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Women in interdisciplinary science: Exploring preferences and consequences

Diana Rhoten[a,*], Stephanie Pfirman[b]

[a] Social Science Research Council, United States
[b] Barnard College, United States

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Abstract

For at least a decade, U.S. funding agencies and university campuses have promoted the expansion of interdisciplinary research. At the same time, federal and local programs have sought to increase the participation of women and minorities in science, mathematics, and engineering. Research has focused on each of these trends independently, but very few studies have considered their interaction by asking how intellectual preferences for and professional consequences of interdisciplinary science might be influenced by gender, race, and/or ethnicity. Focused specifically on gender, this paper considers the expectation that women will be more drawn to interdisciplinary research, and explores the learning styles, work preferences, and career behaviors that might anticipate and/or explicate gender differences in interdisciplinary science. Principal mechanisms by which researchers engage in interdisciplinarity – cross-fertilization, team-collaboration, field-creation, and problem-orientation – are tested for evidence of gendering using preliminary empirical data from three studies. The results of this exploratory analysis offer clues about possible tendencies and raise questions about the potential costs and benefits for those who adopt them.
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1. Introduction

Science is "well past the point at which the knowledge required to enhance the health and well-being of individuals and communities can come solely from lone investigators trying to unlock nature's secrets, or from the offerings of any single discipline" (Kahn and Prager, 1994, p. 12). Myriad interdisciplinary research and training programs have arisen, from federal-level and private-sponsored initiatives to community-driven and campus-based endeavors. New cadres and cohorts of interdisciplinary scholars are emerging—scholars whose intellectual objectives, epistemological convictions, and professional strategies may be different from those of their predecessors and orthogonal to many of the disciplinary-based practices of the academy.

Since the mid-1990s, federal research funding agencies have increasingly pushed the research community towards interdisciplinary research. Dr. Elias Zerhouni (director, National Institutes of Health) and Dr. Rita Colwell (former director, National Science Foundation) have argued, for instance, that "disciplinary 'silos' need to be broken" and "interdisciplinary connections are absolutely fundamental [because] the interfaces of the sciences are where the excitement will be the most intense" (Colwell, 1998; Jones, 2003).

* Corresponding author.
E-mail address: rhoten@ssrc.org (D. Rhoten).

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Of the $ 4.11 billion that the NSF requested from Congress for research and related activities in 2004, $ 765 million – a 16.5% increase over 2003 – was earmarked for four priority areas, all of which were designated as interdisciplinary. These priority areas include: Biocomplexity in the Environment, Information Technology Research, Nanoscale Science and Engineering, and Human and Social Dynamics (National Science Foundation, 2003a; Society for Industrial and Applied Mathematics, 2003). Likewise, NIH budgeted $ 130 million in fiscal year 2004 to support the new NIH Road Map, which stresses the establishment of interdisciplinary programs, centers, and conferences. The agency expects to spend more than $ 2.1 billion over the program's 5-year lifetime (Morrisey, 2003). Private dollars are also being poured into interdisciplinary endeavors at unprecedented levels. In April 2003, the W.M. Keck Foundation underwrote a $ 40 million, 15-year grant to the U.S. National Academies to "stimulate new modes of inquiry and break down the conceptual and institutional barriers to interdisciplinary research" (National Research Council, 2003). Similarly, the new Janelia Farm Research Campus, funded by the Howard Hughes Medical Institute to the tune of $ 500 million, will focus on "collaborative research that calls for the development and interdisciplinary application of cutting-edge technological tools [with] originality, creativity and a high degree of scientific risk-taking" (Howard Hughes Medical Institute, 2004).

Despite this context of increasing enthusiasm for interdisciplinarity, little is known about *which* students and scientists align with interdisciplinary education and research, *why*, and at *what* cost or benefit to themselves and their institutions. We view this paper as an introductory step toward understanding preferences for, and consequences of, interdisciplinary versus disciplinary science, with the goal being to stimulate more deliberate research on this topic. This paper is exploratory, and the empirical data brought to the table are slight. But, it is a jumping off point to an important science practice and policy discussion.

To start this article focuses specifically on the intersection of women and interdisciplinary science. We begin here partly out of our own observations, but primarily in response to others' propositions and expectations that there *is* – or that there naturally *will be* or that there necessarily *should be* – a tendency for women to be attracted to interdisciplinary science. For example, current reform efforts to attract women to science courses and careers often direct administrators, teachers, and researchers to: rely more on integrative methods, provide cooperative learning and working environments, use less-competitive models of teaching and more flexible models of tenure, frame science in its social context, present practical applications along with theoretical motivations from the outset, and undertake problems with a "holistic, global scope" (Henes et al., 1995; Jamieson, 2001; Margolis et al., 2000; National Science Foundation, 2003b; Rosser, 1995).

Our intent is to explore these arguments and assumptions about learning styles, work preferences, and career behaviors as a basis for understanding whether and why there might be real and/or perceived gender differences and preferences related to interdisciplinary science. Of course, over-generalizing and over-essentializing differences between women and men is a common pitfall, and one we do not wish to stumble into here by arguing for generic categories. Although we focus here on women, we believe that the arguments we propose may, in some cases, also resonate with men and minority groups. Using gender as a lens, the purpose is to develop an awareness how intrapersonal, interpersonal, and socio-structural factors may contribute to decisions about interdisciplinary research and how such actions might then affect individual careers and institutional strategies. We hope that this paper will stimulate a discussion of both individual and group differences as an aspect of thinking about choosing – or not choosing – an interdisciplinary research program or career.

The article begins by defining different facets of interdisciplinary activity and briefly examining the literature on women and science as related to these facets. The discussion is then grounded in early empirical data culled from three studies on interdisciplinary research practices and programs, two of which were conducted by Rhoten. After exploring these data for evidence of gendering, the focus then turns to some potential benefits and costs of choosing an interdisciplinary path. Finally, as this article is meant to be more provocative than conclusive, it closes by calling for a research design that can examine scientist and student choices around interdisciplinarity versus disciplinarity on the basis of gender but also other group characteristics (e.g., race and ethnicity, cohort, original discipline) as well as further interrogate whether, why, and at what consequence shifts in knowledge production and changes in science demographics are connected.

2. Literature review

2.1. *Interdisciplinary science: definitions from the literature*

Across the literature, the term "interdisciplinary" is used to refer to continuum of possible meanings and activities ranging from an individual's orientation toward knowledge acquisition to a system-wide shift in knowledge production, with intermediate and variant notions in between. Underlying these diverse definitions, however, we have found a shared kernel of understanding: interdisciplinary refers to the integration or synthesis of two or more disparate disciplines, bodies of knowledge, or modes of thinking to produce a meaning, explanation, or product that is more extensive and powerful than its constituent parts (Boix-Mansilla and Gardner, 2003; Klein, 1996; Kocklemans, 1979; Hackett and Rhoten, 2006; Weingart and Stehr, 2000). Moreover, underpinning its various expressions, we have identified four fundamental categories or mechanisms of interdisciplinary activity: *cross-fertilization*, *team-collaboration*, *field-creation*, and *problem-orientation*. These categories are not meant to suggest a progression in quality or complexity as the earlier categories are neither a prerequisite to nor a guarantor of the latter. By focusing on the four categories of interdisciplinary activity, we can ground our analysis in a common language and anchor it in observable actions.

First, the process of interdisciplinary integration can be undertaken by an individual scientist whereby s/he single-handedly knits together tools, concepts, data, methods, or results from different fields or disciplines (Frost and Jean, 2003; Klein, 1996; Lattuca, 2003). A common task for those who pursue this type of self-contained interdisciplinarity involves being able to identify the contribution of one's own discipline to a problem and then locate and integrate the necessary tools – conceptual schemes, theories, or methods – from other disciplines to properly fill the gap and successfully advance the question (Hansson, 1999). This type of *cross-fertilization* requires the ability to process the ways of thought and the language of other fields as well as establish the connections between them.

