue that such exclusion impedes the contribution of women's deeply situated knowledge of the natural world (because of their standpoint in kind and caring work) and hence undermines the possibility for an alternative, emancipatory scientific practice (Haraway, 1991: 8–10; Rose, 2004 [1983]; Wajcman, 2002). For these scholars, a truly materialist approach to science needs to transcend the narrow focus on production that abounds in traditional Marxist accounts, and include that other materialist necessity of history, which is *reproduction* (see Rose, 2004 [1983]; Tuana, 2003 [1996]).

As Alex Loftus (2012) contends, rich potentials lie in excavating the roles and everyday lives of women who, in societies both shaped by patriarchal and capitalist relations, are brought much closer to the material interchange with nature (as well as with technology, one might add) that is so important to challenge the objective structure of the modern world.

In this sense, feminist STS has important points of convergence with the materialist philosophy that orients my argument. Besides being profoundly historical, this strand of thought emphasizes the active side of life that also punctuated Marx's materialism. As Sandra Harding (2004) demonstrates, empowering oppressed groups, valuing their geographically and historically situated experiences, constitutes a core concern of feminist STS. Against the alienated and abstract knowledge of modern science, feminist methodology seeks to bring together objective and subjective views of the world, and to theorize from practice. Its starting point is the shared experience of oppression, and its horizon is the prefiguration of alternative modalities of scientific knowledge and practice (see Haraway, 1991, chapter 9; Rose, 2004 [1983]). This, Donna Haraway (1991) notes, can only be achieved by means of material struggle and oppositional consciousness. Forging a socialist-feminist science, Haraway forcefully asserts, requires dismantling the teleology of domination that is inscribed in the very fabric of modern regimes of scientific knowledge.

At this point, it is important to stress that the purpose of this intervention is not to be unappreciative toward the contributions of new materialist thinking. Just as Feuerbach's anthropological humanism pluralized decades of idealist philosophy, a plausible contribution in its own right, contemporary materialisms have been the harbinger of a turning point in social theory where materiality is back in the agenda, especially after the "discursive" and "cultural" turns that started in the 1970s. But most importantly, new materialist thinking has emphasized the urgency of overcoming the anthropocentric hubris of social theory, which also involves decades of scholarship in the Marxist tradition. Recent reinterpretations of Marxian theory, however, have demonstrated that a focus on class and mode of production is not only compatible with a more-than-human geography. They also bring into focus the infinitely creative, endlessly expressive potentialities of human and extra-human natures, especially when mediated by capitalist technologies. It is to these contributions that we now turn.

Technology and modes of existence

In a passage of *The German Ideology*, Marx and Engels (1998 [1845]: 45) argue that the cherry tree that Feuerbach experiences as an object of sensuous certainty, is actually the historical result of a succession of generations of industrial and commercial intercourse that led fruit trees to be transplanted to Bavaria centuries before their interlocutor was born. With this, Marx and Engels hint at the fact that it is not possible to think of any part of nature that has not already been mediated by industry. Such was the claim that Neil Smith (2008 [1982]) deepened and fully developed in the "production of nature" thesis, and which needs to be directly integrated into the development of a materialist STS. Years before the now ubiquitous term "Anthropocene" was coined, Smith (2008 [1982]) contended that capitalist society had put itself squarely at the center of nature, because no part of the earth's surface, oceans, atmosphere, or geological substratum was immune from transformation by capital (79). Although new materialist thinking unfolds concepts such as actants, thing-power, quasi-objects, and assemblages, among others, to capture the recalcitrant, almost willful properties of nature, these are usually employed in blissful unawareness of the manifold industrial and political-economic mediations in which they are

already imbricated. Like Feuerbach's cherry tree, such lively objects and entanglements are ahistorical only in appearance.

