Views on Female Under-Representation in Physics: Retraining Women or Reinventing Physics?

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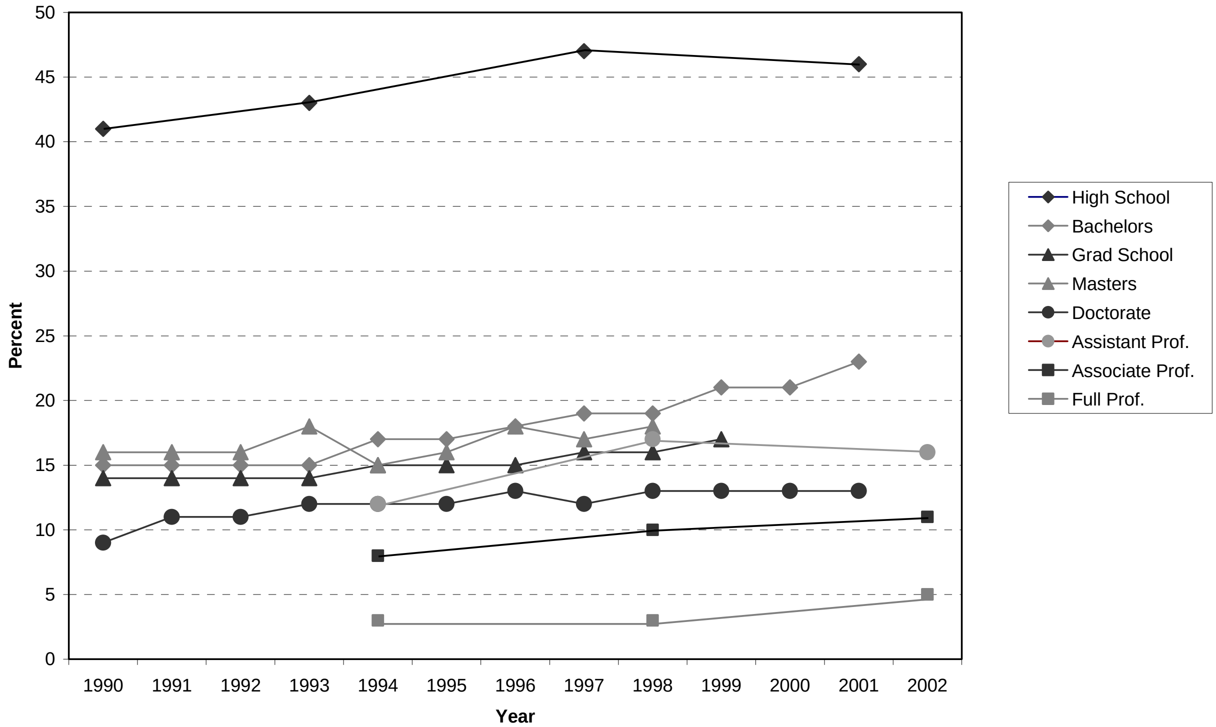
Introduction

Female under-representation in science has been a topic of discussion and research within the science education community for several decades. In particular, physics is the least successful of all the sciences in attracting and retaining females within the field. Figure 1 shows the drop in percentage of women studying physics in the United States with each step up the academic ladder. More than 40% of high school physics students in 1993 were girls, but women earned less than 20% of bachelor's degrees in physics five years later (Ivie, and Stowe, 2000).

Figure 1. Percentage females at various educational levels in physics by year.



Source: National Science Foundation (2002); Ivie, Stowe, and Nies (2002); Mulvey and Nicholson (2000)

The largest percentage drop of females studying physics occurs between high school and university. This is problematic because most female physicists are attracted to physics and decide to study it in high school, according to the International Study of Women in Physics (Ivie, Cuzjko, and Stowe, 2001). Although high school may be the most important time to attract females, it is in fact the time when most females in the U.S. begin to actively opt out. Even though half the students taking one year of physics in high school are female, they are significantly less likely than males to take a second or Advanced Placement (AP) physics course, at least in schools where they are offered (National Assessment of Educational Progress, 2000). In addition, one could argue that the reason for females taking even one course in physics is probably not because they are interested in physics but more likely is due to the fact that they want to prepare themselves for college physics and make themselves more eligible for admission to the college of their choice or scholarship opportunities. In fact, studies have found that female interest in the physical sciences wanes before they get to the high school physics stage (Baker and Leary, 1995; Dawson, 2000; Jones et al., 2000; Weinburgh, 1995). Furthermore, the fact that females opt out of higher level physics in high school may simply be the result of the fact that this is their earliest opportunity to get out without any repercussions to any future college plans. Had they been given the choice in primary school, they may have opted out then too. Research has shown that even at the primary school level, females are less interested in the physical sciences than other branches of science (Baker and Leary, 1995; Dawson, 2000; Jones, Howe, and Rua, 2000; Weinburgh, 1995). Dawson (2000) writes

> …it has consistently been found that boys' interest in physical science topics is greater than girls…These findings are important in that the level of interest is likely to be a major factor in the documented reluctance of many girls to proceed with physical sciences, especially physics, when options are provided. (p. 559).

There are two concerns that are central; first, that female disinterest begins at such early stages of schooling and second, that physics in high school (even when taught by a teacher with physics training) is not making a sufficient appeal to reverse any previously-established lack of interest. These concerns are central to the problem of under-representation of females in physics.

