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Developing collaboration race and gender repertoire theory as applied to STEM policy

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Abstract

This paper develops a collaborative race and gender repertoire (CRGR) theory explaining how racial and gender awareness influence science, technology, engineering and mathematics (STEM) collaboration behaviors and choices of team members. We are particularly interested in the application of CRGR in the STEM higher education context, which persists as a hotbed for diversity initiatives. Using the scientific technical human capital (STHC) model as a departure point, we cultivate the CRGR theory considering three primary factors: the collaborative norms of scientists; social exchange dynamics; and the development and use of racial and gender awareness. While theories abound specifically explaining the role of race and gender in educational, career and social outcomes, fewer of these theories consider the unique aspects of STEM culture and institutions - particularly collaboration and team based science, which are critical for STEM knowledge production. We assert that a specific theory accounting for the STEM context can motivate more strategic efforts to achieve substantive diversity; promote STEM production; and avoid public value failure.

Keywords

Gender; race; collaboration; science; inequality

Introduction

As minorities and women continue to increase their representation in the science, technology, engineering and mathematics (STEM) fields, facilitating successful diverse collaborations becomes more critical (Burke & Mattis, 2007; National Science Foundation, 2015). Team science that transcends disciplines, sectors and geographic lines requires an understanding of how to strategically leverage and configure diverse teams in scientific institutions, especially in higher education where much scientific productivity and human capital development occurs (Hall et al., 2012; Stokols et al., 2008). Moreover, the role of scientific institutions in shaping quality of life, economic welfare, innovation and other key social dimensions highlights the public value it creates towards building more equitable societies, meaning that such equity should be mirrored on the production and supply side of STEM productivity (Jasanoff, 2009; Latour, 1987; Pielke, 2007). Together, these realities underscore the need to address how racial and gender barriers in STEM influence collaboration outcomes and vice versa.

Research generally affirms some long-term value accrues as a result of diverse teams and workgroups along multiple dimensions (Rowe, 2003; Van Knippenberg & Schippers, 2007). Nonetheless, the knowledge of racial and gender dynamics in STEM collaborative arrangements still contains gaps because of limited approaches to understanding how bias effects individual and subsequent group behavior in science teams. In particular, while some literature determines that having diversity on STEM teams creates overall value (Bear, 2011), the focus on individual team members, including their behaviors, productivity and experiences tends to occupy much of the literature (Bozeman & Corley, 2004; Bozeman & Gaughan, 2011; Lee & Bozeman, 2005). Moreover, many of these studies focus on gender as opposed to race or ethnicity (Bear, 2011). This means that overall, little is known about how awareness and framing of race and gender; the intersection of the two; and the process of enacting racial and gender awareness affects STEM teams and the individuals in the teams.

The potential hazard of not addressing research team members' perspectives on race and gender is that notions of diversity in STEM graduate education may fail fully to address the specific social triggers determining researchers' ability to work most effectively with one another. This paper contributes to current understandings of racial and gender STEM collaboration dynamics by examining the other side of the bias equation. In particular, it explains how biases may or may not develop and be enacted in different phases of collaboration and subsequently influence multiple productivity dimensions. More specifically, the paper describes the concept of collaborative race and gender repertoire (CRGR). The CRGR concept accounts for how perspectives, conceptions and understandings of race and gender held and enacted (or not enacted) by individual group member's impact team dynamics and multiple STEM productivity outcomes. While this theory can be applied to multiple types of scientific institutions, the continual focus on diversifying STEM higher education programs makes it an ideal backdrop to explain this theory. Thus, the paper starts with a brief discussion of the diversity landscape in U.S. STEM higher education.

Next, we discuss the scientific technical human capital (STHC) model created by Bozeman, Gaughan and Dietz (2001) as a departure point for developing the CRGR theory. As a foundation for the theory, we use the model's emphasis on social capital in STEM collaborations, which result in individual and collective gains. As part of explaining the relevance of STHC, we explore the anatomy of STEM collaboration. We assert that race and gender are unique dimensions influencing how scientific teams forms and how social capital develops in them. However, rather than including these dimensions in the existing STHC framework, the complexity of how they influence collaboration behaviors warrants the development of a separate explanation (i.e. CRRG theory).