Foregrounding the historicity of technology, however, does not come at the expense of losing the vitalist impulse that inspired the young Marx, as Jane Bennett (2005) seems to suggest. For Bennett, Marx was so "overzealous" in his critique of the abstractions produced by capital, that he lost touch "with the remarkable appreciation of agency within nature that Epicurus actively affirms" (121). Such a claim is intriguing, because authors in the field of STS have explained that Marx was the first author to grapple with the hybrids of human–machine, capital–consciousness, automatism–will (Kirsch and Mitchell 2004; Mitchell, 2002: 30). Indeed, recent studies have sought to emphasize the post-Cartesian orientation that underpinned Marx's mature work, where the unpredictability and expressiveness of nature takes center stage. Value, which is but the restless, formally boundless and self-expanding motion of capital as it scours the world for profit, is the most powerful engine of territorial and socioecological change in contemporary society. Its ongoing reproduction hinges upon the technologically sophisticated, sublimely dynamic multiscalar networks of trade, production, and logistics that stretch across continents. They weave together transnational corporations, systems of machinery, hydroelectric dams, micro-organisms, agroindustrial enclaves, and tropical forests, into a complex unity under a spatial division of labor.

Given the sheer complexity and breadth of these metabolic exchanges, Jason Moore (2015) has recently proposed to think of capitalism not as a social system but as a form of environmental history. Capitalism, he continues, is not external to nature but instead develops and flows through the web of life. Far from affirming capitalism's unfettered capacity to remake planetary natures, the notion of capitalism in the web of life opens up a way of understanding capitalism as already co-produced by manifold species, and extending even to the planet's geobiophysical limits and cycles (Moore, 2015). On this basis, Moore contends that value offers an unparalleled vantage point from which to visualize the ways in which human and extra-human natures become densely interwoven in relations of co-evolution and metabolic exchange. Value, says Moore (2015), is encoded simultaneously through the exploitation of labor-power in commodity production, and through the appropriation of unpaid work performed by both human and extra-human natures. He notes how classic Fordism is for example unthinkable without the life-making capacities of steel, rubber, and oil, but also without labor-power in the factories and unpaid reproductive work in the household.

In Moore's account, nature is not merely an input or limit for capitalist exploitation and appropriation; it is also recalcitrant, uncooperative, and immensely generative. He for example considers the "superweed effect" (i.e. the relentless proliferation of herbicide-resistant plants in industrial agriculture) to be the creative response of extra-human natures to the biotechnology agricultural revolution of recent decades (Moore, 2010, 2015, chapter 10). Monstanto's RoundUp Ready GMO crops, Moore (2015) shows, have been at the forefront of an unprecedented outburst of superweeds that has spread like wildfire through millions of acres of soybean plantations in the United States, Brazil, and Argentina—with an estimated 60 million acres affected only in the US (271–272). In a similar vein, Rob Wallace (2016) demonstrates how pathogens such as novel influenza variants, Hepatitis E, Campylobacter, and others, are the unintended byproduct of biological mutations emerging from highly engineered and capital intensive megabarns for meat production. These trends not only evince the relative inability of capital to fully govern neoliberal natures but also illustrate the role that technology plays in Marx's notion of the declining rates of profit. According to Moore (2010), the overproduction of machinery

(or fixed capital in general) tends toward the underproduction of raw materials. Rising socioecological exhaustion and rising capitalization, Moore (2010) concludes, are two sides of the same coin (405).

Mazen Labban (2014) also offers an exploration of biotechnological innovations in the mining industry to illustrate how nonhuman organisms have been harnessed and engineered to break the resistance of recalcitrant ores and metals that cannot be extracted by traditional methods. In extending the material basis of the process of extraction at the cellular-elemental scale, Labban shows how the production of value is contingent upon a metabolic articulation between the creative capacities of human and nonhuman forms of life. At the core of such productive articulation is the cohesive force of value, which homogenizes the most disparate temporalities (in this case, the temporality of microbial metabolism is synchronized with that of the human laborer and of geological strata). In Labban's (2014) account, nature is at once recalcitrant and productive, because bioleaching technologies allow mining companies to overcome geological limits to extraction, but in so doing create new obstacles arising from microbial metabolism itself.