Another consideration is to ask why it is important that female representation in physics be comparable to male representation or even why we should want more females to be interested in physics in the first place. The rationale is that heterogeneity rather than homogeneity will lead to progress in the field by introducing new perspectives. Kenway and Gough (1998) observe that the intellectual potential of females is an untapped source for furthering scientific knowledge. Science will only suffer if there are factors that impede the participation of any particular group. By including a larger cross-section of the population within the study of physics, it is reasonable to expect that public interest in general towards physics will increase as well, especially in the case of females since they make up slightly more than half the population. In addition, for those women who want to study physics, a clear path should be available to them, which is currently not the case, given the social barriers they must hurdle in order to reach even the lower echelons of the scientific hierarchy. Given this motivation, science education researchers are trying to discover the reasons why females are scarce in physics so that they can implement changes to the system that might improve the situation. McMahon and Patton (1997) assert that if we understood the obstacles preventing girls from enjoying and succeeding in science the situation might be easily remedied.

In this paper, three viewpoints on the reasons for female disinterest in the physical sciences commonly held by physicists, science education researchers, and the broader community will be examined and compared from the literature. Their viewpoints are important because they have the potential to positively or negatively influence the teaching and communicating of physics to females and hence influence female interest and learning. The three viewpoints ascribe a different root cause to the problem and, hence, offer different solutions. Although some of the views seem old-fashioned, it is argued that they are still commonly held, although masked by more contemporary (and politically correct) views. In some ways this is more detrimental – the wolf in sheep’s clothing – since it provides the illusion of security when in actuality, the viewpoints, the treatment, and the disguised network are as threatening a social barrier as ever. Perhaps this is why there has not been significant change at the higher levels of physics.

Why Are Females Under-Represented in Physics?

The viewpoints outlined in the following sections are not mutually exclusive. They interact and influence one another and are usually held simultaneously. However, the weight given to each viewpoint by academicians usually differs; causality for female under-representation is attributed more to one viewpoint than the others. This weighting also dictates the solutions that the person is willing to offer up and, more importantly, the level to which they are willing to implement solutions themselves. The importance of this dialectic was famously emphasized in the recent comments of the President of Harvard University, Larry Summers, and the subsequent aftermath, when aspects of this issue came to the forefront of public attention. (Summers, 2005)

Inherent Differences

The *inherent differences* viewpoint is similar to the 'nature' side of the age-old 'nature vs. nurture' debate. It suggests that inherent differences between males and females lead them to have different interests. In other words, females are less inclined towards physics than males due to some natural tendency. Inherent differences in males and females are transmitted through genes and those genetic differences result in males and females responding differently to the same external conditions, for example, enjoying physics and opting to study it. To better understand this viewpoint, it is important to understand the arguments for genetic links to human behavior.

Sociobiologists, those interested in studying the biological basis of animal behavior, assert that humans are born with a number of inherited behavior patterns, such as those associated with sex, that are generally unaltered by the environment because they are evolutionary adaptations through natural selection (Lorenzen, 2001). Hence, sociobiology may describe ‘instinctive’ elements in male and female behavioral dispositions. For example,

> boys’ competitiveness and dominance strivings are seen as preparation for adult male competition over mates, whereas girls’ greater social responsiveness and cooperativeness with other girls can be seen as preparation for participation in the kin-based social groups of females in which most rearing of the young ones occurs…(Maccoby, 2000, p. 403).

In other words, for the purposes of survival and continuation, males have evolved a naturally competitive and aggressive side whereas females have developed a cooperative side. This is one example but there are many other behaviors associated with the sexes that sociobiologists would argue are genetically transmitted. Perhaps humans can evolve out of these behavioral predispositions but evolution acts on a time scale much greater than a century, roughly the length of time that Western society has been giving women new opportunities outside the home and in scientific fields. Recall that it was only in 1918 that some women (over 21) were given the right to vote in federal elections in Canada and in 1920 in the US.

The physicist or science educator who assigns weight to the *inherent differences* argument believes that, similar to the sociobiologist, females have genetic influences that lead them to being disinterested in physics. Often, they believe that females have a natural tendency to be more concerned with ‘people science’. This would be their explanation for why there has been consistent evidence across the world for girls being more interested in biology topics and boys being more interested in physical science topics. As Lie and Bryhni noted, “…girls’ interests are characterized by a close connection of science to the human being, to society, and to ethic and aesthetic aspects. Boys more than girls are particularly interested in the technical aspects of science.” (Lie and Bryhni, 1983, p. 209). One social scientist commented, “ ‘Wherever you go, you will find females far less likely than males to see what is so fascinating about ohms, carburetors, or quarks’ ” (Holden, 2000, p. 380).

A careful examination of the literature shows that the *inherent differences* viewpoint clearly exists, although its prevalence is normally difficult to ascertain because of the recent political incorrectness of viewing behavioral differences in the sexes as being genetically directed. Notwithstanding such pressures, the President of Harvard University, Larry Summers, placed himself in this camp:

> …in the special case of science and engineering, there are issues of intrinsic aptitude, and particularly of the variability of aptitude, and those considerations are reinforced by what are in fact lesser factors involving socialization and continuing discrimination. (Summers, 2005)