After describing the relevance of social capital and collaboration dynamics, we describe how knowledge and awareness of race and gender influence individual's choices to engage in social exchanges within scientific teams. Then, we provide the underlying assumptions of CGRG theory prior to offering a full explanation of the theory. The paper ends with recommendations of how the theory can inform research agendas with examples of relevant questions.

Diversity in stem higher education

Given the Herculean efforts over the past several decades dedicated to understanding and attenuating the sources of racial and gender inequalities in U.S. STEM education, one might expect a proportional outcome of diversity (Butler, 2006; Maton & Hrabowski, 2004; Tsui, 2007; Whittaker & Montgomery, 2012). Yet the many important victories in attaining diversity in STEM to date have created but a few ripples in large pond. Despite the overall increase in the number of women and underrepresented minorities (URMs) including African-Americans, Hispanics/Latinos and Native Americans in pursuing STEM education in the U.S., they are still woefully underrepresented in certain disciplines such as engineering, computer science, mathematics and physics (National Science Foundation, 2015). This underrepresentation is also strong in certain sectors, such as the relatively low number of minority STEM faculty as compared to the number of STEM doctorate degrees awarded to them (National Science Foundation, 2015).

Moreover, while the amount of women and minority students expressing interest in STEM education has increased (and in some instances is comparable to white males), their persistence and graduation rates in STEM degree programs is still significantly less than white males (Ohland et al., 2011; Riegle-Crumb & King 2010) . Additionally, expansive racial and gender differences exist in *how* students experience success and failure in STEM education institutions (Price, 2010; Griffith, 2010; Chang et al., 2008). More explicitly, women and URMs who are able to successfully pursue STEM education still experience racism and sexism from faculty, administrators and fellow students that make pursuing STEM degrees more burdensome (Johnson, 2007). Contending with stereotype threat, external misconceptions of ability and social isolation are but a few significant barriers that marginalized groups must navigate in chilly educational environments (Bilimoria, Joy & Lang, 2008; Carlone, 2004; Carlone & Johnson, 2007; Callister, 2006; Seymour, 1995). Encountering such challenges results in a socio-emotional strain that can hinder performance and requires different strategies for achieving success (Gonzalez, Blanton & Williams, 2002; Nguyen & Ryan, 2008; Steele, 1997).

Over several decades, STEM education stakeholders increasingly espouse the performance and economic value of diverse human capital in STEM by pointing to enhanced problem solving and innovation that can lead to better products and knowledge (Fagen & Olson, 2007). They also contextualize gender and racial based STEM education disparities as reflective of larger social justice issues (Kaiser, 2005; Keitel, 2001; Lee & Luykx, 2007; Oakes, 1990). These perspectives have driven the many past and current strategies used to alleviate the aforementioned disparities, most focusing on human capital factors that would 'fix' individual deficiencies and provide better and more abundant learning opportunities to URMs and women. Examples include the following:

- Improving educational structures, policies and curriculum to provide better and more inclusive instruction and participation (Brotman & Moore, 2008; Oakes, 1990; Ong et al., 2011; Muller, Stage & Kinzie, 2001;Mutegi, 2011);
- Enhancing exposure to STEM education and occupations (Billimoria et al., 2007; Hanson, 2010; Hill, Corbet & Rose, 2010; Hurtado et al., 2007; 2009; Russell et al., 2007); and
- Changing cultural practices related to social and economic empowerment that affects overall educational attainment (Butler, Atwater & Russell, 2014; Lee, 2005; Lee & Luykx, 2007; Oakes, 1990).

Why hasn't racial and gender equity that includes significant statistical representation as well as fairness in experiences and outcomes been consistently achieved in STEM higher education? While these strategies have tremendous validity and inspire necessary solutions, they summarily or partially fail to acknowledge what we believe is a core issue. In particular, we assert that the acquisition, development and application of knowledge about race and gender (including related dynamics) through the institutional, organizational and collaboration chain in STEM higher education programs is an overlooked perspective with major implications for diversity.