Maria Kaika and Erik Swyngedouw's (2000; see also Heynen et al., 2006) view of modern urbanization, as a metabolic unity of human and nonhuman entities that is socially and technologically mediated by the value relation, is another relevant example of approaches that reveal the expressiveness of the material world while foregrounding its political-economic context. Like micro-organisms and plants, Kaika and Swyngedouw (2000) demonstrate that the nature of the city is not easily governed. Although the commodity relation usually obfuscates and renders invisible the multiple socioecological mediations that make possible the process of urbanization, these hidden relations often erupt to the surface in the form of technical malfunction (an apartment-block explosion, a failure in an electric plant), natural disasters, or social revolt (see Kaika and Swyngedouw, 2000). Such events, these authors argue, dismantle the illusion of autonomy that capitalist modernity invariably creates and in so doing, reveal the violence and immanent contradictions of capitalist forms of social mediation as they transform nature into urbanization. Such obdurate character of urban natures, it should be noted, has become relentlessly upscaled and intensified in recent decades, as the infrastructural networks that connect cities to their operational landscapes have undergone considerable technological transformation (Arboleda, 2016).

As these novel approaches to technological change demonstrate, recurring to Marxian categories to explain the ways in which contemporary sociotechnical systems are shaped and reshaped by the movement of capital does not imply—as new materialist authors consider—to silence the heterogeneity of human and nonhuman actors involved in the object of critique (see Bennett, 2005; Braun and Whatmore, 2010, footnote 13; Edwards, 2010; Farías, 2011). On the contrary, value is the cohesive, transformative force that welds together geographies, life-forms and materials by means of social and technological mediations. Hence, it should offer a very productive methodological starting point for understanding the process of environment-making in contemporary society. What I want to propose with this article is therefore to supersede traditional engagements with the more-than-human, and appropriate the notion in order to lay bare the subversive elements already latent in it. That nonhumans very often display certain forms of agency has now become self-evident, even to the point of being tautological and platitudinous. The challenge, then, is to problematize the forms of violence, exploitation, racial domination, and socioecological suffering that are mediated by human–nonhuman agencies in modern, capitalist society.

Also, it is equally important for social studies of science to identify the emancipatory possibilities that are embedded within, but often suppressed by the existing state of things. According to Neil Smith (2008 [1982]), with the development of technologies for capitalist

production, the material unity of society and nature is reproduced in more advanced form than ever before. This means that with the generalization of commodity production and exchange relations, previously isolated individuals and geographies become knitted together into a complex social whole (65). On the one hand, this produces suffering and destruction but on the other, it sets into motion the possibility for vibrant encounters between workers and technological infrastructures at a truly planetary scale. Such encounters enable the possibility to hack and repurpose technology in such a way that it does not serve the abstract imperatives of exchange value, but the embodied needs and potentialities of use value (i.e. the material life process). The section that follows interrogates such encounters, as well as the possibility for an emancipated science that emerges from them.

Recalcitrant human nature and the radical critique of science

The labor process is inherently one of metabolic exchange where the material unity between human and nonhuman natures is concretely realized. As Marx (1976 [1867]) reveals in Volume I of *Capital*, through labor humans act upon external nature in order to change it, and in so doing transform their own nature (283). Although Neil Smith (2008 [1982]: 55) considered that the production of nature also encompasses the production of human consciousness, his theory of uneven development was mainly aimed at elucidating the first moment in the Marxian notion of metabolism, that is, the transformation of external nature. Indeed, the production of internal nature, especially in the form of revolutionary consciousness, has been overlooked to a large degree within existing treatments of technological change in Marxist geographical scholarship. In the *Paris Manuscripts*, Marx (2007 [1844]) suggests that it is precisely in the historical transformation of the material and social forms of labor, where the key to revolutionary subjectivity, and hence to the abolition of capital, should reside (see Starosta, 2011). A radical critique of science that is adequately positioned to transform the ways in which the world is produced and reproduced is not to emerge from normative-political orientations or transcendental ideas, but rather from the sociotechnical mediations taking place in the experiential fabric of everyday life.

