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Scientific Literacy and the Sociology of Science: New Frontiers for the 21st Century

The intellectual legacy of Robert K. Merton has imprinted the sociology of science in fundamental ways. Along with Joseph Ben-David, Merton directed sustained attention to the social systems and social factors that produce scientific contributions across society. However, as the field evolves, questions related to social diversity remain unresolved. For example, how is scientific literacy or scientific innovation generated across or within ethnic populations, geographical regions, and other social contexts? Which social factors are most salient under what conditions? By analyzing and reviewing the literature, this paper briefly assesses the core intellectual legacy inherited in the sociology of science and expands it to explore unresolved matters related to social diversity. It identifies a range of pertinent questions that must be addressed in order to expand the research horizons yet to be explored during the twenty-first century.
Keywords**:** Robert K. Merton, sociology of science, scientific literacy, ethnic diversity, social contexts.

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Across many sustainable domains, the perpetual enterprise of science has transformed societies wherever it has been nurtured or institutionalized for good. Thus, science matters severely for any human population and national infrastructure, no matter the inadvertent imperfections in its utilization by political or business elites. Systems of popular sovereignty can benefit from science, but they also have the capacity to degrade it across generations. Indeed, between or within various institutional or market sectors, science can be delegitimized or corrupted by shortsighted neoliberalism, systemic neglect, and a rapacious populism. As the pioneers of the sociology of science, both Robert Merton and Joseph Ben-David understood the sociological consequences of science. Yet, beyond their paradigmatic ideas, the twenty-first century presents the sociology of science with many fresh challenges and opportunities. This paper will examine these challenges and opportunities.

Over a hundred years ago in 1905, Albert Einstein (1961) revolutionized our thinking about the cosmos by postulating a set of innovative ideas that culminated in his theory of relativity. These powerful ideas and their mathematical structures have mesmerized the planet in visible and inconspicuous ways. Yet, one can become fascinated by how Einstein's work built upon the scientific edifice of generations before his time in physics and mathematics. Decades before this momentous accomplishment in physics, Charles Darwin (1859) had perplexed the world by postulating ideas pursuant to the biological theory of evolution. One can safely say that the world and its thinking have never been the same since these two epic breakthroughs in the natural sciences. Each breakthrough combined has contributed exponentially to the predominant worldview (cosmology) of evolutionary naturalism that pervades the highest levels of science. Modern developments and technological discoveries in nuclear energy, biotechnology, space exploration, and computational science would not have been possible without the groundwork laid by the natural sciences. Hence, Gerard Piel's (2001) recent, yet strategic, allusion to the "Age of Science".

A generation ago, sociologist Joseph Ben-David (1984) alerted the social sciences to the pivotal impact of science upon societies and their systems of higher education. Recognizing how scientific innovations among core professional societies and academic institutions were gradually diffused to the semi-periphery and periphery, Ben-David urged a systemic investigation of the role of scientists in society. Around these ideas, and those of Robert Merton (1973) decades earlier, the sociology of science emerged as a field of inquiry. In brief, the sociology of science ponders: 1) the origins of scientific innovations, 2) their antecedents as well as impact on societies, 3) the role of scientists and the institutionalization (or organization) of science, 4) the ideologies and values of scientific disciplines, 5) the structure and content of science, and 6) the social implications of science.

These themes have received increasing attention by scientists themselves: Whitehead [*Whitehead*, 1967], Kaku [*Kaku*, 1997], Wilson [*Wilson*, 1998], Bar-Yam [*Bar-Yam*, 2003], Casti [*Casti*, 1994, 1989], Penrose [*Penrose*, 1989], Sagan [*Sagan*, 1997a, 1997b, 1995]. Nearly half a century ago, Whitehead identified how societies benefit from the ongoing scientific enterprise. During the 1990s, Edward O. Wilson, father of sociobiology has called for more attention to the interconnections between the natural and social sciences. Kaku has interviewed Nobel Laureates around the world to record and assess their ideas about the spread of scientific innovations during the 21st century. Bar-Yam, an evolutionary biologist, has probed how complex systems underlie the structures, processes, and outcomes of natural as well as social systems. Casti [*Casti*, 1992a, b], an eminent mathematician, has explored how mathematical models link scientific innovations within both the social and natural sciences. Penrose [*Penrose*, 1989] has used physics to unlock the deepest mysteries of our existence. Before he died, Sagan [*Sagan*, 1997, 1995] pondered the social implications of scientific thinking.