Second, in close proximity to the first approach, is the notion that interdisciplinarity involves multiple researchers with mastery in their distinct fields or disciplines, working collectively as a network or team of individuals to trade and exchange tools, concepts, ideas, data, methods, or results around a common project (Palmer, 1999; Rhoten, 2003). From this perspective, interdisciplinarity can be seen as a vehicle by which a set of purposeful arrangements and sense of community are established to iterate ideas with others through the course of work, thereby transforming the structure of scientific practice from autonomous, hierarchical, and competitive to interactive, horizontal, and cooperative (Gibbons et al., 1994; Hansson, 1999). Distinct from the communal patterns of communication and sharing in science that Robert Merton described decades ago (Merton, 1973), interdisciplinary *team-collaboration* involves the merging of expertise, credibility, resources, and symbolic and social capital (Katz and Martin, 1997; Maienschein, 1993).

As a third category of activity, interdisciplinarity seeks to shift epistemic domains, enabling individuals to work at the cross-roads of well-trodden paths or break whole new ground. In this sense, interdisciplinarity is viewed as a "challenge to the limitations or premises of the prevailing organization of knowledge or its representation in an institutionally recognized form" (Salter and Hearn, 1996, p. 43), and is often discussed in terms of *field-creation* and the creation of new spheres of inquiry at the intersection of existing disciplines – *aka* interdisciplines (Bird, 2001; Rheinberger, 1997). In these new interdisciplines, the peer group – sometimes referred to as an "invisible college" (Crane, 1972) – is often small, dispersed, has fewer influential colleagues, and is often without clear status structures, divisions of labor, or gatekeepers among them (Klein, 1990). This compares to a discipline, where formalized "tribes" (Becher, 1989) are organized around a recognized corpus of knowledge with consensus on future research directions, established communication systems, socialization processes, and professional resources (Bechtel, 1986).

Fourth and finally, interdisciplinarity is often used to denote implicitly or explicitly the application of multiple disciplines and sectors to societal concerns, which may require not only an intellectual answer but perhaps a policy action or technological strategy. In this regard, interdisciplinarity is often imputed with the purpose of addressing socially relevant "real-world" problems whose solutions are beyond the scope of a single discipline or area of research practice (National Research Council, 2004). The rising tide of "applied" and "use-inspired" research along with the current push of technology has made interdisciplinary "problem-solving" a new focus of knowledge production for academic as well as extra-academic science (Klein, 2000). This problem-orientation has been furthered by new accountability measures of the Government Performance and Results Act (GPRA), which require that all NSF research proposals be evaluated both in terms of "intellectual merit" and "broader impacts". However, these trends come in an environment that does not always value equally the assets of "applied" scholarship with a *problem-orientation*. As Jonathan Cole among others has argued, traditionally there has been a "fairly clear hierarchy of value associated with scientific work" within academia, ranging from the theoretical to the experimental to the technological and the applied (Cole, 2000).

2.2. Women and interdisciplinary science: suggestions from the literature

In an effort to understand whether and why there might be a gendering of interdisciplinary science, we reviewed the literature from various disciplines and schools of thought for insights on gender-based learning styles, work preferences, and career behaviors.

With respect to *cross-fertilization*, it has been argued in some cognitive psychology circles that whereas men tend to look for abstract and theoretical arguments, dissociating it from any distracting information, women are more apt to see and make connections between ideas and the larger context (Halpern, 2000; Kimura, 1999, 2004; Moir and Jessel, 1992). According to a recent study, while male and females brains have equivalent potential on broad measures of cognitive ability, there are gender-based differences in the neuroanatomical structure of human brains such that women's brains have more white matter (nearly 10 times that of men) and men's more gray matter (approximately 6.5 that of women). Whereas gray matter represents information processing centers in the brain, white matter represents the networking of – or connections between – these processing centers (Haier et al., 2005; Science Daily, 2005). Based on such scientific studies as well as popular myths (Hales, 1999; Moir and Jessel, 1992; Sax, 2005), it is often argued that women are more oriented toward and better at assimilating diverse forms of information whereas men prefer to isolate explanations and excel in tasks requiring more local processing (Wyer et al., 2001).

Although essentialist neurobiological explanations about male and female thinking and learning styles are highly controversial, scholars of feminist science studies have long theorized that women can know the world in ways not available to men because they are less bound to the norms of science (Harding, 1986). The modern scientific method and most modern disciplines are based on masculine epistemology and knowledge which emphasize the principles of objective rationality, reductive explanation, and dichotomous partitioning between the social and natural worlds. In contrast, a feminist epistemology is centered on the notions of affectual rationality, inter-connectedness, and holism, thus allowing for a multiplicity of ideas and truths (see, for example, Benston, 1982; Fehr, 2004; Haraway, 1997; Keller, 1985; Rose, 1986). As Wyer states: "Bring[ing] the strengths of interdisciplinarity perspectives to the examination of disciplinary content is a touchstone for feminist scholars of all stripes" (Wyer, 2001, p. 77).

As far as practicing interdisciplinary *team-collaboration*, it has been argued in some of the psychology of gender literature that females are more likely to be inclined toward group work and that males are more apt to prefer independent work (Hayes, 2001; Keashly, 1994; Seymour and Hewitt, 1997). However, analyses of patterns and rates of scientific collaboration from the science studies literature do not reveal female scientists as necessarily more collaborative than their male colleagues. In fact, earlier studies suggest that female scientists previously tended toward fewer collaborators than men (Cameron, 1978; Cole and Zuckerman, 1984; Fox, 1991; Scott, 1990), and contemporary analyses find female scientists to average as many, but not more, collaborators than men (Corley, 2005; McDowell et al., 2006). The most common explanation for these findings is that, while women may be more inclined toward scientific collaboration, they are also likely to be more marginalized within the culture and structure of traditional science. As a result, and perhaps despite work-style preferences, women tend to be more limited in their access to formal and, particularly, informal networks, resources, and opportunities that often foster team-collaboration (Cole, 1981; Corley and Gaughan, 2005; Fox, 2001; Mählck, 2001).

There is a growing body of research within the gender and science literature which suggests that female scientists are as invested as their male counterparts in the epistemological rules of science and in the goal of discovery (Subotnik and Arnold, 1995; Sonnert and Holton, 1995a). This research also suggests, however, that female scientists may not be (or want to be) as committed to the traditional social rules of science and style of interaction (Max, 1982; Rolin, 2002; Schiebinger, 1999; Zuckerman, 1991). Thus, as common as it is to hear about the risks inherent in interdisciplinary *field-creation*, women may be attracted to participation in a new interdiscipline, particularly at early stages of field development. Various studies concerned specifically with male–female career performance differences suggest that females are inclined to be more cautious in their work than males because they fear "being shot down" (Etzkowitz et al., 2000), "being wrong" (Seymour and Hewitt, 1997), or "shooting from the hip" (Sonnert and Holton, 1995a; Rier, 2003, pp. 273–274). Similarly, Barinaga (1993) and Sonnert and Holton (1995b) provide evidence that women are less interested than males in seeking the exposure and recognition that accrues from high profile publications or positions. Such real and/or perceived differences in behavior might be explained by inherently distinct male–female work-style preferences, or by the fact that current modes of scientific practice and reward put women into unequally competitive positions (Kemelgor and Etzkowitz, 2001) and into conflicting role expectations (Rolin, 2002). Unfortunately, competitive deportment is demanded from and expected in some of the more traditional and well-established scientific fields (Bird, 2001; Boxer, 2000; Max, 1982; Traweek, 1988). This may explain why some women (and men) – particularly those making early stage career decisions – choose to specialize in comparatively "un-crowded" and "niche" domains where it could be seen as easier to exercise a sense of autonomy and control (Bird, 2001; Fox, 1999; Sonnert and Holton, 1995a).