Sociobiologists have been criticized for propagating 'biological determinism' which sometimes upholds racist and sexist practices over egalitarian ones (Lorenzen, 2001). The same criticism applies to the physicists and science education researchers who believe in the *inherent differences* viewpoint. They often offer no solution to the problem of under-representation of females in physics because they argue that a solution is unnecessary and irrelevant since females should not be forced to participate if they are not interested in the first place. " 'If you insist on using [parity] as your measure of social justice, it means you will have to keep many men and women out of the work they like best and push them into work they don't like' " (Holden, 2000, p. 380). Thus many of the holders of this viewpoint feel no change is necessary or that they have no power to change the natural interests of females. Urry (2003) writes, "…he [a physics department head] is convinced that women simply don't like physics and there is nothing he can do to change their minds…Another physicist nods his head in agreement, convinced that women are simply more interested in other fields, like biology and chemistry." (p. 12). One female social scientist researching the issue agrees, saying that reinventing the curriculum will not make her more interested in learning how her dishwasher works (Holden, 2000). Another discouraging aspect of this viewpoint is that its proponents do not seem to be confined to a particular (read: older) generation but are found amongst researchers of all ages.

Although many of the proponents of the *inherent differences* viewpoint would argue for no intervention, there are physicists and science education researchers who hold the viewpoint but feel intervention is necessary for other reasons. They do not give the *inherent differences* viewpoint as much weight as some of the other viewpoints and subsequently have significantly different perspectives than those who give the most weight to inherent differences.

Socialized Differences

Just as the *inherent differences* viewpoint is comparable to the 'nature' side of the 'nature vs. nurture' debate, the *socialized differences* viewpoint is comparable to the latter. The *socialized differences* viewpoint suggests that males and females are socialized to have different interests. In this case, females are less inclined towards physics than males due to values and behavioral dispositions that are transmitted by society, family, education, and other influences surrounding them. Early in the study of socialized behavior, researchers believed that these patterns may be transmitted through direct socialization where children adopt actions that are typical or valued for their own sex when sex-appropriate actions are positively reinforced by parents, teachers, or other children and when actions associated with the opposite sex are negatively reinforced (Maccoby, 2000). Later it was also shown that socialized behaviors may be transmitted through indirect socialization by children who choose to imitate gender-appropriate behavior after observing those behaviors being positively reinforced when others of their own sex displayed them (Maccoby, 2000).

Behaviorism, a contrasting school of thought to sociobiology, is important to consider when trying to understand the *socialized differences* viewpoint. Behaviorists believe that animal behavior is mostly dictated by environmental trial-and-error conditioning (Lorenzen, 2001). Thus, male and female behaviors are governed by the environmental influences surrounding them. For example, consider the following way in which children are trained to play in a gender-acceptable way. Girls are given dolls to play with, they see commercials with other girls playing with dolls, and they are discouraged to play with mechanical toys or use their toys in a more aggressive masculine style (e.g. playing war). This type of social training applies to most behavioral differences observed between the genders. Most studies find that children begin to label themselves (and others) as males and females and associate traits with genders around the age of two (Golombok and Fivush, 1994). So adoption of gendered behaviors starts at a very young age and is reinforced throughout the years of schooling when children interact.

The physicist or science educator who gives weight to the *socialized differences* viewpoint believes that females are either trained directly to feel that the physical sciences are not for them or are trained toward behaviors that indirectly lead them away from interest in studying physics. This training, especially in the case of the physical sciences, occurs through the influence of two major social arenas: the education system (teachers, professors, peers, curriculum, etc.) and everything else outside the education system (such as parents, television, or society).

One example of direct training from the non-educational arena is the social stereotype which deters females from the physical sciences by portraying the physical scientist as male. Kahle and Meece (1994) found that both male and female students rated physical science as a ‘masculine’ subject. One physicist writes, “the popular image of success, of competence, of science, is male. We are almost all prejudiced in the sense that we have absorbed the gender and race stereotypes that prevail in our society” (Urry, 2003, p. 12). In addition, the standard-bearers, those characters that are portrayed as the super-human examples of what a physicist is and should be, often held views that greatly underestimated female capabilities. For example, Einstein once wrote to an admirer, "where you females are concerned, your production center is not in the brain," and elsewhere, "It is conceivable that Nature may have created a sex without brain!" (Wertheim, 1995, p. 187-188). Although such stark stereotypes are no longer acceptable, stereotypes undermining the capabilities and interests of females in physics still permeate society and the educational system. There has been some effort through the educational sector to encourage girls by showing them more female role-models in the sciences, but these effort have not affected the numbers of females entering physics-related professions. Therefore, more sophisticated ways of attracting the interest of females need to be developed. It is important to note that the 'female role-model' argument has yet to be proven. It seems more likely, in fact, that encouragement from a physicist or physics teacher of *either* sex who is balanced in their views and treatment will set the best example.

An example of indirect training is the greater social emphasis on females to develop nurturing characteristics. So 'people science' becomes more interesting than the physical sciences. Like the *inherent differences* supporters, socialized difference supporters do not deny that females are found to be more interested in 'people science' or science that has direct social relevance. However, they believe that those interests are trained rather than passed on genetically, and that the teaching and learning practices of physics can be modified to neutralize these socialized differences. The *socialized differences* proponents are far more optimistic in that they feel there are, in principle, ways to get females interested by utilizing or countering their socialization, at least in the education system arena, whereas the *inherent differences* proponents often feel that there are no ways to counter genetic predisposition. Thus, the *socialized differences* proponents can be recognized by their desire to intercede to improve female interest. Dawson (2000), a science education researcher, calls for intervention after studying upper primary boys' and girls' interests: "…boys' interest in physical science items exceeds that of girls, and the difference is large enough to continue to argue for intervention." (p. 566).