Moreover, scientists have also engaged the implications of postmodernist assumptions [*Gross, Levitt*, 1994; 1996]. Given its salience in differentiating the life chances of societies, organizations, groups, and individuals, it is not surprising that science is controversial. Recent studies in the sociology of science swirl chaotically around these matters [*Otto*, 2016]. Controversy has erupted mostly among postmodernists, icons of popular culture, religious fundamentalists, and scholars within the humanities who have challenged the ideas and privileged status of science in society [*Alumkal*, 2017]. Unfortunately, however, few of these critics have distinguished themselves by producing scientific discoveries commensurate with their criticisms or rhetoric.

In 2016, the National Academy of Sciences (NAS) released a major report about scientific literacy in the United States [*United States*, 2016]. Essentially, they reasoned that scientific literacy is not just an individual asset, but rather a vital *community* resource in a complex society [*United States*, 2016]. It consists of: 1) an appreciation for science; 2) a general understanding of its scope and promise; 3) a trust in its endeavors; 4) a realistic knowledge of its impact within social organizations or associations; and 5) tangible insight regarding how scientists produce empirical evidence and robust explanations. In sum, the report views scientific literacy as a *social* process with content shaped by *contextual* factors across and within communities. Foundational literacy, social structures, systemic factors, attitudes, and disparities all interact to generate scientific literacy in *unknown* ways at present. The authors of the report caution that existing research does not validate the notion that increasing scientific literacy automatically increases support for science.

In 2017, NAS [*United States*, 2017a, 2017b] published a second crucial report about communicating science more effectively. Here, they invite researchers to probe effective methods or strategies for communicating the excitement of scientific investigation, for helping *communities* comprehend scientific findings, and for engaging *diverse communities* in the scientific realm. Once again, *social* factors were stressed explicitly, along with impediments related to the complications of learning science and processing its results. Of course, all of the aforementioned factors affect the formation, execution, and implementation of societal policies. This paper will analyze these and other new frontiers in the sociology of science for the 21st century.

Without question, science and its contributions depend on the dispersion of scientific literacy within and across societies [*Allen*, 2018]. Scientific literacy must be inculcated as a prelude to scientific innovations. Given the pivotal legacies of Merton, Ben-David, and others, how and why does this occur? Starting with Merton's seminal ideas, and Ben-David's core perspectives, we assess their contributions before recognizing unexplored gaps in the sociology of science, gaps that present splendid opportunities for multidimensional research frontiers to be explored for the duration of the twenty-first century. The gist of this research incorporates various ethnic or subgroups that have not obtained optimal levels of scientific literacy, even though civil rights have expanded *superficially* across the United States. No ethnic group or human subpopulation can reach its full potential without drastically increasing scientific literacy. Scientific literacy can be diffused across *inclusive* (for example, via citizen science movements) and *exclusive* (advanced sponsorship) pathways. Therefore, all human citizens have a vested interest in developing this essential toolkit.

The Legacy of Robert Merton in the Sociology of Science[1]

One cannot peruse the foundational rubrics of the sociology of science without recognizing two absolutely seminal contributions by Robert Merton: 1) the *Matthew Effect* in science, and 2) the role of *religion* (especially Protestant religious ideas and networks) in establishing Britain's Royal Society — probably the most pivotal scientific organization in the history of science. The era of industrialization that was the catalyst for technological innovations which subsequently transformed the world began at the feet of Protestant scientists in what is now the United Kingdom [*Light*, 1983]. In a real sense, the Royal Society catapulted British society from the periphery to the core of global civilization.

Merton realized so well that the intangible, often inconspicuous, aspects of science produce the tangible, technological infrastructures and products that sustain postindustrial societies and virtual worlds. Boorstin [*Boorstin*, 1983] chronicles the diffusion process that infuses scientific transformations around different civilizations. Moreover, as mathematician Keith Devlin [*Devlin*, 2002] has indicated so well, robust ideas from the invisible realm of basic science often unleash powerful forces in experimental sciences [*Kline*, 2014; *Mazzucato*, 2013; *Simon*, 1996; *Kemeny*, *Snell*, 1972].

The Matthew Effect indicates succinctly how those scientific exemplars who produce the most robust ideas and discoveries acquire such centrality and high statuses within the core social networks and reward structures of science that they receive an exponential boost in accumulating more reputational resources and regard. Like a snowball that cascades into an avalanche, those who have this core status have strategic dominance over other scientists in other social locations or dimensions at the periphery. The Matthew Effect can possibly encapsulate a trajectory of dominance or a monotonic rise in proficiency and acclaim. *Why does this occur? Under what conditions? For which social actors? These questions indicate that there is much sociology to unmask.*

Other scholars have validated Merton's perceptive insights into the impact of religion upon scientific endeavors. Hodson [*Hodson*, 1988], a physicist at Oxford University, observes how the ideas of a Christian world view anchored the foundational premises of science. More recently, Efron [*Efron*, 2014] has indicated how norms within Jewish culture can stimulate scientific achievements. Mathematicians and others have begun to probe much more deeply how the characteristics and processes of social networks influence social outcomes of any type [*Porter, Onnela, Mucha*, 2009]. In many ways, the contours of Merton's sociological work predated the massive explosion of research and knowledge about social network science [*Barabasi*, 2016; *Borgatti*, 2009; *Lax*, 2008].