As stated earlier, interdisciplinary research is also often positioned as having a *problem-orientation* toward "real life" questions confronting society (Hansson, 1999; Roy, 1979). Within the psychology literature, there is much data documenting consistent differences in the kinds of activities that appeal to men and women in their idealized jobs and careers (e.g., Häußler and Hoffmann, 1998; Lippa, 1998; Cejka and Eagly, 1999). For example, there is an average difference between women and men of about 1 S.D. in the desire to work with "people" (women) versus "things" (men) (Pinker, 2005). The occupations that fit best with the "people" end of the continuum could be considered "problem-oriented" in their focus (e.g., medical practitioner, social worker, lawyer), whereas the occupations that fit best with the "things" end are more concerned with fundamental theory, experimentation and/or computation (e.g., physicist, chemist, mathematician).

Without being as biologically deterministic, the literature from science studies claims that feminist research is often rooted in "[w]omen's concerns about what is wrong with society, such as violence, poverty, sexual abuse, and the misuse of power over people and resources . . . in contrast to conventional [male] scientific motivations, such as the accrual of knowledge for its own sake, the advancement of capitalism, or personal ambition" (Spanier, 1995, p. 41 in Roy, 2004, p. 263; see also, Harding, 2001; Keller, 1985; Shiva, 1989). These gender-based preferences have consequences not only for whether the two sexes go into science but for which branch of science they select and what problems they choose to research. It is already well-known, for example, that law, medicine, and social science disciplines which seek to advance knowledge oriented toward the community and are applicable to meeting human needs tend to attract more women (and minorities) than do theoretically oriented fields in the biological, physical or engineering sciences (Ibarra, 2001). With this in mind, faculty have been exhorted to introduce more real-world problems into science classes as a way to attract and retain women and minorities (National Council for Research on Women, 2001; National Research Council, 1995).

2.3. *The gendering of interdisciplinarity: questions from the literature*

Combining our four categorical definitions of interdisciplinary activity with the theoretical suggestions for why a gendering of interdisciplinarity might be expected, four central questions emerge:

- *Cross-fertilization*. As compared to male scientists, are female scientists more likely to want to adapt tools, concepts, data, methods, or results from different fields and/or disciplines?
- *Team-collaboration*. As compared to male scientists, are female scientists more likely to want to collaborate in teams or networks that seek to exchange and/or create tools, concepts, data, methods, or results across different fields and/or disciplines?
- *Field-creation*. Are female scientists more likely than male scientists to want to engage research in domains that sit at the intersection of or the edges of multiple fields and/or disciplines?
- *Problem-orientation*. Are female scientists more likely than male scientists to want to engage topics that not only draw on multiple fields and/or disciplines but also serve multiple stakeholders and broader missions outside of academe?

Below, using what limited empirical data there are from some of our own work as well as that of others, we examine each of these questions for evidence and explanations of gendering in interdisciplinary science. Note that we include the phrase "want to" in each of the questions above to distinguish between preference and performance. Because of the strong disciplinary bias that exists within the university, while women may be motivated in one direction, that desire may be suppressed in their attempt to conform to the norms of academia.

3. Data sources

The ensuing discussion is based on data from one secondary source and two primary sources: a survey conducted by Evaluation Associates in the United Kingdom as well as two multi-method studies conducted by Rhoten and by Rhoten and Hackett in the United States. These data are very slight but, as some of the only available empirical data measuring participation in interdisciplinary science, they represent a critical first step toward addressing the questions above. Answering these questions more fully and with greater confidence will require the testing and augmentation of these limited data with further evidence from other analyses and assessments.

We acknowledge three weaknesses upfront in interpreting these data. First, in both the Rhoten study and the Rhoten and Hackett study, just over 40% of the analytic sample is comprised of (post-)graduate students. Moreover, in both cases, the relationship between "rank" and "enrollment" is the inverse for males and females, with the bulk of the female population clustered in (post-) graduate student positions and more of the male population clustered in senior faculty posts. Thus, there is a generational cohort effect to consider in our data (Xie and Shauman, 1998), especially in light of the strong disciplinary orientation of academia which imposes varying effects at different career stages in the scientific life-course (see, for example, Pfirman et al., 2005a,b). Second, our analysis may be picking up on certain temporal effects. For example, the current high profile attention to interdisciplinarity and the recent birth of new inter-disciplines may have a particularly strong and positive signaling effect for interdisciplinarity, thus momentarily exaggerating rates of interdisciplinary participation among scientists and especially students. Third, these studies were not initially designed to examine the role of gender in the pursuit of interdisciplinary science. Thus, the data make it difficult to discern between the effects of individual attributes, group characteristics, and socio-structural conditions (or their interactions) on gender-based differences in thinking, learning, and working.

3.1. Interdisciplinary research and the research assessment exercise (evaluation associates)

Commissioned by the U.K. Research Councils and the Higher Education Funding Bodies, Evaluation Associates Ltd. conducted a study focused on the assessment of interdisciplinary research in higher education institutions of the United Kingdom. As part of this study, Evaluation Associates mail-surveyed 10,992 researchers, including an estimated 2200 heads of departments in summer 1998. This population of researchers was limited to those affiliated with higher education institutions that had been previously involved in an earlier Research Assessment Exercise (1996). This yielded 3254 surveys. To ensure adequate coverage of all subjects, a short questionnaire was mailed to a new 'booster' sample of 5330 researchers in autumn 1998. This yielded another 2251 surveys, resulting in a total researcher response rate researchers of 37% ($n = 5505$). The survey posed a series of questions related to, for example, time allocated to interdisciplinary research, modes of interdisciplinary engagement (e.g., individual versus team projects), and patterns of disciplinary and interdisciplinary citation.

3.2. A multi-method analysis of the social and technical conditions for interdisciplinary collaboration (Rhoten)

Data for this study were collected in a sample of interdisciplinary research centers between January 2002 and June 2003.[1] These centers were selected using both purposive and convenience sampling methods from the population of interdisciplinary centers funded under the NSF Environmental Research and Education portfolio. All of the centers in our sample had been assembled for the express purpose of conducting interdisciplinary research and research training, but differed on the basis of organizational size, age, type, structure, and format; disciplinary diversity and distance; and, researcher composition. Rhoten's investigation of these centers combined techniques of social network analysis with those of ethnographic fieldwork. Relevant data on researcher attributes, actions, and interactions were gathered in a three-part survey with the population of researchers in each center by means of census (mean response rate = 73%). Additional individual, relational, and organizational data were collected via site visits and systematic interviews ($n = 81$ interviews). The population across these five centers totals 315 researchers, including tenured/tenure track faculty (39%), postgraduate and graduate students (43%), non-tenure track scientists (17%), and "other" (1%). Women represent 26% of the total population across all centers, and 13% of all tenured/tenure track faculty, 57% of the (post-)graduate students, and 27% of the non-tenure track scientists.

3.3. Integrative, interdisciplinary graduate education: new concepts for assessment (Rhoten and Hackett)

This larger NSF-funded study still underway is designed to explore the fundamental intellectual, social, and cultural workings and outcomes of Integrative Graduate Education and Research Training programs (IGERT). In 1997, the National Science Foundation implemented the IGERT initiative to meet the challenges of preparing Ph.D. scientists and engineers with

[1] Because of the very different research structure of one center in the sample, only five of the six centers are analytically comparable for our purposes here.

interdisciplinary backgrounds. Rhoten and Hackett's inquiry into the IGERT programs combines general social science survey methods with social network analysis, ethnographic fieldwork, and experimental observations. The data presented below come from the initial surveys conducted with the principal investigators in 120 IGERT programs (response rate = 65%) and from interviews conducted with faculty and survey in a stratified random sample of 20 IGERT programs ($n = 45$). IGERTs in the sample differ on the basis of institutional characteristics (e.g., institutional type; student body size; geographic location) and program characteristics (e.g., start date; central theme; participating departments; student and faculty composition). With regard to this last characteristic, the population across this sample totals 1145 individuals, of which 43% are graduate students. Women represent 29% of the total population, which translates to 41% of the aggregate graduate student population and 20% of the aggregate faculty population across all programs.