The existence of the *socialized differences* viewpoint amongst physicists and science education researchers is evident when the literature is examined. One physics educator writes that "while anatomical sex is universal and unchangeable, gender, which refers to all the duties, rights and behaviors a culture considers appropriate for males and females, is a social invention…" (Parker, 2002, p. 13). Examples of the ways in which the socialization viewpoint emerges in the literature include:

- gender stereotypes (Barman, 1997; Steele, James and Barnett, 2002; Yoder and Schleicher, 1996)
- the effect of less 'prior experience' in physics for females (Chambers and Andre, 1996; Jones et al., 2000)
- lack of equitable assessment (Bell, 2001; Hazel, Logan, and Gallagher, 1997)
- lack of broader world/human perspectives in physics teaching and learning (Jones et al., 2000; Stadler, Duit, and Benke, 2000)
- lack of encouragement of females (Alexakos and Antoine, 2003; Jones and Wheatley, 1990; Taber, 1992)
- lack of female self-confidence in studying physics (Gillibrand, Robinson, Brawn, and Osborn, 1999)
- lack of relevance/interest of physics to females (Alexakos and Antoine, 2003; Jones et al., 2000; Reid & Skryabina, 2003; Williams, Stanisstreet, Spall, Boyes, and Dickson, 2003)

In particular, the fact that females rapidly determine physics to be irrelevant, but males do not, indicates that physics may be given more relevance through social training for males because they are more consistently encouraged toward and exposed to technical ideas (mechanical toys, tinkering, sports that employ physical concepts, etc.). Of course, physics is equally relevant in the lives of males and females. Lisa Meitner, a great 20th century female physicist, was initially captivated by physics as a child when she noticed a rainbow in a puddle with a layer of oil and was told what caused it. Similarly, Jones et al. (2000) found that female sixth graders were significantly more interested than males in rainbows and what they are. If physics classes use contexts that are more appealing to females instead of only those that are appealing to males, which is traditionally the case(i.e. cars, rockets, canons), then perhaps, like Lisa Meitner, girls will become more interested.

Another piece of evidence supporting the *socialized differences* viewpoint is the diminishing self-confidence of females as they progress to higher levels of physics education despite the fact that they perform equally well (Haussler & Hoffmann, 2002; Debacker & Nelson, 2000). This might be because women are not encouraged in physics, but also because they are socialized to question their abilities far more than men. Many studies have found that females tend to attribute their success to hard work whereas males attribute their success to ability (DeBacker and Nelson, 2000; Golombok and Fivush, 1994). The diminishing self-confidence of females as they continue through the educational stages definitely contributes to their early departure from the field. Lips (2004) found that females in university might be actively closing off possibilities for science careers that they had not dismissed in high school.

The physicists and science education researchers that give weight to the *socialized differences* viewpoint have many suggestions for improving female interest and participation.

For them, there are two areas to contend with: social barriers that prevent females from studying physics and socialization that influences females away from physics. Since society and socialization cannot be changed by the science education community alone, the way to address the issue is to promote teaching methodologies that counter the barriers and influences. For example, one barrier that females may face is lack of encouragement. This can easily be countered by teachers and parents taking it upon themselves to encourage girls. Other solutions suggested from the *socialized differences* perspective include using female friendly contexts and a broader world perspective in physics teaching (Jones et al., 2000; Stadler, 2000), more equitable assessment practices (Bell, 2001; Hazel et al., 1997), employing well designed cooperative learning strategies (Pearson, 1992; Rosser, 1993), and having single-sex classrooms (which have been found to increase female confidence and persistence) (Gillibrand et al, 1999) amongst others.

Many physicist and physics educators agree that a combination of inherent and socialized influences affect female interest in physics. Some give more weight to inherent differences as being the source while others feel that it is socialization that is the dominant factor. Conflict between the two viewpoints arises because one viewpoint is less open to strategies leading to change while the other is forthcoming with solutions, at least for the educational sector. However, both viewpoints have a major limitation in that they focus on what is different about females (either in their biology or socialization) that leads them away from physics rather than asking what is wrong with the physics community in that it blocks the participation of diverse and able minds. In other words, the problem of girls and physics may have more to do with the nature of the field of physics than with the nature of girls (Baker, 2002). This growing stance is the foundation of the third viewpoint.

Culture Bias of Physics

The last viewpoint presented in this paper is that of culture bias. The *culture bias* viewpoint is different from the *inherent* and *socialized differences* viewpoints since it focuses on problems in the community of physics that causes females to lose interest or opt out rather than the differences between sexes that cause their interest in physics to be different. Ideally, physics "should welcome all comers and adapt to their visions rather than vice versa." (Lederman, 2003, p. 605). The *culture bias* viewpoint suggests that physics is not a gender neutral subject but rather is tightly bound by masculine tendencies and preferences. Females (and males) that lack such tendencies might feel disinclined to the subject and/or alienated within the field. The culture bias of physics is transmitted in three ways: pedagogically, by transmitting a narrow message about what it means to do physics rather than allowing for individuals to define it for themselves; academically, by defining what is acceptable physics research and what is not, primarily through various peer review processes; and socially, through the structure, interactions, and treatment in the field.