To sum, while Merton contributed many other profound ideas in sociology, none can eclipse his paradigmatic explorations within the sociology of science. We are just beginning to decipher and understand the complications or complexities of how and why the Matthew Effect operates in science. Our tested, codified knowledge of how concepts or ideas, rudimentary or intuitive theories, networks, institutional structures, socialization, cultures, decisions, policies, and social intelligences inculcated via religion affect science is still in its infancy [*Goleman*, 2006]. Robert Merton launched us empirically but there are vast infinities or mathematical dimensions yet to be discovered [*Hunt*, 2007; *Nash*, 1996; *Blalock*, 1984, 1982, 1979, 1975, 1964; *Coleman*, 1990, 1964; *Fararo*, 1973; *Lazarsfeld*, 1954]!

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[1] [*Merton*, 1968].

Yet, Merton's work also includes gaps or opportunities that have become much more apparent across the ensuing decades as more *social diversity* has encroached upon the scientific enterprise and scientists. Regarding the precise theoretical contours of the Matthew Effect, for example:

- Under what conditions or contingencies does it occur? Does it occur always? Do different social systems matter?
- What interpersonal, structural, and ecological forces affect it? Is social network location salient? How? Why? When?
- How/why does it emerge *within* social or ethnic groups? (ethnicity, class, gender, etc.)
- How/why does it emerge *between* social groups?

The indisputable answers to, and theoretical evidence for, these essential questions remain at the research frontiers of the sociology of science even to this day. In the realm of religion, we consider another set of questions compatible to the above:

- Can different religious ideas, histories, and structures stimulate different sciences or scientific pathways? How? Why?
- What are the effects within and across various social groups?
- Does social network structure and location matter? How? Why? When?

Still other questions are relevant, such as:

How/why does institutional ecology or organizational demography matter [*Carroll, Hannan*, 2000]? What would a robust, multilevel and multidimensional, contextual analysis reveal [*Carley, Newell*, 1994b]? Can we now explore these phenomena via iterations of computational models (as advocated by mathematical physicists Stephen Wolfram)? Can the sociology of science be advanced via non-Euclidean mathematics [*Devlin* 2002; *Kline* 2014]? Could fresh computational models be developed that accentuate insights related to simulated annealing and genetic algorithms, etc. [*Carley, Prietula*, 1994a; *Gilbert, Troitzsch*, 1999]?

The Legacy of Joseph Ben-David in the Sociology of Science

Another key exemplar in the sociology of science is Joseph Ben-David, whose work encompasses how science is mediated through academic systems or networks within or across institutions of higher educations in various societies [*Ben-David*, 1984]. Ben-David used historical methodology to investigate:

- Cross-national, historical studies of scientific development within and between nations
- Role of scientific development (including scientific literacy and scientific innovations)
- Impact of the scientists' role in society
- Strategic structure of academic systems in societies

This research examines the role macrosociological forces have in distributing scientific outcomes. In short, Ben-David's work seeks to answer *under what conditions* science is enhanced or atrophies. What makes the institutionalization of scientific innovations possible? Most poignantly, how does the scientific role structure scientific outcomes across nations? Together with Merton, Ben-David urges us to move into the uncharted waters of scientific discovery among countries or various social systems regardless of notions of popular sovereignty or oligarchic political ideologies!

New Frontiers: Scientific Literacy

With this multifaceted background, we can now grasp the timeliness of recent research related to the sociology of science. In 2010, the United Kingdom's Royal Society released a report about global science. They focused on:

- Impact of science via publications in premier journals
- Cross-national comparisons
- Effects of global competition and investments in science upon the destiny of nations
- Per capita measures of scientific prowess or impact
- Significance of global scientific networks (invisible colleges)

Each of these areas generate lines of fresh discovery in the sociology of science, notably *per capita measures of scientific productivity* that can be used across nations and adapted to probe subpopulations or salient ethnic disparities. The Royal Society has also explored how global social networks and invisible colleges create the Matthew Effect in science within the United Kingdom and elsewhere. Invariably, computational and other technological advances have made it easier and faster for scientific results to be distributed across social institutions [*Wagner*, 2008; *Wolfram*, 2002].