Why are collaboration behaviors and practices in STEM higher education a potentially useful means for fostering diversity? A twofold answer exists to this question. First, universities and colleges are major developers of STEM human capital and create the bedrock for future STEM career development and attainment. They are spaces for important professionalization and socialization into the scientific community and provide future practitioners with critical knowledge, experiences and opportunities that prepare them to engage in substantive scientific productivity (DeHaan, 2005; Lopatto, 2007). Essentially, the post-secondary phase is a critical juncture for students where significant activities can either make or break outcomes essential for subsequent development--a key activity being collaboration, which is increasingly common in STEM production (Elgren & Hensel, 2006; Hathaway, Nagda & Gregerman 2002; Hippel et al., 1998; Hunter, Laursen & Seymour, 2007). Thus, students' exposure to diverse collaboration (or lack thereof) in the college or university setting will likely dictate how they will navigate, process, invite or avoid diverse collaborations—at least during the outset of early career experiences. For women and minorities in particular, their participation in collaborations will likely influence their perspectives on the hostility and inclusivity of science communities, thus determining if and how they persist throughout the pipeline (Carter, Mandell & Maton, 2009; Jones, Barlow & Villarejo, 2010; Schultz et al., 2011; Stewart et al.,2007; Tsui, 2007).

Second, scientific identities do not necessarily develop absent of socio-cultural identities such as race and gender (Carlone & Johnson, 2007). In other words, as scientists determine their professional pathways, which merge with personal values and goals, their race and gender may consciously or unconsciously influence such development. For example, it is not unheard of for minority and women STEM students to pursue science degrees not only because of an appreciation for the scientific process or fulfilling their potential of mastering certain disciplinary matter, but also to address certain issues that are unique to or prevalent in their communities or are related to enhancing social welfare overall (Carlone & Johnson, 2007; Farmer, Wardrop, & Rotella, 1999; Smith et al., 2014; Thoman et al., 2014). Conversely, it is not uncommon for racial and gender identities to conflict with scientific values and norms, thus complicating the experiences women and minorities have in STEM institutions (Johnson, 2007; Johnson et al., 2011). Considering these factors, the extent to which students interact with like or similar others in collaborations likely encourages or discourages the merging of these identities. The next section briefly discusses STEM collaborations in the context of social exchanges, along with the complementary social dynamics that uniquely facilitate or hinder them.

STEM collaboration dynamics

For all of the benefit that scientific teams and partnerships creates in the form of products and knowledge, critical value lies in the very process of collaboration. The STHC model (Bozeman, Gaughan & Dietz, 2001) highlights this by emphasizing how collaboration involves social exchanges facilitating the creation of social capital (e.g. resources such as information and opportunities gained as a result of social connections). Social capital subsequently enables team members to enhance their human capital such as knowledge, skills and cognition. Thus, whether a final product or body of knowledge from collaboration is successfully realized or not, group members benefit from the synergistic nature between social and human capital. The basis for this assertion comes from social exchange theory indicating that personal contacts offer access to a bevy of critical information, resources and opportunities necessary for personal and professional growth (Burt, 1997, 2000; Ibarra, 1995; Sparrowe et al., 2001).

What does this synergistic exchange actually look like in STEM collaborations? A number of studies illustrate that STEM teams converge and produce based on a number of factors reflecting scientific norms and values (Beaver, 2001; Lee & Bozeman, 2005; Melin, 2000). Among the most obvious is the value emerging from the commonalities among team members' disciplinary knowledge and technical acumen, which is consistent with the collegial nature of STEM productivity. As team members from relatively similar disciplines and technical backgrounds interact and learn from each other, their field expertise grows and gains in efficiency are realized (Beaver, 2001; Beaver & Rosen, 1978; Lee & Bozeman, 2005; Melin, 2000; Shrum, Genuth & Chompalov, 2007). However, the increasing complexity of social and technological problems benefiting from scientific solutions requires crossing disciplinary and knowledge boundaries, resulting in plural collaborations (Cummings & Kiesler, 2005; Sonnenwald, 2007). Collaborations also offer the opportunity to expand a scientist's knowledge repertoire that can complement his or her disciplinary expertise (Masse et al., 2008; Oh, Choi & Kim, 2005; Pennington, 2008;). Additionally, the global nature of STEM productivity has also called for more cosmopolitan collaborations that expand geographic proximity, which can offer team members a wide range and spread of knowledge pools (Bozeman & Corley, 2004; Sonnenwald et al., 2001; Wagner & Leydesdorff, 2005). This is particularly relevant given the strong international presence within the academic science community.