An underlying perspective for the *culture bias* viewpoint is that physics has been primarily a male endeavor for many centuries, while females have actively participated for only the past century or two. Thus, physics is not "neutral, apolitical, gender-free knowledge which just happens to have a masculine 'image'…[it] is strongly enmeshed with masculinity" (Gilbert & Calvert, 2003, p. 875). Especially since scientific theories and practices are defined by individuals living in a particular society and, as such, are neither universal nor unquestionable. Kuhn, the renowned philosopher of science whose training was in physics, would agree, arguing that the typical scientist is not an objective free thinker but rather seeks solutions to problems within a certain paradigm that is just one possible conceptual worldview (Kuhn, 1996).

The culture bias of physics is more pronounced than that of the other sciences but many science education researchers believe culture bias exists for the sciences in general. Lederman (2003) sums it up tenaciously that

> Science is hegemonic and androcentric, two characteristics that proceed from the fact that practitioners of science as we know it have traditionally been white, male, and Western. It is they who define the rules, methods, instrumentation, descriptions of results, and criteria for knowledge production. It is they who define what counts as science, both theoretically and in practice. It is they who are the gatekeepers for access to, and definers of, a life in science. (p. 604).

Furthermore, as Barton emphasizes, this culture bias works itself into the language of scientific discourse: "in the case of science ... the language of science has promoted a worldview that has normalized masculine, white, and middle- and upper-class values. (Barton, 1997, p. 159).

Among the sciences, physics is the most extreme in the male hegemony of its culture. In 1998 in the US, 46% of the bachelor's degrees in chemistry were earned by females and 55% in biology, whereas in physics it was a mere 19%. Women even earned 47% of the bachelor's degrees in mathematics (National Science Foundation [NSF], 2002). From this fact alone, it is clear that, in North America at least, the culture of physics is harder for females to break into than that of the other sciences. Perhaps this is because historically, though females were not the forerunners in the other sciences either, they were at least contributing. For example, females have been involved in the biological/medical sciences through formal and informal health science jobs for a long time. This bridge into the biological sciences in turn led to their participation in chemistry due to the close connection between modern biology and chemistry. But female involvement in these fields did not help them gain quick access to the field of physics. Especially since biology and chemistry have a link to 'people science' whereas physics has a closer link to mathematics and engineering. Engineering is also lacking female representation at a level close to that of physics (NSF, 2002).

The physicist or science educator who assigns weight to the *culture bias* viewpoint believes that females face active and passive discrimination and have little or no role in defining the field. Thus, there is an intrinsic bias in the field favoring males. This bias is transmitted when physics is taught and studied at all educational levels and through all other interactions within the field.

An example of the pedagogical transmission of culture bias is that introductory physics is taught in a way that is often more unrealistic and abstract than necessary. Students must learn to ignore air resistance, friction, and objects with structure when necessary, in contradiction with their daily experiences. The idea that physics is attempting to describe the laws by which the natural world operates is not clear to students because they do not understand that the abstractions made to simplify the framework can be easily generalized to include more complicated elements like air resistance and friction. Stadler et al (2000) write, "they [girls] try to understand the relations of the system of physics to the world as a whole…Boys, in contrast, tend to accept physics and technology as valuable in themselves. They appear to be more interested in the *internal* coherence of physics whereas the girls tend to look for an *external* coherence…" (p. 420). Unfortunately, physics as a field often focuses on the internal coherence of a theory more than on its application in the real-world. There are real-world sub-fields of physics like biophysics, geophysics, and atmospheric physics but these areas are frequently ignored or minimized in introductory physics. If they are discussed at all, it is usually as peripheral examples to support theory rather than the basis for introducing and wanting to know the theory. They are also much less glorified within physics culture as well as popular culture. For example, every layperson can identify Albert Einstein but few can identify J. Tuzo Wilson (highly influential pioneer of plate tectonics). Thus, one of the pedagogical concerns of *culture* *bias* supporters is that traditional teaching of physics perpetuates elitist elements and does not expose students to all the ways in which physics can be pursued in the world.

The social transmission of culture bias through interactions within the field acutely affects the retention of females also known as 'the leaky pipeline' issue. In figure 1, note that a higher percentage of females leave the field with a master's degree than the percentage entering graduate school or finishing with doctoral degrees. This is because "in physics departments around the country, women are feeling ill at ease, out of place, not at home." (Urry, 2003). It is especially deterring for females to face discriminatory actions because research shows that it occurs more frequently for them, is a more negative experience for females than for males (Branscombe, 1998) and that they are less likely to take action against it (Foster, Arnt, and Honkola, 2004). The social culture bias is also noticeable at the lower educational levels in physics classes with the intimidation of girls by boys during lessons (Jones and Mahoney, 1989). Additionally, "in typical classroom activities, boys often dominate and girls receive less experience" (Chambers and Andre, 1997, p. 118). However, when isolated from boys, girls in single-sex physics classes gained more confidence in physics than their co-educational counterparts, improved achievement, and subsequently the likelihood of their studying physics at higher levels was increased (Gillibrand et al, 1999).

The culture bias prevalent in physics needs to be addressed with action-oriented solutions that will help change the system from within. It is physicists, physics educators, and physics education researchers that have to act in order to diversify and create an equitable field of physics. The *culture bias* supporters, like the *socialized differences* supporters, also call for pedagogical change. However, the *socialized difference* perspective calls for pedagogical change at early stages to nurture female interest and it does not require that the field of physics be changed itself. But changing female training in physics so that they fit in to the old mold is not the solution. It is an attempt to remold females so that they satisfy the requirements of the community instead of remolding the requirements so that everyone can fit in. On a long enough time scale the solutions offered by the *socialized differences* camp may help improve the initial number of females enrolling but will not help retain them because it will not change the structure or social bias within the culture at higher levels. Physicists and science education researchers that give weight to the *culture bias* viewpoint suggest that more comprehensive solutions are needed in order to address both the pedagogical and social issues. To them, revamping physics curriculum and culture to include broad and diverse worldviews, to make it more accessible to everyone, to change the social climate towards collaboration instead of competition seem to be the first steps along this road. Barton summarizes this pointedly:

> To fully recognize the socially constructed nature of science means, in part, to think about the gendered, raced and classed nature of knowledge, and to make problematic the political and academic stance that science, as a generalizable subject, with its specific discourse and epistemological traditions, represents all of human experience. (Barton, 1997, p. 161).