Joining this voluminous research imperative, the United States National Academies of Science, Engineering, and Medicines (NAS or NASEM) have again released multiple reports in 2016–2017 about the need for scientific literacy to be nurtured across *ethnic and community groups*. They also stressed how urgently scientific communication must be improved for increased public understanding of issues related to climate change and health disparities along with other critical public policy matters. No longer can the scientific enterprise in the U.S. presume to have the vital political support it needs. Incorporating the *social sciences* in a major way, these studies target *community groups* and *social disparities* even as they critique the validity of empirical evidence from current measures and surveys. This corpus of research builds upon the *intersectionality* typical of sociological inquiry and it must be incorporated into new frontiers affecting generations of scholars in the sociology of science [*Allen*, 2018]. For example, a plethora of sociological questions might be explored such as:

- How/why does scientific literacy and the effectiveness of scientific communication vary within and between ethnic (social) groups?
- Under what conditions do any observed effects occur? What regional disparities? Any relevant urban/metropolitan disparities?
- What are the effects of observed disparities in scientific literacy between various states, school districts, institutional ecologies, social networks, generations, etc.?

The American Association for the Advancement of Science published a May 25, 2018 article in *Science* [*Allum, Besley, Gomez, Brunton-Smith*, 2018] that examined statistical disparities among major ethnic groups via a national database from survey research (n=2339). Herein, those authors conclude that measures of *quality* are needed to enhance scientific literacy (SL). *Nonetheless, informal and other intangible contextual factors escape their study, along with other theoretical factors across sociological subfields (or specializations).*

The sociology of science is more relevant than ever because other pertinent resources[2] have emerged via:

- United Nations (UNESCO) reports [*UNESCO Science Report*, 2016, 2010]: scientific comparisons or evaluations across the planet;
- PEW foundation reports [*Pew Research Center*, 2015a, 2015b]: variations in public attitudes about science among subgroups, international comparisons, acute disparities in education, the cumulative disadvantage of inadequate exposure to scientific literacy;
- OECD reports/website [*Office of Economic…*, 2018]

For brevity's sake, the voluminous contents of all this research will not be elaborated here. Recent insights from the academic systems of Canada, Israel, Sweden, Norway, Denmark, Finland, the Netherlands, and Switzerland must also be incorporated in the sociology of science [*Allen*, 2016, 2012, 2011; *Oquist, Benner*, 2012]. To sum, we must probe: 1) the exact nature and impact of scientific literacy (SL) across subpopulations or social groups; 2) the effects of SL upon scientific innovation (SI); and 3) both qualitative plus empirical research on SL per states, provinces, counties, cities, institutional ecologies, organizational demographies, and social systems. To reiterate, sociologists cannot do this without studying the interrelations between SL and mathematical and/or computational competencies; the nature and impact of scientific literacy (SL) across professions, occupations, subpopulations or ascriptive social groups in the division of labor; the effects of SL upon *scientific innovation* (SI); multilevel, multidimensional empirical research on SL per states, provinces, counties, cities, institutional ecologies, organizational demographies. Thus, SL, SI, and OECD concerns intersect because the nation (or set of countries) that masters the sociology of science masters the globe.

Implications and New Frontiers in the Sociology of Science

Building the legacies of Merton and Ben-David, why then does scientific literacy and the sociology of science matter in the 21st century? First, as a sociologist and global citizen, I conjecture that most, if not all, liberal democracies are suffering from a deep social or collective psychosis rooted declining scientific literacy in an age of complexity where it is most needed to forge a better future for all the nations of the world [*Rand Corporation*, 2018; *Thompson*, 2008]. Otto [*Otto*, 2016] has written about the anemic, substandard politics associated with a lack of scientific leadership among political leaders at all levels of society. Bauerline [*Bauerline*, 2008] has observed how technological proficiency is insufficient for establishing the critical thinking competencies embodied in scientific literacy. The Rand Corporation (2018) has sounded a clarion call against the misinformation, disinformation, confusion, and truth decay presently threatening the social fabric of institutions and policymaking within the United States. Tested intergenerational, trans-subjective norms and institutionalized protocols are being abandoned for the voodoo of magical impulses or being replaced by visual chicanery of an indulgent, misguided populism.

[2] These and other resources are listed in the bibliography.