In the *Paris Manuscripts*, a young Marx (2007 [1844]) adamantly rejected eschatological interpretations of science and technology as abstract forces by asserting that "one basis for life and another basis for science is *a priori* a lie" (111). In what could be an early theorization of Donna Haraway's (1991) conception of the cyborg, a hybrid of organism and machine, Marx (2007 [1844]) claimed that nature in the form of industrial technology, albeit in alienated form, "is true anthropological nature" (111). The project of bourgeois science, Sohn-Rethel (1978) illustrates, has nonetheless been to instill a bifurcation between sensuous experience and abstract scientific knowledge objectified in technological devices. Chapter 15, Volume I of *Capital*, which is considered by David Harvey (2010) to be the first comprehensive critical history of technology, offers an extensive account of how mechanized industry and organizational form (i.e. proto-Taylorite forms of scientific management) were gradually introduced not only to overcome natural limits to productivity but also to fragment and discipline the workforce (Marx, 1976 [1867], chapter 15).

I therefore want to focus on a vibrant tradition of theorists of technology that has shown how the artificially created cleft between natural science and the human life-process is to be overcome in the practical, everyday exertion of the working classes. This lineage of work can perhaps be traced back to Georg Lukács' (1971 [1923]) foundational work *History and Class Consciousness*, which has been considered not only an archetypal statement on situated knowledges and STS (Loftus, 2012) but also the first attempt to theorize the revolutionary consciousness of the working class (Starosta, 2003). According

to Fredric Jameson (2004 [1988]), the intellectual project of *History and Class Consciousness* remains unfinished, because posing the question of the class preconditions for an alternative scientific praxis has become more meaningful and urgent than ever before. For Jameson, it was early feminist standpoint theory—a precursor to feminist STS—which had deepened Lukács legacy through an interrogation of the political possibilities emerging from the group experience of women in patriarchal society. Indeed, the developmental potentialities that capitalist technologies inadvertently bring to marginalized organs of the collective laborer is paradigmatically encapsulated in Donna Haraway's (1991) concept of the cyborg as the "illegitimate offspring" of military and patriarchal capitalism that turns against its origins.

A focus on Marx's materialism, however, can further elucidate the complexity of such technological mediations as they unfold in daily life, and thus contribute to the Lukácsean openings traced by feminist standpoint theorists. For this reason, I want to highlight the fundamental contributions of an overlooked, historical-materialist offshoot of work in this vein. On the basis of a reinterpretation of Marxian thought, the work of Juan Iñigo Carrera (1993, 2013 [2003]) and Guido Starosta (2003, 2011, 2015) demonstrates that the political action of workers is not underpinned by a transcendental or ahistorical moral imperative. Rather, it is socially and historically determined by the various layers of scientific-technological knowledge embodied in systems of machinery—or what Moishe Postone (2003 [1993], chapter 8) refers to as the "objectification of historical time." Juan Iñigo Carrera (2013 [2003]) shows how the restless pursuit for relative surplus value that demands a constant revolution in the technical conditions of social production also exerts a revolutionizing effect upon the worker's consciousness and will, who gradually begins to discover herself as unfree. Technical systems of large-scale industry do away with the need for specialized skill, something that degrades the worker by transforming her into an "appendage of the machine," as Marx famously noted (Starosta, 2011). At this stage, Starosta (2011) explains that scientific knowledge takes the form of an alien, hostile power objectified in systems of machinery.

However, these automated systems demand at the same time the tendential expansion of the productive subjectivity of the collective laborer, henceforth requiring from individual workers ever more complex forms of labor (Iñigo Carrera, 2013 [2003]; Starosta, 2011: 53). In Marx's words, large industry, by its very nature, "necessitates variation of labor, fluidity of functions and mobility of the worker in all directions" (cited in Starosta, 2011: 617). Workers then become increasingly competent to scientifically organize the production process of any automated system of machinery, and therefore any form of social cooperation beyond the grasp of the capitalist (Iñigo Carrera, 2013 [2003]; Starosta, 2011). The production of this scientific consciousness in the laboring classes as a result of the material development of the forces of production, argues Iñigo Carrera (2013 [2003]), is capital's constitutive contradiction and sets the foundations for its supersession. Crucially, the forms of political organization that emerge from the scientific consciousness of the collective laborer, Iñigo Carrera (1993) concludes, constitutes the abolition of the separation of manual from intellectual labor. The artificial separation between organism and machine, science and life breaks down, and the capital-form radically transfigures itself into political action. For this reason, human agency is not to be understood as a bounded and distinct realm of existence, but rather as interwoven with the rest of nature (including nature in industrial-technological form).