However, resistance of physics departments and physicists to change is a formidable barrier, especially since the change must come primarily from within the field. The first step is then to increase awareness within physics departments of these issues and begin sensitizing all current members of the community to the idea of openness to different worldviews and approaches to physics.

Discerning the Viewpoints: An Example

It was previously suggested that the viewpoint a person considers the largest contribution to gender differences tends to dictate the solutions the person is willing to propose and/or act on. A single person can believe that all the viewpoints contribute to the dearth of females but the viewpoint that weighs the most will dictate the primary solution the person thinks is necessary.

To illustrate this position, an example will be drawn from a series of more than a dozen interviews conducted by the first author. Interviewees were professors who taught first year physics courses in a group of schools representing a broad spectrum of university sizes and demographics in the American Northeast. The following example provides an illustration of, although on its own not a sufficient proof of, the authors' position and, further, is typical of the interviews conducted.

The interview was with a physicist, call him Professor X, at a large well-known U.S. university. Professor X teaches introductory physics nearly every year to undergraduates and is fairly influential in his research and outreach (he has appeared in television science documentaries). The purpose of the interview was to uncover Professor X's beliefs about why there are so few females in physics. During the course of the interview, all three of the viewpoints mentioned in this paper emerged, although some more than others.

The interview began with Professor X recalling the number of graduate students he had supervised throughout the years and his recollections of them. Immediately the dearth of female students became apparent and it was asked whether a greater representation of females in physics is needed. Professor X did *not* feel that females need to be represented in the field. He did, however, feel that they need to receive equal treatment in terms of opportunity to pursue the field – "You should give them the opportunity. That's equality. But you shouldn't force them." Already at this stage in the interview, Professor X is alluding to his belief that in order to have more women in the field, there would have to be some element of "force" against some internal will of their own. Later, he repeats this belief but clarifying that the internal will is instinctual – "Equality is great in terms of giving opportunity but you shouldn't force people into doing things that go against their instinct."

Continuing in line with the professor's thoughts, the question was raised whether females have equal opportunity to enter the field. Subsequently, the viewpoints began to emerge with the more politically correct ones emerging first. They emerged in the following order:

- Direct socialization through the societal arena
- Direct social culture bias within physics departments to female faculty
- Inherent differences in interest of women

The last viewpoint was frequently repeated and seemed to be the crux of the matter for Pf. X. Table 1 lists some of the statements made that could be clearly categorized under each viewpoint. The professor did not mention indirect socialization or socialization through the educational arena. He even goes so far as to say that "There is no bias in the physics department against them [female students]," although he did perceive a bias within the field towards female faculty. He only conceived of socialization through direct bias or discrimination rather than the training of females into certain characteristics. Those characteristics he considered to be a more inherent part of female nature like the lack of a "killer instinct". In the course of the interview, he even describes an experiment (which he believed to have actually occurred sometime in the past half-century) in which males were made into women anatomically and were socialized as females, but even then they behaved as males:

> They made them females and they raised them as if they were females. So they showed them dolls and doing all the things men are not supposed to do. These 'women' started to play with trains, not because they were given trains. They had a genuine interest and some of them who later found out that they had had this sex transformation or whatever you call it, were not only extremely upset and extraordinarily angry, but they changed back.

Clearly, Pf. X believes that socialization has less to do with female interest in physics than innate predisposition. As for culture bias, it only affects females in that there is subtle discrimination directed towards them from the "invisible network of men". He finds nothing wrong with the field itself or the way it operates; even the “killer instinct” is appropriate since it drives scientific growth through competition.

For Pf. X, the *inherent differences* perspective weighs the heaviest and thus he feels that trying to increase the representation of females studying physics would amount to forcing some of them to study a subject “that goes against their instinct”. In addition, he implies that females may not have the tendencies needed to succeed in physics like the “killer instinct”. He does not see that needing a characteristic like the “killer instinct” might be a flaw in the way the community functions, though he concedes that females are discriminated against at higher levels.