Aside from the gains in knowledge and expertise, STEM collaborations offer the opportunity for reputation enhancement and material support, which are two priorities in the academic STEM environment (Laudel, 2001; Sonnewald, 2007). In particular, research activity with highly productive and reputable academic scientists (i.e. faculty) provides critical benefits for students. They receive hands-on learning, mentoring, material support (e.g. tuition reimbursement and stipends); access to a pool of powerful connections; and high regard from community members-all of which can bolster career development (Adams et al., 2005; Hara et al., 2003; Russell, Hancock & McCullough, 2007). Relatedly, collaborations with fellow students offer the benefit of peer learning, which facilitates a sense of inclusion, encourages self-efficacy, promotes better performance and provides connections that can be used for later career development opportunities (Hofstein & Lunetta, 2004).

What calls for a separate theory that accounts for the role of race and gender in collaboration? In other words, why not just include race and gender as variables within the existing STHC model? This is because that while very useful, the STHC model does not examine in-depth how specific network structures (e.g. weak or strong ties, density and hierarchy) influence the flow and accessibility of certain types of social capital, which have been known to be influenced by race and gender (Combs, 2003; Ibarra, 1995; Mehra, Kilduff & Brass, 1998). Additionally, the STHC model does not account for how collaboration decisions are determined (e.g. who to collaborate with and the determination of team members' roles), which can be influenced by race and gender (Dreachslin, Hunt & Sprainer, 2000; Klein et al., 2004). Most salient to this last point is how conceptions of race and gender often dictate expectations for who and how social roles will be fulfilled, which are not uncommonly played out in a microcosm of team collaborations. The next section addresses this by describing the CRGR concept.

Developing race and gender awareness for STEM Collaborations

Our working definition of CRGR is an individual's or group's set of available concepts, meanings and assumptions about race and gender- generally and about specific races, ethnic and gender groups. Bem's (1981) schema theory is the closest antecedent to our CRGR conceptualization; however, the two have important differences. First, while Bem's schema focuses on the framework for developing expectations and knowledge of race and gender roles, CRGR accounts for the development and application of knowledge and experiences. Second, in the CRGR context racial and gender knowledge and expectations develop through a hierarchical funnel starting at the institutional level.

Figure 1 depicts both causes and effects of CRGR. One important aspect of our conceptualization is the dynamic nature of the process. This process operates in real time with each new piece of knowledge or experience potentially updating CRGR which then in turn update attitude and behaviors and so on. A second important aspect of this model is that we expect CRGR to have both a direct effect on decisions, but also an indirect effect through its relationship to attitudes. This indirect effect, if verified, suggests some capability of CRGR to have spillover effects beyond the work context. Finally, it is important to note we expect that individual race and gender repertoires can create aggregate effects beyond those of the individual repertoires.

In addition to the Bem (1981) model, our CRGR conceptual model has some kinship to Fazio's (1990) work. Our approach resembles Fazio's in its focus on both social norms and knowledge as vital to the framing of the decision context. While most theories relating cognitive processing of information and experiences tend to work directly through framing and attitude formation, our framework posits the intermediary structure of an CRGR (Ajzen and Fishbein 2005) which, if validated, can provide greater agency for dealing with race and gender issues in the STEM workplace and particularly in research collaborations. For example, in a collaboration composed of a mix of Whites, African-Americans, Hispanics, Asians or multi-racial individuals, their collaborative success will in part depend upon the CRGR the constituent members bring to the interaction, including the depth of the CRGR, the social tools enabled by the repertoire and the correspondence of group members' CRGR.