Like the micro-organisms, geologies or superweeds discussed in the previous section, it is important to understand the production of recalcitrant and uncooperative human nature as a genuine product of the various material configurations assumed by large-scale industry.

Industrial technologies not only produce the material nature of the external world but also the internal nature of conscious being. These configurations of internal nature can assume a degraded form whereby the worker, according to Marx (1976 [1867]), becomes stripped of a world of productive drives and inclinations and is transformed into the "automatic motor of a detailed operation" (481). But internal nature can also exist in recalcitrant and generative form, even as it is produced by the same technological context—and hence the unpredictability and vitality of the material world. Andrew Herod (1997) suggests that geographers have actually made great efforts to understand how capital shapes the world in its own image, but that they have tended to bypass the ways in which workers also actively shape landscapes and the economic geography of capitalism. It is, for example, no secret that worker insurgency in China has become a key limit to further capitalist expansion (see, for example, Friedman, 2014), and that this has had dramatic sociospatial repercussions inside the country as well as abroad. In other words, internal and external natures become engaged via technological mediations in dense relations of co-production.

The instruments of production that confront the laborer as an alien, hostile power are no longer only those involved in menial tasks, but increasingly encompass those employed in the laboratories and universities of the world. In the face of the heightened proletarianization of scientific and intellectual labor that defines our era, a microscope or a computer program can exert violence toward the intellectual laborer, nowadays increasingly overworked, indebted, and alienated. However, such instruments of production can also revolutionize her consciousness and will in politically progressive ways. The emergence of open source forms of collaborative engagement constitutes a very relevant example of the scientific/intellectual practice that can emerge from the standpoint of the organs of the collective laborer in charge of codifying knowledge and mobilizing algorithmic information. Open source production refers to cooperative knowledge work within information networks, yet outside of the wage relation (Smith, 2010, 2013). Peer-to-peer file-sharing software, encryption software, image editors, and even social networking tools are a few examples of the potential that lies beneath these cooperative arrangements (see Smith, 2010: 209). In being directly anchored to the situated needs of concrete living beings, these forms of scientific practice are therefore radically at odds with the abstract laws of profit-making.

These technologies are not confined to a mere "virtual" existence, as some of them exert definitive effects on the production of the physical nature of households, cities, or infrastructures. For example, Adrian Bowyer began in 2005 a project to collectively design and engineer an open-source 3-D printer that was affordable and could print the parts to assemble a copy of itself and thus be able to set an endless chain of replication (Rundle, 2015). These open-source "replication" technologies, Rundle (2015) notes, could offer the possibility of an "everyday communism" that overthrows capitalist laws of value as it would allow people to replicate many of the necessities of life at a very reduced cost. The Open Source Architecture Network, founded by Cameron Sinclair in 2006, is an initiative for bringing together hundreds of thousands of design ideas that can radically transform the built environment and improve the lives of many (see Ratti, 2015, chapter 5). WikiHouse is one of the initiative's most renowned platforms, and consists on open source user-generated house designs that anyone can download, print with plywood on a CNC mill and then snap together in a similar way to IKEA furniture (Ratti, 2015). From community gardens, to alternative-energy microstations or WikiHouses, Corsín Jiménez (2014) notes how these emerging forms of "open source urbanism" are slowly reconfiguring the environments of cities by means of technological-scientific practices that are external to the cash nexus.

Michael Hardt and Antonio Negri's (2009) notion of "the common"[3] captures to some extent the political possibilities that open-source forms of collaborative engagement can generate. However, in uncritically welcoming the technical content of these arrangements, it is easy to reproduce the contemplative worldview that considers technological artifacts to have a seemingly autonomous existence from relations of production. This is precisely where autonomist/post-workerist and traditional strands of Marxism tend to disagree, as the former tend to be overly optimistic over the emancipatory potential of the technical composition of labor under digital capitalism. Post-workerist authors consider digital connectivity and computerization a turning point in the capitalist political-economic system because they are usually construed as giving back autonomy to the worker, who is increasingly able to produce networks of cooperation outside of capitalist command. Skeptics, on the other hand, point out that despite the emergence of new divisions of labor, immaterial commodities, and complex cybernetic systems, capital's disciplining of labor through both traditional and new tactics like deskilling, surveillance, streamlining, outsourcing, off-shoring, and patenting, is rampant (see Camfield, 2007; Huws, 2014; Starosta, 2012). A discussion on the specificities of such debates is beyond the scope of this article. However, it is important to point out that according to Smith (2013), a key contribution of post-workerist thought has been to highlight how digital capitalism has added new layers of complexity—and possibility—to the practical, everyday interplay between human and machine.[4]