Table 1. Extraction of three viewpoints from an interview with a physicist

Views of a Physicist on Female Under-Representation		
Inherent Differences	Socialized Differences	Culture Bias
"That [studying physics] is not an interest. They [female students] are free, they are absolutely free to choose. There is no bias in the physics department against them …It is just not their interest….What is wrong with certain races and certain sexes having different preferences. There is nothing wrong with that."	"I think that [equality] is only 'face' equality in this country…there is a bias against women still all around us."	"I think the bias [within physics depts] is very subtle. If there is a meeting and a woman speaks, in general, people listen but don't take it so seriously as when a man speaks."
"Long experiments have been done…If you raised the male in an absolute 100% female environment, then the person would behave and act like a female – it's not true…it's absolutely not true. There is really intrinsic difference between a woman and a man. That includes their interest… [The experiment] was sort of God's word that it only had environmental influences is absolutely not true. There is a basic difference."	"In this country, people are crazy about about basketball and baseball. I can assure you that baseball is not popular in Russia. It's a cultural thing. And so it's by no means a surprise that also within the infrastructure of our society that…certain people with certain colours of their skin prefer to do different things. And people with different sex prefer different things."	"When there is a committee formed, more often what you see [is] a higher percentage of men on that committee than you would expect on the basis of how many women are in that department.
"Equality [for females] is great in terms of giving opportunity but you shouldn't force people into doing things that go against their instinct."		"This sort of invisible network of men who run this place and women play a very minor role. It's a subtle way. But it's in many ways that women are being discriminated against."
"You must understand, to be successful in science not only do you have to be academically good, but you also have to have a killer instinct…In this case, you have to be obsessed, you have to be phonetic, and you have to be willing to topple, eliminate, annihilate the competition by always writing proposals which are better…Some people [females] don't have that killing instinct…If you don't have it, you're just not going to make it."		

However, he feels that doing something to change the situation, like hiring more women to change the environment for women, would cause science to suffer –

> You pay a price for everything…Suppose if you have to decide on a faculty position and there are ten people at the top…And there is one woman. She is number nine. Would you hire her or would you go for number one who is a man, number two who is a man, number three who is a man, number four who is a man, number five who is a man and so

> on. If you go for number nine, you put water in your wine. So yes, you help the cause [of under-representation of females]…but you do harm [to the field], too.

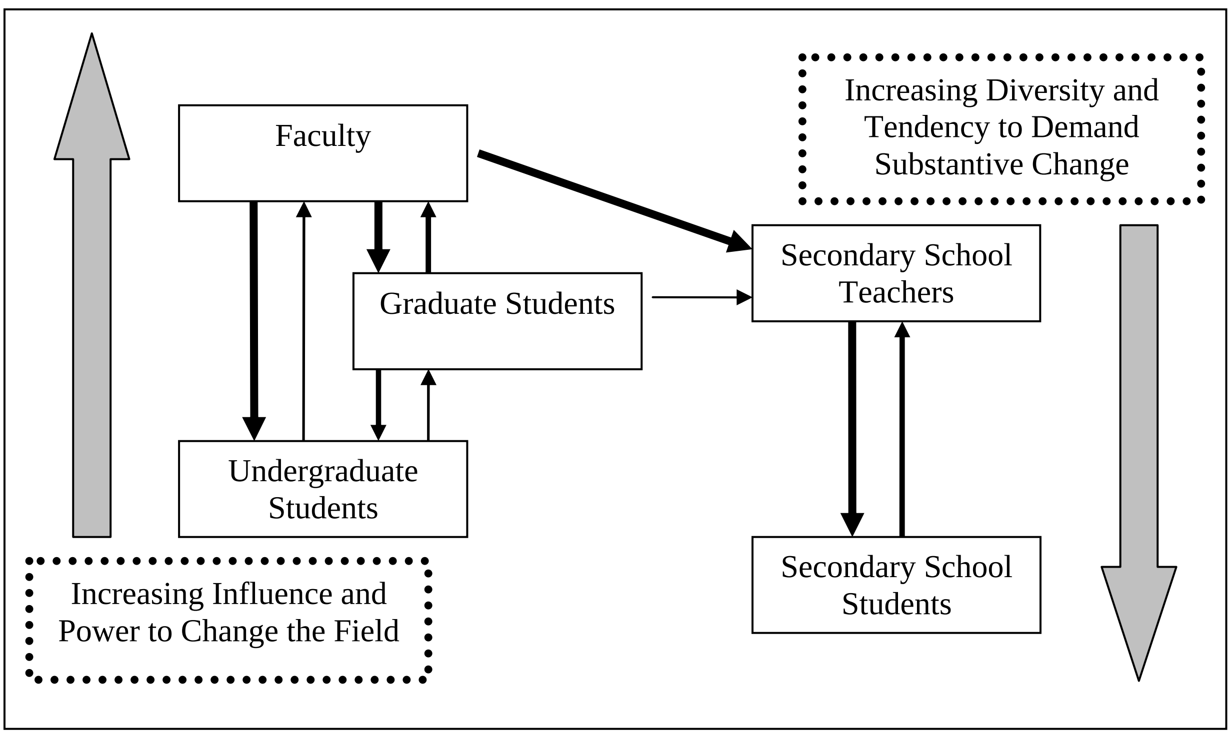
Unfortunately, he does not feel that females might have a new perspective to bring to the field that would advance it in significant ways. More significantly, he ignores the probability that his ‘one-to-ten’ ranking already incorporates the culture bias of the community. Although Professor X holds each of the three viewpoints, the *inherent differences* viewpoint is the strongest and hence dictates the solution; in this case, to make no significant change at all.

Implications

“You can’t be rational if you pretend that everything you do is rational; if you don’t examine and come to terms with what you feel, your feelings will interfere anyway, but in a hidden and uncontrollable way.” (Wallsgrove, 1980). The key idea outlined in this paper is that the beliefs held by members of the physics community, primarily faculty members, are important in determining who participates and who does not, though often in an indirect manner. Their beliefs influence the type of interventions – academic, educational, and social – that are implemented to encourage diversity. These interventions will subsequently influence the population and practices of future researchers in the field and future secondary school teachers, which in turn will influence teachers and students at other levels.