Secondly, I fear that SL is being contaminated by the rapacious social viruses of narcissistic capitalism and political-ideological sophistry [*Allen*, 2018; *Derber*, 2013]. Delusional rhetoric and cryptic politics abound in the United States where sophistry has replaced a tenacious reliance on dissecting tangible evidence as rigorously as possible [*Allen*, 2018; *Rand Corporation*, 2018]. In an era of climate change, political and societal traumas as well as global ecological disasters, the advantages of scientific thinking have been neglected via higher superstition [*Gross, Levitt*, 1994]. Hence, in the United States, we observe a plethora of consequences such as ridiculous conspiracy theories and inadequate jurisprudence (systemic injustices, delusional leaders or politicians, police shootings/criminality in using deadly force, shortsighted policies and decisions, etc.). Like a frog boiling in hot water, the lack of scientific literacy is killing the societal or global needs of the many to benefit the corrupt appetites and interests of the few [*Derber*, 2013]. Under optimal conditions, the perpetual diffusion of scientific literacy can assist citizens in various social systems in discerning stupidity and ignorance wherever and whenever it occurs. It might also raise the level of social intelligence in populations, especially where legal reasoning is suspect, paralyzed, or maladaptive [*Goleman*, 2006].

Conclusions

Like human beings, science is not perfect — especially when implemented by naïve or inept leaders. It can have dangerous, unfortunate consequences wherever accountability is sacrificed and ignored. While *scientism* is a misguided or inappropriate worship of science, scientific literacy yet remains a powerful heuristic toolkit for the benefit of all humanity — an insight grasped profoundly by Merton, Ben-David, and others who value the contributions or potential of the sociology of science [*Otto*, 2016]. Epidemiological models of how and why SL can spread among societies, networks, institutions, and their subgroups may suffice for now [*Blalock, Wilken*, 1979]. Robust computational models of complex adaptive systems are also imperative for the future [*Miller, Page*, 2007]. No theory of everything is possible [*Barrow*, 2007], but new generations must boldly probe the profound scientific questions that conceptualize new frontiers in international sociology [*Wallace*, 1983]. An abundance of new issues related to the role or impact of various sciences in society, climate change, health disparities, cybersecurity, gender inequalities, and ethnic diversity await exploration[3].

[3] Because of the disruptive intellectual chaos permeating the populace in the United States, I closed my presentation by urging the Canadians to look to the future, become a global exemplar of scientific literacy, and lead us (the globe) away from paranoia, xenophobia, idiocy, rapacious capitalism, autocracy, cheap pettiness, sophistry, and regressive, racist thinking! See the *OECD Economic Survey of Canada 2018* for hopeful signs.

Table 1. A Synopsis of Key Themes in the Sociology of Science

Exemplar or Source	Contributions to Sociology of Science	Frontier Concerns or Issues
Merton's contributions	Matthew Effect Role of religion (Protestantism)	– the impact of scientific literacy in diverse subgroups – the impact of religion impact upon science
Ben-David's contributions	Cross national comparisons of scientific development History of science The role of academic systems	– the impact of science across diverse social systems – the impact of science in academic systems
Royal Society's contributions	Per capita measures of science Role of invisible colleges or scientific networks	– the effects of science upon national economies and global markets – the recruitment and distribution of scientists across nations
National Academy of Science	Scientific literacy among diverse subgroups Scientific communication	– measuring scientific literacy – developing effective methods of scientific communication
UNESCO	The impact of science in nations	– improving scientific outcomes
American Academy for the Advancement of Science	Scientific literacy among diverse ethnic groups	– statistical disparities in empirical surveys
Pew, OECD, etc.	Impact of public support Public understanding and awareness of science	– surveys of public understanding of science – international comparisons of how science affects economic and cultural development

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Научная грамотность и социология науки: новые границы в XXI веке

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Интеллектуальное наследие Роберта К. Мертона фундаментальным образом повлияло на социологию науки. Наряду с Джозефом Бен-Девидом Роберт К. Мертон обратил пристальное внимание на социальные системы и социальные факторы, которые производят научный вклад в обществе. Однако по мере развития данной области знаний вопросы, связанные с социальным разнообразием, остаются нерешенными. Например, каким образом научная грамотность или научная инновация возникает в определенных этнических группах населения,

географических регионах и других социальных контекстах? Какие социальные факторы наиболее важны и при каких условиях? Анализируя и рассматривая литературу, данное исследование предлагает краткую оценку основного интеллектуального наследия социологии науки и распространяет его для исследования нерешенных вопросов социального многообразия. Данная работа определяет ряд вопросов, к которым необходимо обратиться для того, чтобы расширить исследовательские горизонты и которые еще предстоит изучить в XXI веке.
Ключевые слова: Роберт К. Мертон, социология науки, научная грамотность, этническое разнообразие, социальные контексты.

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