The embodied knowledge produced in the course of the labor process therefore provides a rich platform from which to engage in a radical critique of science, because the shared experiences of exploitation and collective environment-making can prefigure alternative ways to reimagine and repurpose the productive forces of society. As such, a genuinely materialist STS should problematize such geographies of labor and interrogate the complex interactions between humans and their surrounding technical infrastructures, as well as the political possibilities emerging from them. A more-than-human approach to political agency needs to recognize the life-making capacities of technical artifacts while simultaneously revealing the class relations where they are imbricated. But most importantly, bringing the productive forces of society under democratic control should not be misunderstood as an invitation to replicate past experiments of socialist regimes based on mere appropriation of capitalist technological infrastructures and organizational form. Such promethean ideologies of endless industrial growth have been paradoxically attributed to Marx after he criticized Proudhon for them in *The Poverty of Philosophy* (see Foster, 2000, chapter 4). The next subsection briefly explores such controversies.

On prometheanism and technological determinism

One of the most common misconceptions about Marx's philosophy of history in terms of technology is that it supposedly endorses a so-called "Promethean" view of the world that welcomes unbounded growth and industrial development (see, for example, Benton, 1989; Giddens, 1981). Although such misinterpretation has been debunked by the foundational accounts of Neil Smith (2008 [1982]) and John Bellamy Foster (2000), ideological visions of socialist futures as being ecologically dystopian still remain in contemporary environmentalist thought. Pope Francis' 2015 Encyclical *Laudato Si*, for example, epitomizes the tendency of environmentalist thought to conflate technological development with ecological destruction. In this document, the pope repeatedly refers to the "technological paradigm" as being the force that creates pathologies and injustices toward the environment (see Wright, 2015). Marx's work, as Foster (2000) shows,

was deeply oriented by environmental concerns. In fact, Marx (1981 [1894]) considered that the "irreparable" metabolic rift created by capitalism could only be overcome in a society of associated producers, where the metabolic exchange with nature,

> is governed in a rational way, bringing it into their collective control instead of being dominated by it as a blind power; accomplishing it with the least expenditure of energy and in conditions most worth and appropriate for their human nature. (959)

A materialist conception of technology would therefore not be at odds with a genuinely sustainable and democratic relation to the earth, its life-forms, and its resources. Technological infrastructures are currently being systematically utilized to restore metabolic rifts by introducing organic materials for construction, engineered bacteria to stop desertification, and even human excrement as an alternative source of power for public transport, among many other examples (see Battistoni, 2014; Ginsberg et al., 2014). For Harvey (2010: 219), a socialist revolutionary project in the long term simply cannot avoid the question of the definition of an alternative technological basis—of course that alongside alternative relations to nature, conceptions of the world, and everyday life. The acute failure of actually existing communisms, he notes, consists in having *only* appropriated capitalist technological infrastructures and organizational form (Harvey, 2010: 219).

Claims about determinism also tend to gravitate around what is perceived to be the stance of Marx's materialism, where technological change—in and for itself—is construed as the path to human liberation. STS scholar Donald Mackenzie (1984) dissipates such erroneous interpretations by arguing that a careful reading of Marx's critique of political economy reveals that technology is by no means conflated with forces of production. An authentically techno-determinist approach would require that forces of production be interpreted as equivalent to technology, and that forces of production are in turn considered autonomous from broader relations of production (Mackenzie, 1984). In his critique of Bukharin's mechanistic reading of historical materialism, Lukács (1966 [1925]: 29) clarified how technique is "a part, a moment, naturally of great importance, of the social productive forces," and not simply identical with them. Likewise, Harvey (2010, chapter 7) and Loftus (2015) illustrate how Marx systematically avoids causal language in his accounts of technological change, considering science and technology to evolve dialectically—not causally—with other constitutive elements of social life such as mental conceptions of the world, social relations, and everyday life. The future is therefore fundamentally open, so the remainder of this article develops some concluding remarks on the prospects for a research agenda on materialist studies of science and technology.