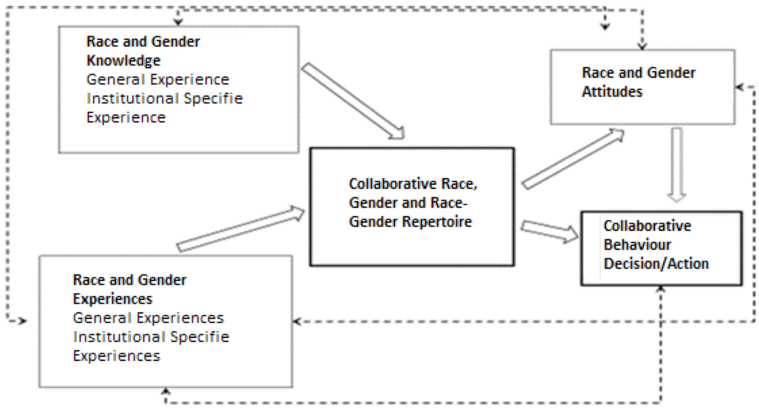

Figure 1: Initial CRGR exploratory conceptual model

Previous research tends to focus on the role of racial and gender knowledge and experiences directly or indirectly shaping STEM diversity and outcomes based on either institutional or individual behavior, without accounting for the connected, reflexive pathway between both (Greenhaus, Parasuraman et al., 1990; Ilgen, 1986). Moreover, reactive behaviors resulting from racial and gender socialization dominate the research about the extent to which diversity manifests itself in STEM. The conceptual model of collaborative race and gender repertoire accounts for the hierarchical nesting of experiences. It starts with how knowledge and experiences of race and racial dynamics shape institutional behavior and ends with how individuals (and social configurations of individuals) nested within the various layers of the institutional framework develop and then apply their own CRGR, resulting in various proactive and reactive behaviors as well as subsequent outcomes.

The nested conceptual model of CRGR starts with the layer describing the influence of the overall external racial climate on the institutional context. We specifically focus on how the current conceptions of race and gender and racial and gender dynamics inform the practices, policies, culture and goals prevalent in the institution of higher education. Next, specific types of institutions (e.g., research universities, liberal arts colleges, minority serving institutions, women's colleges) further interpret institutional knowledge of race and gender. Then, units within the specific type of institution that also intersect with other institutional contexts (e.g., academic STEM department) subsequently interpret knowledge of race and gender. Lastly, those interpretations influence the attitudes and behaviors that affect outcomes of organizational members within smaller units (e.g., students, faculty, administrators and staff). We have interest in behaviors related to how organizational members navigate through organizational culture, react to policies and norms, embody practices and interact with each other. We suggest how these behaviors can influence educational attainment outcomes (e.g., persistence, access to social capital and human capital). Finally, the sum of the enacted CRGR at the individual and collective levels can either alter or reinforce the institutional knowledge of race and gender dynamics.

It is useful to present the guiding questions informing the presented model and should be considered when applying it.

1. What are the prevailing definitions of race and gender at the individual and level and within the STEM institution (e.g. university or college) and where do they come from? What are the underlying themes in these definitions and their implications?
2. How do definitions shape the formation and interpretation of narratives describing the individual and interactivity of the racial-gender majority and minority? And what are implications of the various racial narratives?
3. How do policies related to STEM education and funding uphold or combat dominate notions of gender and race and the related dynamics?
4. How do practices and policies about hiring, promotion and tenure, student acceptance, student assistance within a STEM subunit (e.g. university or college science department) uphold or combat conceptions of who is science eligible based on race gender status?
5. How do previous personal or group experiences (or lack thereof) influence interactions with other of similar or different racial backgrounds? How may such experiences reinforce or counter narratives in way that influences social interactions?

The CRGR concept entails a number of assumptions. First, one's actions in dealing with race and gender with both external action and internal reflection implicitly reflect one's repertoire. This is because one's entire set of assumptions and cognitive tools about race and gender inform actions and self-reflection. Second, CRGR refers not only to individuals, but also to social configurations of individuals. Thus, a corporation or a private voluntary organization, or a frequently interacting informal group or partnership can be viewed as having CRGR. Third, the CRGR for a social configuration is constrained by the aggregate CRGR of the constituent individuals. In other words, some individuals' CRGR may be more fully represented than that of other group members or the organization; or some individuals' CRGR may not be represented at all in the group or organization race repertoire. Fourth, when enacted CRGR has a normative dimension whereby it may be used for "good" or "bad" purposes, manifested through an entities' action or inaction. Fifth, new life experiences and attained knowledge continually facilitate changes (expansion, contraction or replacement of elements) of CRGR. However, individuals and organizations must take purposeful action to apply the lessons from these facilitating factors for them to manifest in a changed race repertoire. Sixth, knowledge of how other identities (e.g., religion, sexuality, socioeconomic status) intersect with race and gender results in a more nuanced, richer, yet more complex CRGR.

For instance, understanding the variations between experiences and conceptions of minority low-income men and minority middle class women can make the difference between a moderate and expansive CRGR. Seventh, CRGR may have more marginal utility for some individuals than others. This will likely depend upon whether the current institutional and organizational race repertoire favors the majority or minority. For example, it may be more useful for an African-American to have an extensive CRGR to survive in a majority White academic science institution that does not actively support or promote inclusivity or diversity. Eighth, while all race-gender interactions are circumscribed by the CRGR, many other factors may affect the nature of the interaction, such as resources competition; but if these factors are external to the CRGR, then they are not conceived as part of a race-gender dynamic. For example, competition for external grant funding may drive individual behavior of academic faculty seeking those resources. Because race-gender dynamics may still implicitly shape other factors that do not directly address race or gender, this assumption requires a vigilant and careful verification of the role of race and gender.