4. Preliminary evidence and explanations

4.1. Interdisciplinarity as cross-fertilization

In the survey of higher education researchers in the United Kingdom (Evaluation Associates, 1999), a striking finding was that female respondents reported spending more time on interdisciplinary projects in almost all fields at every age (Fig. 1). Women overall indicated committing slightly more of their total research time to interdisciplinary research projects (50%) compared with men (45%). More significantly, on average, women less than 30 years old reported spending 20% more time on interdisciplinary research than men. The only age/field class where women reported dedicating less time on interdisciplinary research than men was the less than 30 year olds in physical and engineering sciences. What is the impact of this early difference in research orientation in terms of positioning women for future advancement?

In addition to spending more time on interdisciplinary research relative to men, female respondents also reported drawing from a slightly broader range of fields than their male colleagues. For instance, when asked to classify their research against 574 subject fields, women reported citing an average of 3.6 different fields whereas men reported citing an average of only 3.2 fields. Alone, this may not seem noteworthy. However, the distribution of males versus females reveals that 21% of the female respondents reported citing seven or more research fields in their work as compared to only 8% of the male respondents (Evaluation Associates, 1999).

Finally, by controlling for "individual" versus "team" interdisciplinary research projects, the study found that, as individual researchers, female scientists were much more likely than male scientists to engage in interdisciplinary research projects. Women reported spending 44% of their independent research time on "lone" interdisciplinary projects, whereas men indicated spending only 33% of their independent research time on interdisciplinary projects (Evaluation Associates, 1999). Collectively, the data suggest that women tend to be more interdisciplinary than men. Moreover, that the delta between the time that male and female scientists allocate to partic-

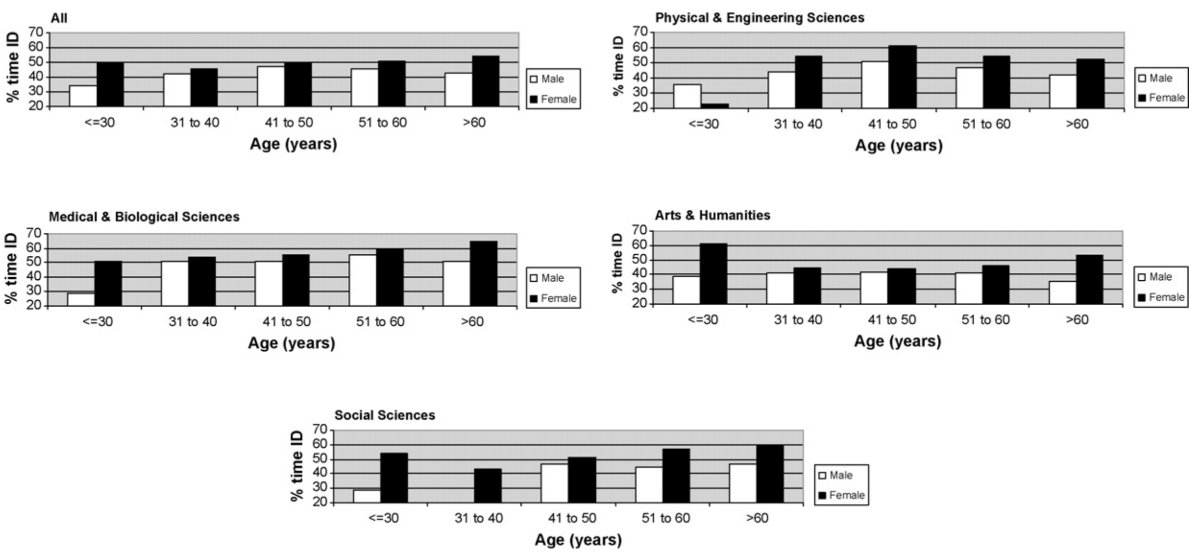

Fig. 1. Percentage of research time spent on interdisciplinary research by age and sex (*source*: Evaluation Associates, 1999).

ipation in interdisciplinary research more than doubles when controlling for individualized projects suggests that women may be specifically more inclined to pursue interdisciplinarity through cross-fertilization (i.e., integrating results and approaches of the other disciplines at the individual level).

It is impossible to discern from these data alone why comparatively higher rates of female versus male researchers in the U.K. are engaged in interdisciplinary cross-fertilization. Although we lack respondent narratives to explore causality further with this sample, interview data from Rhoten and Hackett's analysis of Integrative Graduate Education and Research Training programs (IGERTs) may lend some preliminary evidence to the argument that gender-based differences in thinking – or the *expectation* of gender-based differences in thinking and learning styles – are contributing to a gendering of interdisciplinarity. For example, the principal investigator (PI) of one IGERT in this study noted that he had been trying for years to draw more female students into the engineering department but that it was not until he implemented a program in bioengineering that he was successful in this endeavor. While he acknowledged that the IGERT program stipend enabled him to offer female students financial incentives for the first time and that the connection to life sciences increased the overall pool of female applicants, he attributed new female enrollments in the engineering department directly to the cross-fertile nature of the IGERT program. He explained this by pointing to what he construed as different "gender-based ways of knowing".

> For some reason there is a difference between males and females. I don't know what it is, but there is a difference in how they actually perceive information. . . . engineering really requires some – at least at the beginning – focus on a specific thing. . . . Whereas biology . . . you actually have to have the different view. You have to have a much broader view; you have to be willing to look at huge, complex systems without understanding any of the components. And men don't do very well with that. A prime example: a guy watching TV, right? That is what he's doing. People can talk to him and you're like, "I don't know what you just said." And that I think is a male-female thing because women have this ability to multitask, which men can't. It's not that cut and dry but in general men are very much focused on specific, little details. Even though women are detail-oriented, to some degree, it's a more global picture of details.

Similarly, a co-PI from a second IGERT program in the study, this one from the domain of environmental systems, commented that one of the single most important implications of her IGERT program had been the effect on female enrollments. Like the PI above, she explained this by reflecting on the "power of networked thinking", something she saw as required by interdisciplinary pursuits and as associated with female traits.

> At the interface of life sciences and geochemistry, you have to keep a lot of things in mind . . . it's a network of influences. I think women network better than men, whether it is cultural or innate, I don't know. We do it with our friendships, with our social interactions.

In a separate interview, the PI from this same IGERT made an analogous observation about female enrollments and interdisciplinarity, focusing on what she understood to be women's preferences for complexity and their tolerance for diversity: ". . . there is something particular about interdisciplinary work that is attractive to females. It certainly is for me; I think it is a really rich intellectual territory and there aren't simple answers. I am happy with that; I don't need to have the 'right' answer".

It is possible that the gap between male and female participation in interdisciplinary cross-fertilization can be explained by differences in male–female cognition and information processing. This gap might also be attributable to differences in male–female socialization as learners and researchers, whereby perceptions and expectations lead to different strategies of knowledge construction and validation between men and women (Rolin, 1999, 2002; Valian, 1998). Or, perhaps it could be explained by distinctions between "high-context" (i.e., females and ethnic minority groups) and "low-context" (i.e., males and ethnic majority groups) students and scientists, where the former tend to draw from streams of information that surround an event, situation or interaction and the latter seek to filter out extraneous conditions or circumstances surrounding an event (Ibarra, 2001). The influence of biologically based versus socially learned or culturally transmitted factors when accounting for gender differences in interdisciplinary science is a topic of much longer discussion and broader debate than can be addressed here, and one that should be investigated more deeply in the future.