This paper has discussed in some detail the beliefs of this most powerful and influential group. Though they have the best opportunity to implement change in the community, it is logical that they will tend to be less interested in implementing such changes because they are precisely the group who succeed via (or despite) the status quo. Thus, scientists and science educators who are interested in fostering change should seek to understand the beliefs of the community members at each level of the academic hierarchy and to incorporate these beliefs into the interventions they develop. For example, the pool of graduate students will contain the future faculty of the field but also another group that will not proceed to a higher level, either by choice or otherwise. Thus it is to be expected that the beliefs and, hence, interventions suggested by graduate students to improve diversity in physics will be more responsive to the actual needs than changes suggested by faculty. At the very least, the interventions suggested by graduate students will partly coincide and partly complement those suggested by faculty. Similarly for all groups in the community, who have varying levels of influence and interconnections (See Figure 2). This will provide an understanding as to why females and minorities might opt out at each level and a solid basis for changing physics education and practice to make it more inclusive and incorporate the needs of diverse populations.

Figure 2. Flowchart of influences amongst subpopulations within the field, indicating relative power, diversity, and tendency to demand substantive change. The arrows connecting the various subpopulations have varying thicknesses and directions, indicating the strength and direction of influence between them.



To this end, future work in this area should include studying the beliefs of other groups in the physics community as to why women and minorities are under-represented. In particular, the authors plan to further interview professors and expand the interview process to include graduate and undergraduate physics students. It is especially valuable to determine the beliefs and values that influence the decision of the students who do, in fact, opt out of their pursuit of physics at the various levels. Of course, students will not always have a clear understanding of the reasons they leave physics, therefore, other modes of research such as those already being pursued on pedagogical and social influences need to continue.

In any event, using excerpts from these interviews, a questionnaire for eventual use in determining the prevalence of the various beliefs on a larger scale could be developed. This would be sufficiently fine-tuned to examine variation in the prevalence of the beliefs at colleges and universities of different sizes and research capabilities, at research institutes, and in the industrial sector. A final, but most important, goal would be to implement interventions and evaluate their efficacy. Such interventions might include implementing within a physics department a mentorship program where all students have a "mentor", an independent (non-supervisor or committee member) who focuses on evaluating the success of the program for that individual. This structure will automatically give more voice to students and lead to greater incorporation of relevant interventions for helping them, regardless of gender or race.

Discussion

If scientists and educators truly want to develop an inclusive, diverse community of learning and research then the issue of female under-representation in physics cannot be ignored. Though females and males may be inherently different or socialized to be different, those differences cannot dictate who participates and succeeds in physics. The two traditional viewpoints, that of *inherent* and *socialized differences*, allow physicists and researchers to avoid reforming the field itself – they can simply point their fingers at genetic predisposition or societal training. Although the *socialized difference* proponents make pedagogical reform efforts that are supported by the *culture bias* proponents, it is simply insufficient. The focus must be directed inwards, toward a fundamental change within the field itself. Researchers who hold to the *culture bias* perspective see the need for this because female under-representation in physics is far more serious than that of nearly any other science, representation is barely improving, and females continue to experience discrimination and alienation.

Increasing diversity in physics is a desirable goal in and of itself but it should be reiterated that diversity would be expected to improve the quality of research in the field. That is, historically speaking, researchers often learn a great deal from a subject by taking a new approach to the established beliefs, using a new formalism, etc. So a pool of researchers with broader modes of thinking would inevitably lead to greater understanding of frontier physics. Also, by including a more diverse group of active researchers, each with their own judgment as to the utility and desirability of various research endeavors, the community's resources (personnel and financial) would be redistributed in a way that would presumably lead to progress in our understanding of subjects that have long been overlooked and/or ignored. These improvements to the field would be on top of the fact that increased diversity would make it harder for influential traditionalists to maintain the status quo.

In many ways, the struggle for change is between a traditional style of academic pursuits and a new one. Cohen (2003) writes

> In one corner reside the standard-bearers of academic machismo: the hard-nosed male professors of math and physics…who have fought the good fight. By their side stand several equally stalwart women – the blunt-spoken, the widely published; in short, the women 'with balls'. In the other corner reside 'those people': the politically outspoken women – feminists, multiculturalists, and the like…who have dragged the campus into its current morass of soft, mushy interdisciplinarity…And by their side stand (however limply) those emasculated men who occupy the bottom rung on Blume's ladder of academic virility. (p. 10)

Although Cohen paints a *highly* stereotyped picture from the perspective of the first group, there is something to be taken from it, especially since the first group he mentions is dominant in physics. This is troubling because physicists at academic institutions are the primary agenda setters for physics and physics education at all levels. They are the main researchers in the field and they teach and train future physicists. Their curriculum is followed by science teachers in secondary school in an effort to prepare students for the physics they will have to learn in university. Thus, the teaching and learning of physics in high school and university is not an endeavor towards greater inclusivity but is a process of isolating and pre-training an elite group that will go on to further study physics. This elitist form of teaching is what alienates many females and perpetuates stereotypes. Once the other forms of culture bias in the field are added to this situation, the few females who manage to get through to the higher levels will continue to drop out of the field disproportionately.

The second group mentioned in a derogatory manner by Cohen's quotation is comparable to the newly emerging supporters of the *culture bias* perspective in the physics and science education communities. Their influence within these communities will hopefully lead to reform efforts where the two modes of academic pursuit can harmonize and all individuals will be free to participate in physics without preference to natural tendencies, socialized tendencies, gender, race, learning style or research style.

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