Conclusion: Occupy STS!

Raoul Vaneigem, a situationist and long-time comrade of Guy Debord, argued back in the 1960s that those who spoke of class conflict without understanding the subversive role of love, had a corpse in their mouth. Mckenzie Wark (2013) claims that today this formula needs to be inverted, because to talk of object-oriented ontologies (as well as of *actants* and of vibrant matter, one might add), but without reference to class struggle "is to speak, if not with a corpse in one's mouth, then at least a sleeper" (4–5). One of the central aims of this article has been to stress the urgency of transforming the field of STS, because it has increasingly become a shorthand for the forms of new materialist thinking that present a contemplative view of technology that fails to problematize its context. The vital and expressive attributes of technology—and of matter broadly considered—will be but

an empty truism if they are not understood as imbricated in relations of class and of production. Through social forms of labor, human beings have produced all the nature that has become accessible to them. To wish otherwise, Neil Smith (2008 [1984]) argued well ahead of his time, is mere nostalgia. Foregrounding the historicity of technology, however, should not imply a descent into crude mechanistic determinism or economic reductionism, and for this reason, I have explicitly decided to foreground the vitalist orientation that always inspired Marx's materialist philosophy of history. Such vitalist worldview not only demands being attentive to the contingent and unpredictable features of the nonhuman world, but also quite crucially, to the infinite potentialities of humans to consciously regulate and transform the sensuous nature of their existence.

The latter point is of fundamental relevance, because a model of scientific production that serves the abstract imperatives of self-valorizing value will only procure the obliteration of planetary natures, including human natures. The conditions of possibility for worker empowerment, and hence for an alternative scientific praxis that nourishes human and nonhuman, should therefore be placed at the center of scholarly efforts to engage with technology. A radical critique of science, however, is not to emerge from liberal foundational principles of ethics, but from the embodied practices unfolding in the workplace and household. For this reason, I have argued that the Lukácsean insistence on the standpoint of the working classes needs to assume renewed relevance in the 21st century. This path was already opened by feminist STS scholars and Marxian theorists of technology in productive ways. However, it needs to be brought back and revisited against the background of our present context. I have argued that 3-D printing techniques and emerging forms of open source urbanism are examples that demonstrate the generative capacities of technology when it becomes directly anchored to life and not to the abstraction of exchange value. It is precisely the radical antithesis and juxtaposition between science and life, which underpins the forms of violence, exclusion, and dispossession that are immanent to bourgeois society. Questioning such distinction, as well as striving to overcome it, should lie at the heart of a revitalized, genuinely materialist STS.

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Notes

1. As Neil Smith (2008 [1982]: 50) argues, nature is a differentiated unity. This means that despite the dialectical interconnection between human and nonhuman natures, it is important to understand the historical specificity of human productive activity (i.e. labor) as the process that mediates such material unity.

2. This claim, has been misinterpreted by both critics and proponents of Marxism across various historical periods as a statement in mechanistic thinking and crude base/superstructure relations of causality—see for example Lukács' (1966 [1925]) famous critique of Bukharin's rendering of technology and historical materialism.
3. Hardt and Negri (2009) distinguish between a "natural commons," embedded in the material elements of land, water, and minerals, and a "common," which is produced by collaborative, open-sourced networks, is intangible and eschews capitalist enforcement of private property.
4. Smith (2013) illustrates how notions of "mass intellectuality" and "diffuse intellectuality" developed by Paolo Virno and Carlo Vercellone, respectively, are aimed at reclaiming Marx's idea that the workforce develops new capacities and new forms of knowledge in the course of its practical experience with industrial/digital technologies. These notions emerged from the interpretation that post-workerist authors made of the *Grundrisse*'s "Fragment on Machines." In that text, Marx (1973 [1939]: 706) presciently observed how general social knowledge (i.e. the "general intellect") embodied in systems of machinery was becoming a force of production in its own right.

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