4.2. Interdisciplinarity as team-collaboration

Although not originally designed to address the question of gender, the study of U.S.-based interdisciplinary research centers by Rhoten offers some evidence to suggest that interdisciplinary centers may be facilitat-

Table 1
Female representation across a sample of interdisciplinary centers and across academia (by field)

Field of science	All sciences	Engineering	Mathematical and computer sciences	Natural sciences	Social sciences
Representation in centers in Rhoten (2003) study sample					
% population in centers by field (both sexes, all positions) (2001)	–	26.3	2.2	60.0	11.5
% population in centers by field (female, all positions) (2001)	26.1	18.1	14.3	25.4	22.2
% senior faculty in centers by field (female) (2001)	13.9	7.4	0	17.9	13.3
% graduate students in centers by field (female) (2001)	38.3	27.0	0	45.8	75.0
Representation in academia					
% senior faculty employed in field (female)[a] (2001)	23.1	5.4	11.9	20.8	26.0
% graduate students enrolled in field (female)[b] (2001)	41.4	20.3	31.3	45.1	60.2

[a] Appendix Table 5.23. S&E doctorate holders employed in academia, by type of position, sex, and degree field: 1975–2001. National Science Foundation (2004) and Science and Engineering Indicators (2004), National Science Board, Arlington, VA.
[b] Appendix Table 2.13. S&E graduate enrollment, by field and sex: selected years, 1975–2001. National Science Foundation (2004) and Science and Engineering Indicators (2004), National Science Board, Arlington, VA.

ing change in scientific collaboration for both men and women (Rhoten, 2003). As indicated, Rhoten identified 26% of the total population of 315 scientists and students across these centers as female. Looking strictly at senior tenured faculty (i.e., full and associate professors) and graduate students, women represented 14% and 38% of these subgroups, respectively. For both senior faculty and graduate students, female representation across all sciences was comparatively lower in the centers than was estimated in the academy more broadly for 2001. As suggested in Table 1, this difference is likely due in large part to the lack of female representation in the mathematical and computer sciences in the centers at both the senior faculty and graduate student career stage. In engineering, the natural sciences and the social sciences, there was a higher proportion of female graduate students represented in the centers than in academia broadly. Engineering was the only area for which this was true for senior faculty.

Beyond rates of female participation, Rhoten found moderately higher rates of female collaboration than might be anticipated, particularly amongst graduate students. Within these interdisciplinary centers, female and male affiliates were identified as having, on average, identical numbers of collaborators ($N_{\rm w}$, $N_{\rm m} = 13$ collaborators). This finding parallels results from Elizabeth Corley's analysis of university-based research centers (Corley, 2005). Moreover, in terms of the nature of these collaborations, the survey data suggest that the female center affiliates tended to have, on average, more collaborators with whom they engage in formal "knowledge producing" relations than did their male colleagues ($N_{\rm w} = 6.0$, $N_{\rm m} = 5.4$), although they had fewer informal "information sharing" collaborations ($N_{\rm w} = 7.0$, $N_{\rm m} = 7.6$).[2] This pattern remained when the data were further controlled for specifically "interdisciplinary" versus "intradisciplinary" collaborations.[3] On average, women had more "interdisciplinary knowledge producing" collaborations than did men ($N_{\rm w} = 3.0$, $N_{\rm m} = 2.7$) but fewer "interdisciplinary information sharing" collaborations ($N_{\rm w} = 4.0$, $N_{\rm m} = 4.6$).

These data suggest that, overall, female affiliates in these centers may have more close, or knowledge producing, collaborations that span disciplinary boundaries than male affiliates. However, across the full population of affiliates, there is actually no significant effect for gender on the number of "interdisciplinary knowledge producing" collaborations, $t(313) = 0.665$, $p = 0.05$; mean for females = 3.00, mean for males = 2.73 (equal variances not assumed). Only when rank is controlled at the level of graduate student was the difference in means for gender statistically significant, $t(110) = 2.924$, $p = 0.01$; mean for female graduate students = 9.25, mean for male graduate students = 6.56 (equal variances not assumed).

[2] Survey respondents were asked to identify other researchers with whom they had "close" and/or "collegial" collaborations. A "close" collaboration referred more to a formal "knowledge producing" relationship and was defined for the respondents as a "relationship with someone you count among your closest professional and/or intellectual collaborators . . . with whom you develop and prepare papers, articles, presentations". By comparison, a "collegial" collaboration denoted an informal "information sharing" relationship and was defined as "a relationship with someone whom you talk and share information, data and ideas casually but do not necessarily produce papers, articles, presentations".

[3] "Interdisciplinary" here refers to relations that cross-boundaries at the level of scientific field (e.g., engineering, physical science, life science, and social science).

That gender is a statistically significant factor among the graduate student population in these centers, along with the higher participation rates, could imply two things. First, early changes could be underway in male–female roles and relations among junior scientists, and/or interdisciplinary participation and interaction is an early career stage phenomenon. Given that evidence of greater rates of interdisciplinarity was similarly found among U.K. women under 30 years old, testing for career stage and cohort effect will be important in future studies. Second, without being able to test definitively a negative hypothesis, the data also offer provisional evidence that, amongst faculty, gender does not predict the number of collaborators scientists have in these interdisciplinary centers. This is not the case in mainstream departmental or disciplinary science, where the size of a senior scientist's collaborative networks appears to be related to gender, with men having larger networks (Cole and Zuckerman, 1984; Bozeman and Corley, 2004). Thus, investigating whether interdisciplinary centers have a leveling effect on the collaboration opportunities of women will also be critical to future work.

Absent further data, one cannot say much more about gender and interdisciplinary team-collaboration. The small differences could be the result of only minor distinctions between men and women in terms of collaboration, or it could be because there are two competing factors—a desire on the part of women for more teamwork, which is confronted by interpersonal and socio-structural barriers to their building larger networks. Without additional data, it is impossible to discern whether more junior women participated in team-based research in these centers because the interdisciplinary context reduces some of the known interpersonal and socio-structural barriers to collaboration, thus allowing for more collaboration in general and for women in particular (Corley and Gaughan, 2005). Or, because collaboration plays to assumed female preferences for team-based work (Dickens and Sagaria, 1997) such that women are in both greater supply and demand as interdisciplinary investigators and/or collaborators. Or, because, when science is organized into interdisciplinary teams, more attention and a higher premium is placed on an individual's knowledge contribution rather than gender distinction (Corley, 2005).

4.3. Interdisciplinarity as field-creation

Early data from Rhoten and Hackett's study also suggest that women scientists – and, again, specifically, younger women scientists – may be migrating toward interdisciplines at greater relative rates than men. It is difficult to assess enrollment rates in IGERTs against enrollment rates by field given that each IGERT program cuts across different fields—atmosphere, earth, and ocean sciences; biological sciences; computer and mathematical sciences; engineering; physical sciences; and social and behavioral sciences. However, by looking at the combination of disciplines and the topics addressed in the programs, Rhoten and Hackett have clustered IGERTs into different domain areas—biosciences and bioengineering; cognitive and neuroscience; computation and complex systems; environmental systems; materials science and engineering; new technology and applications; and social science and management (Rhoten and Hackett, 2005).

In 2004–2005, across IGERT programs concentrating on emerging interdisciplines in the area of environmental systems (e.g., those focused on earth systems, ecosystem management, and environmental science and engineering), the ratio of female students averages 57% and climbs as high as 80% for individual programs. According to the National Science Board Science and Engineering Indicators (2006), in 2003,[4] female students represented 45% of the graduate enrollment in earth, atmospheric, and ocean sciences and 55% in biological sciences; both lower than the female enrollment rates in the IGERTs that cross-cut these fields (National Science Foundation, 2006). Moreover, preliminary data from the 2004–2005 IGERT sample in Hackett and Rhoten's study indicate that enrollment rates of women in IGERTs focused on new interdisciplines in materials science such as nanotechnology, polymers, and lasers/optics/photonics average 33% and in some cases reach 47%, whereas only 22% of all graduates enrolled in engineering were women in 2003 (National Science Foundation, 2006). By comparison, however, the average 2004–2005 enrollment of female students in IGERTs clustered within the more established interdisciplinary area of cognitive and neuroscience was only 28%. Not only is the percentage much lower than the emergent interdisciplines describe above, but it is also much lower than the ratio of female graduate students enrolled in psychology (74%) or in medical and life (non-biological) sciences (60%) (National Science Foundation, 2006). This is perhaps because cognitive science is a highly developed interdiscipline that has become part of the structure of scientific research, as compared to newer,

[4] Science and engineering graduate enrollment data are not available for 2004, making the available 2003 data the most comparable to Rhoten and Hackett's 2004–2005 data.

evolving domains such as environmental studies which is not yet embedded in knowledge categories or academic institutions (Klein, 1996; Palmer, 1999).