The development of a comprehensive CRGR construct and its subsequent measurement will facilitate a deeper understanding of how intersectionality among gender and race affects choice of collaborators and collaboration outcomes. Often research on STEM collaborations has looked at race or gender. Small numbers of both URM and minority students in STEM graduated programs have hindered systematic investigation into the joint effects of race and gender. However, understanding the intersection will offer a far more detailed picture of how race and gender affect group interactions. For instance, one individual might have very different CRGRs for Latino females, Latino males, African American males, and African American females - each driving different choices in the context of collaboration. Knowledge of this nuance can help programs structure and design effect programs to support graduate student collaborations in STEM education.

As a complex and dynamic concept, characterizing variation of the CRGR theory requires an understanding of three sub-dimensions. First is *accuracy*, which captures the extent to which CRGR characterizations of race, gender and their interaction are empirically valid. Second is *complexity*, which emphasizes aspects of a CRGR that can discriminate between more nuanced settings. The final sub-dimension is *relevancy*, which taps the extent to which aspects of the CRGR are matched to the application context, here specific decisions about STEM research collaboration and work group practices. All three sub-dimensions are important to understand how CRGR works. For example, high levels of accuracy and complexity may be insufficient predictors of more equitable choices if the relevancy sub-dimension is not well developed. Similar outcomes are possible though in the presence of high relevancy and accuracy but insufficient levels of complexity.

Conclusion

It is important to re-emphasize that the aim of the CRGR concept is to stimulate thoughtful considerations of how race and gender influence STEM collaboration dynamics. As such, we do not present our conceptual model as a holy grail upon which to make normative judgments regarding the value of race or gender. Instead, we view this theory as a framework to evaluate how race and gender influence decision making of collaborators regarding the formation of teams and subsequent engagement. Given the complex reflexive relationship among race, gender, institutions, organizations and social exchanges, we would be remiss to believe that this model or its presented description is comprehensive. Upon empirical testing, we aim to refine it. In the meantime, we emphasize the following take away message: understanding the benefits and hindrances in group social exchanges depends upon recognizing this complexity.

We anticipate that a number of research questions can utilize the CRGR concept including, but not limited to the following:

1. To what extend does the race and gender of individuals in STEM collaborations influence how groups form and work together? For example, nuances in the cultural dimensions of various minority groups may result in different collaboration behaviors. Furthermore, the intersection of race and gender can also significantly influence social exchanges in collaboration.
2. How does CRGR (and its manifestation) vary based on the intersection of individual team member attributes and collaboration goals? For example, the aims of a collaboration output may encourage the inclusion of diverse collaboration (e.g. a science output focused on disparities in minority or women's health may benefit from insights from minorities and women).
3. What public value do scientific institutions create by fostering diverse collaborations? For example, STEM degree programs emphasizing diversity in collaboration may see more equitable educational outcomes among historically marginalized groups.

The CRGR concept departs from the long-held solution of 'fixing' individuals from marginalized groups, which tends to reflect an inherent deficit perspective and is inaccurate. Instead, CRGR amplifies the importance of how social interactions shaped by environmental and experiential factors facilitate or inhibit the attainment of various benefits necessary for individual personal and professional growth as scientists. Thus, understanding race and gender based STEM inequities goes beyond merely identifying the perceived assets and deficits of individual groups to knowing how those differentials develop because of social exchanges influenced by racial and gender dynamics.

Overall, the STHC model calls for a more in-depth evaluation framework of scientific collaboration that not only considers final outputs, but the value accrued to individual team members that last beyond tangible outcomes. As such, the actual process of scientific production can be evaluated based on the degree to which collaborations enhance the professional development of team members that may be realized during a particular production activity or in the future. Thus, this model may be useful to explain outcomes for minorities and women based on their collaboration experiences. However, the CRGR concept potentially offers a more in-depth framework by examining how diverse teams form and engage. Overall, both models complement each other by encouraging a more multi-dimensional approach to the determining the public value of science production, particularly values related to social justice and equity.

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