Beyond simply achieving a larger presence, Laurel Smith-Doerr has found that female scientists are also experiencing greater gender equity within newer biotechnology domains as compared to older, more traditional life science or engineering disciplines. She argues that these new interdisciplinary domains offer "opportunities to do challenging research with fewer hurdles (i.e., the tenure clock) for non-traditional scientists [which] appeal to women ... the combined carrot (biotech as good science opportunity) and stick (gendered academic politics) attracts women with leadership potential ..." to these less contested areas (Smith-Doerr, 2004, p. 43).

Along these lines, a co-PI of one IGERT program in Rhoten and Hackett's study reported noticing that increasingly more women are participating in various interdisciplinary field-building activities, which he attributes directly to "risk-taking."

> In 1980, long time ago, they had to really work hard to get women to join, to take these [interdisciplinary] courses, they were all male ... now it's a real problem because it's almost all women ... So, we've sat down and talked about this, "Why, you know, what's going on? What do you think this is?," you know. And the best explanation I've had actually has to do with risk-taking. ... [women] are more exploratory ... they're not worried about, "Is this the fastest route from point A to point B?"

The PI of a different IGERT echoed this, describing participation in an interdisciplinary field as "going off and doing something else" away from the mainstream. In both instances, the lateral nature of interdisciplines was thought to make such epistemic domains more risky but simultaneously less-competitive than core disciplines, a milieu the principal investigator perceived as possibly attractive to certain personalities more common among women.

> ... Now, everything is much more, we're sort of much more goal-oriented in general than we were 25 years ago. But [now] ... women dominate those [interdisciplinary] pursuits ... there's some parallels with the IGERT ... If you're of a personality, and maybe women are more like this, about not being in super-competitive environment, [interdisciplinarity] would be more comfortable ... and it's much more contextual.

The notion that intrapersonal reluctance for and/or socio-structural obstacles to competition may somehow contribute to the feminization of interdisciplines is a crucial point to consider in understanding why marginal and/or exploratory interdisciplines, particularly in early stages of field-creation when the terrain is only sparsely inhabited, might be less male-dominated as compared to central and established disciplines. It should be noted, however, that this quality of interdisciplines may be temporal. As Smith-Doerr (2004) reports, research on the development of new fields indicates that frequently as jobs within them become more mature and thus less marginal, they often shift from "'women's work' to 'men's work"' (Smith-Doerr, 2004, p. 28).

Collectively, these observations offer initial support to the argument that some women as well as less-competitive men, particularly at earlier career stages, may migrate toward new interdisciplines rather than established disciplines in an attempt to circumvent the hierarchical structure and competitive nature of established science. However, the explanations for such migration are multiple and debatable. Is it the action of women who are unable or unwanting to perform in mainstream disciplines due to sex-based cognitive differences (Kimura, 1999)? The reaction of women who shy away from competition and feedback in their performance (Niederle and Vesterlund, 2005)? Or, the transaction of women who prefer a more transformative rather than aggressively reproductive ethos (Newman, 1995)? This cannot be determined from the data collected to date. Understanding these and other motivations is, however, critical not just to the issue of women in interdisciplinary science but to much larger questions about the environment of academic science in general. Is the academic enterprise sufficiently combative that some of our most talented young scientists, both male and female, are deterred from research paths or career trajectories? (Rhoten and Parker, 2004).

4.4. *Interdisciplinarity as problem-orientation*

Finally, there is the question of whether differences in vocational interests translate into differences in disciplinary versus interdisciplinary field choices. Currently, there are no empirical resources to test this question, and thus much of the related discussion question has relied on interpretations of anecdotal evidence and enrollment data. We are able to go only slightly further by analyzing the responses to one survey item collected in the Rhoten and Hackett study. Rhoten and Hackett asked the PI of every IGERT program to identify, on a scale of 1–4 (1 = *not at all*, 2 = *a little*, 3 = *substantially*, and 4 = *very much*), the extent to which they considered their program to be "problem-based" versus "tool-based" versus "vision-based". Of the 14 programs in the sample of 20 IGERTs for which we have responses to this question as well as enrollment data, all seven programs with female student enrollment rates at the upper end of the range (i.e., greater than the aggregate or average IGERT female enrollment rate of 41% and 39%, respectively) were considered *very much* or *substantially* "problem-based". Moreover, six of these seven problem-oriented programs are majority female, with female enrollment rates ranging from 52% to 80%. Six of these programs focus on problems related to earth systems, ecosystem management, and environmental science and engineering and fall within the environmental systems cluster. The last focuses on the application of math to modern biological problems and falls within the biosciences and bioengineering cluster.

It could be argued that these enrollment patterns are unsurprising given that women as a group are often more attracted to the life sciences. However, this seems not to be the whole story. For example, these empirical findings mirror other evidence which suggests that environmental engineering attracts more women than other fields of engineering (Widnall, 2000; American Association of Engineering Societies, 2003) because the former is seen as offering an integrated and interconnected approach that has "social value and relevance" and results in work that has "a positive impact on society" (Farrell, 2002). Research also indicates that women tend to be more concerned specifically with understanding the adverse environmental and health impacts of scientific policies and applications than men; inherently a problem-oriented topic which mandates an interdisciplinary approach (Branscomb et al., 2001).

In this vein, the following quotations from two female students in yet another two IGERT programs, both again in the environmental systems domain, make explicit their motivations for pursuing interdisciplinary science as a problem-oriented endeavor.

> When I first started [my research], I was really scared. The last time I had taken a biology course was in eighth grade. But, the question I wanted to answer required biology. I needed to find a way to work at the interface of chemical engineering and microbiology, or I needed to find a different question . . . Now, I am sorta' on the fringe of science, I guess, but I am dealing with the core problems of society. So, yeah, that is where I want to be.

And,

> I have become very aware of the horrible inefficiency of the scientific enterprise in turning knowledge into useful products . . . so I came [to this interdisciplinary center] to branch out from what I was doing, to do something bigger and better, more intellectually interesting, and more practically important.

In their comments, both women reveal an epistemological commitment to what they see as the social and practical problem-solving purpose of science. Alongside such student expressions of interest in socially relevant and problem-oriented interdisciplinary research, also come endorsements of such activities as strategies for attracting women as well as minorities to the sciences. For example, Dr. Walter E. Massey (President, Morehouse College) remarked at the Conference on Basic Research in the Service of Public Objectives: "I am particularly attracted to the argument that tying research to broad and meaningful national goals may make science more attractive to women and minorities . . . I think that showing how scientific research can be related to visible societal goals can be a strong attraction to many students who might otherwise not consider scientific careers" (Branscomb et al., 2001, p. 82). The fact that students are pursuing and administrators are promoting such work while fully recognizing that such instrumental knowledge-seeking strategies may be orthogonal to the current intellectual habits and institutional priorities of academic science brings us squarely to the question of opportunities and challenges associated with interdisciplinarity.

5. Women in interdisciplinary science: challenges and opportunities

Interdisciplinary science has great potential for engaging individuals who would either not be interested in traditional disciplinary science, or who become disaffected with it along the way. As Anne Preston (2004) found in her analysis of scientific career trajectories, Anne Preston found that the one common thread between male and female scientists who leave the scientific enterprise is that they feel their field is too narrow and that they have to become too specialized to succeed. As one female respondent in her study commented: "I think the biggest [obstacle] for me was that science was not relational . . . No one was really interested in making connections" (Preston, 2004, pp. 117–8). Given the character of interdisciplinary science, it makes sense that individuals who are attracted to the types of activities described above will be people who prefer team-based, problem-oriented and/or socially relevant approaches, and will likely be people who have or pay attention to the requisite interpersonal skills. It also seems reasonable that interdisciplinarity might appeal to some individuals who feel marginalized within established fields or dislike highly competitive disciplines, and thus seek alternative domains where the size of the research population, the level of peer attention, and the degree of community composition is less developed than in core disciplines.

On the one hand, interdisciplinarity may present a haven that could be attractive to women, particularly younger women who have not yet invested in the struggle to overcome the structural and cultural obstacles of mainstream science (Fox, 2001). However, on the other hand, stepping outside of the defined territories may come with its own deferred liabilities. Although interdisciplinarity may offer an alternative to specialization, intellectualization, and internalization which Weber described as contributing to the youth's disenchantment with modern scientific life (Weber, 1946), it does not ultimately insulate the youth from – and in fact may even escalate – the conventional responsibilities, rituals, and reviews of academic life which remain steeped in disciplinarity.

5.1. Interdisciplinarity as cross-fertilization and collaboration

Given the structural reality of much of academic science, the path of interdisciplinarity can run headlong into the hurdles associated with obtaining funding and publishing findings. Because of the way academic science has been historically organized by discipline, considerable effort must go into finding an appropriate place to submit an interdisciplinary proposal, mastering different literatures and languages, and, in the case of collaboration, managing multiple colleagues that often are from different institutions. Once submitted, interdisciplinary proposals are harder to review. Unlike disciplinary research, there is no readily identifiable peer community for interdisciplinary products. Typically, they are sent out to people with diverse backgrounds. Each reviewer tends to be highly critical about the piece s/he knows most about and at the same demanding of more information on those aspects least familiar (Pfirman and Balsam, 2005). This often leads to lack of consensus in reviews and to challenging revisions that prolong the naissance of many research projects (Hackett, 2000).

If proposals are the life source of science, then publications are the lifeblood: "[j]ournals and the articles they contain . . . drive, and perhaps define, the scientific enterprise" (Chubin and Hackett, 1990, p. 83). Apart from communicating new research and ideas (Merton, 1973), publications are also the major yardsticks by which professional funds and rewards are distributed (Grinnell, 1992), at least in academic science. Within this enterprise, moreover, there is a premium on publishing in prestigious, visible journals that can signify importance of the findings, and magnify the impact of the research. Because of the relative dearth of top rank interdisciplinary publications, simply finding high impact journals in which to publish is more difficult for researchers who choose this path. Moreover, the creation of a synthetic publication that integrates across several disciplines often takes more time than a monodisciplinary publication that advances one step – in the same direction – beyond previous work. Leahey (in press) has found that researchers who specialize tend to produce more publications, and that men are more likely to specialize than women. Once published, in order to have impact, research needs to be recognized by others as useful. Often categorized as reviews, synthesis papers can be highly cited (Amin and Mabe, 2000) but are often not thought of as seminal or original.

Delays in publication and the absence of a community prepared to accept the research as a major advance affect both the pace and the perception of publication outputs for interdisciplinary scholars and, thus, their evaluation outcomes. Certainly, this presents obstacles for any interdisciplinary researcher regardless of gender. However, it may be especially damaging to women. Despite improvements in publication rates over the years, women scientists continue to publish fewer papers than men for personal and structural reasons (Cole and Zuckerman, 1984; Xie and Shauman, 1998). Moreover, it often takes a longer period of time and a greater number of publications for women to be recognized as meriting promotion or senior status than for their male peers (Valian, 1999).

Finally, the potential costs and benefits of interdisciplinary collaboration and publication for women in particular cannot be calculated without also turning to the equally if not more complex concern of female contribution, attribution, and recognition—*aka* the Matilda Effect (Merton, 1968; Rossiter, 1993; Zuckerman, 1977).[5] Because female scientists often do not have the same professional social capital that male scientists do (Burt, 1998; Ibarra, 1992), women may be more likely to face challenges getting the internal members of a research team to afford their contribu-

[5] The Matthew effect was originally coined by Robert K. Merton to describe how, among other things, eminent scientists often get more attribution and credit than less well-known researchers even if the latter's work is comparable (Merton, 1968; Zuckerman, 1977). The Matilda effect is a corollary to the Matthew effect and argues that women tend to receive less credit for their scientific work than their male colleagues even when they empirically deserve as much or more.

tions the same priority and follow through that their male colleagues receive (Sonnert and Holton, 1995a; Valian, 1999). Moreover, psychological research on causal reasoning suggests that interdisciplinary collaboration may also cause difficulties for women in terms of receiving external assignment of credit. As Pfirman and Balsam (2005) argue, when collaborators are well-known, others have to overcome the "blocking" and "overshadowing" effects having their ideas attributed to their colleagues (De Houwer and Beckers, 2002; Dickinson, 2001). Given that historically men have often been more prominent figures in many scientific fields, it is possible that a women's participation in a collaborative publication may only nominally add to her curriculum vita while actually greatly advancing her male colleague's reputation. This negative male–female collaboration effect may be further exacerbated by the idea that causal attributions depend on the "relative validity" of a predictor. This means that, if researchers have a career interruption – which women are more apt to have (Shauman and Xie, 1996) – while their colleagues continue to publish, over time their colleagues will begin to get sole credit for the original joint discovery (Pfirman and Balsam, 2005).

5.2. Interdisciplinarity as field-creation and problem-orientation

To their critics, interdisciplines are often regarded as an escape from the scientific rigors of core disciplines. As discussed above, however, interdisciplines can also be construed as ways to leapfrog the contestation of traditional scientific fields or as sites of intellectual empowerment where conventional scientific knowledge can be redefined (Bird, 2001). When scientific fields are still nascent and the research community is not yet established, there is more opportunity to build and influence not only the direction but also the composition of that area. Consequently, interdisciplines may be particularly appealing to those men as well as women who are not comfortable with the "essential structures" or "regimes of truth" of core disciplines (Rowland, 2002), or to those who feel blocked, overshadowed, ignored or even excluded within traditional domains. In newly emerging interdisciplines, individuals may also be able to avoid having to compete head on with peers and/or leaders as they would in more established fields, and thereby evade pressures related to advancing research quickly and/or having "discoveries" eclipsed prematurely. While both sexes may be susceptible to such pressures, they may be particularly intense for women who are likely to face more socio-structural obstacles than men (Etzkowitz et al., 2000).

By definition, interdisciplinary fields are outside of the usual, and thus often suffer from a lack of consensus about what is important. Pfirman and Balsam (2005) point to research which suggests that the impact of information on learning and cognition depends on its "news value"—in other words, how much the information contradicts expectations (Dickinson, 2001). On the one hand, then, high impact research will be that which challenges current expectations most (i.e., new domains of research); on the other, such a challenge will only be most newsworthy where expectations are already the strongest (i.e., established fields of science). Disciplines have a well-defined set of methods, concepts, and tools by which they can more easily come to consensus about the value of a contribution. By contrast, the diverse and diffuse nature of interdisciplinary fields do not lend themselves to the development of clear expectations about outcomes, making advances less easily distinguished as innovative and more easily characterized as "niche" or even trivial. Also, particularly in the early stages of a new field, when interdisciplinary research involves exporting ideas and methods from one discipline to combine and create another, at least half the scholars are not likely to see the resulting hybrid field as anything but derivative (Pfirman and Balsam, 2005). Paradoxically, then, interdisciplines may offer greater prospects for discovery at the same time that they also lower odds of recognition. It is one thing to be the member of an invisible college, but a very different thing to be an invisible member of a college.

Similar issues relate to interdisciplinary problem-orientation. Interdisciplinarity of this type often connects scientific approaches with societal issues, which as stated above are thought by some to appeal more regularly to women than men. Despite the recent attention to problem complexity and the heightened desire to transfer basic knowledge to application, interdisciplinary problem-solving still faces the question of legitimacy within the Ivory Tower (Frost and Jean, 2003; Stehr and Ericson, 1992). This is not to say that problem-oriented knowledge does not exist in academia (cf. law, medicine, engineering, etc. and applied science), but rather that, as was suggested earlier, research that is theoretical and abstract as well as valuable and reproducible for its own sake is still often revered by many within the academia as the most prestigious (Cole, 2000).

As long as the default is departmental and disciplinary, interdisciplinary science and scholarship will be disadvantaged. The question remains whether women and other groups who pursue interdisciplinary science successfully escape from what is or feels like a marginalized status and a disenchanted life in the core sciences, or instead eventually face a double jeopardy of institutional constraints and professional limitations. This and other questions pertaining to interdisciplinary preferences and consequences and the possible effect of gender cannot be answered with existing data. This empirical gap should be addressed before current policies to expand interdisciplinary offerings and programs to enhance female and minority enrollments – often one in the same – in academic science continue unchecked.

6. Women in interdisciplinary science: preliminary conclusions and future directions

In this paper, we asked whether intellectual preferences for and professional consequences in interdisciplinary versus disciplinary science might be influenced by gender, race and/or ethnicity. Focused for the time specifically on gender, we introduced the relevant literature pertaining to learning styles, work preferences, and career behaviors that might anticipate and/or explicate gender differences in interdisciplinary science. Then, borrowing preliminary empirical data from three different studies, we applied these arguments to four principal mechanisms by which researchers engage in interdisciplinary science – *cross-fertilization*, *team-collaboration*, *field-creation*, and *problem-orientation* – in order to test for any evidence of gendering in interdisciplinarity.

The results of this exploratory analysis yield varying degrees of support for the four propositions posed in the paper, with the clearest evidence of the gendering effect appearing at the graduate student level. First, based on the Evaluation Associate's survey of higher education researchers in the U.K., it appears that female scientists, especially in the early stages of their careers, may in fact spend more time on individual cross-fertilization activities as well as borrow tools, concepts, data, methods, or results from more fields and/or disciplines at greater rates than their male counterparts. Second, according to preliminary data from Rhoten's original analysis of interdisciplinary research centers, on average, female affiliates – particularly, female graduate student affiliates – do seem to participate in more cross-disciplinary "knowledge producing" relations than their male colleagues. Third, early results from Rhoten and Hackett's current study of Interdisciplinary Graduate Education and Research Training programs (IGERTs) suggests that female affiliates – again, specifically, female graduate students – may be drawn at greater rates to field-creation activities in emerging interdisciplines than to field-based competition and perpetuation activities in established cognate disciplines. Finally, early findings from this same study offer support to the notion that female students may be more inclined than their male counterparts to engage research that not only draws on multiple disciplines but, in its problem-orientation, also seeks to serve multiple stakeholders inside and outside academe.

Beyond offering a few possible clues about why women might choose interdisciplinary research and at what potential cost and benefit, the results of this exploratory paper raise as many questions as they answer. First, while our exploratory analysis suggests a possible gendering of interdisciplinary activities, it is impossible to discern to what extent this pattern can be explained by individual attributes, group characteristics, socio-structural conditions or some interaction thereof. Thus, without additional data to test these as well as other intervening factors (e.g., race, cohort, disciplinary/interdisciplinary field, institutional context), we cannot claim with any certainty that gender is the significant factor. Nor can we draw any definitive distinctions between the "push" effects of disciplinary science versus the "pull" effects of interdisciplinary science.

Second, our empirical focus here has been primarily on factors that might govern participation in interdisciplinary science and much less about performance in interdisciplinary science (e.g., scientific discovery, professional trajectories). While we have discussed both perceived and projected consequences that interdisciplinary programs and careers may hold long-term for younger scientists, we do not yet have the longitudinal data to know the actual outcomes. Moreover, we do not know how these consequences are or could be mediated by other intervening factors.

Much more explanatory work remains to be done to test the propositions pertaining to gender and interdisciplinarity that have arisen from this exploratory analysis. Table 2 provides an outline of the empirical evidence and the methodological approaches that future studies might employ to accomplish this task.

In addition to the analyses suggested in Table 2, given that tentative findings here seem to imply a possible interaction between gender and career stage, future work should also consider lifecourse analyses of changes in preferences as well as consequences of male and female students or early career scientists just embarking on interdisciplinary research careers. Using survey, interview, and archival methods, individuals at different career stages should be analyzed to determine their current and past intellectual motivations and research priorities; their ideal versus real "work" conditions; and, the impact of accomplishments, obstacles, promotions, recognitions, and personal life changes on their research portfolio. All future work should be designed to control

Table 2
Methodological approaches for future studies on the gendering of interdisciplinary science

Mechanism of interdisciplinary science	Proposed relationship between gender and mechanism of interdisciplinary science	Suggested empirical evidence and methodological approaches for future explanatory studies
Cross-fertilization	As compared to male scientists, female scientists are more likely to want to adapt tools, concepts, data, methods, or results from different fields and/or disciplines	Analyses of male and female brain activity to test for differences in structures and patterns of cognition and information processing Citation and content analyses of a random sample of male and female authored publications to examine frequency with which the two sexes cite research or scholarship from disciplines outside their own; functional distance between their home disciplines and others they cite; and, degree to which the concepts, theories, methods, and/or results from the different disciplines cited are integrated and synthesized, and cited by others
Team-collaboration	As compared to male scientists, female scientists are more likely to want to collaborate in teams or networks that seek to exchange and/or create new tools, concepts, data, methods, or results across different fields and/or disciplines	Co-author analyses of a random sample of publications to examine frequency with which the two sexes co-publish and co-publish with collaborators from disciplines outside their own and functional distance between the co-author disciplines; and, degree to which the concepts, theories, methods, and/or results from the different disciplines are integrated and synthesized Network analyses of male and female collaboration patterns in a random sample of interdisciplinary research programs or projects to compare numbers, types, and outcomes of collaborations between the sexes
Field-creation	Female scientists are more likely than male scientists to want to engage research in domains that sit at the intersection of or the edges of multiple fields and/or disciplines	Cross-sectional analyses of participant structure of interdisciplinary specialty panels, research workshops special sessions, and/or journals emerging within and between larger professional conferences and associations to test for gender as an indicator or predictor of attendance and contribution. Such an analysis could be expanded by adding a time-series cross-sectional analysis of participant structure at two different stages of field development (1: nascent and 2: mature)
Problem-orientation	Female scientists are more likely than male scientists to want to engage topics that not only draw on multiple fields and/or disciplines but also serve multiple stakeholders and broader missions outside of academe	Survey and statistical analyses of a random sample of male and female researchers to examine relationship between gender and motivations, directions, expectations, and applications for research Content and statistical analyses of a random sample of research proposals submitted to grant competitions in problem-oriented domains to examine relationship between gender and proposal submission rates, proposal questions and applications, and proposal attention to broader impacts criteria Cross-sectional analyses of participant structure of interdisciplinary specialty panels, research workshops special sessions, and/or journals emerging within and between larger professional conferences and associations that have an explicit extra-academic mission-driven "problem-orientation" to test for gender as an indicator or predictor of attendance and contribution

for gender as well as other possible intervening explanatory factors.

This work comes at a critical time. Amid fears of a shrinking U.S. scientific workforce and a dulling competitive edge, the expansion of interdisciplinary programs as well as gender and minority participation have become part and parcel of the social restructuring of the contemporary scientific enterprise. Gender gaps in science are complex issues and a justifiable concern for reasons of social equity and for assurance of a diverse and skilled workforce in science. Thus, making better use of the talent of female scientists has been a prominent policy objective for at least a quarter of a century. As the limited data here may suggest, it does seem that interdisciplinarity, in addition to standing on its own as a policy goal, could serve as a strong entry point into scientific studies for women. If funding agencies, university leaders, and individual scholars plan to increase their investment in interdisciplinarity, such initiatives should be accompanied by strategies that facilitate the preferences and mitigate the consequences of scientists who choose this path while on the tenure track.

An empirical understanding of whether and how interdisciplinary practices and domains are chosen (or not) by (or for) women is an essential but to date neglected part of any discussion about the transformation of higher education and science. It could be that women are well positioned to make major advances in interdisciplinary research, they may like to integrate across fields and approaches, work well in teams, and be committed to connecting their research with societal concerns. At the same time, using interdisciplinarity to attract women, as well as other underrepresented minority groups into science, is only practical and ethical if it leads to stable and secure pathways through scientific and academic careers.

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