Graduate Student SYMPOSIUM

Selected Papers*

Vol. 12 2017-2018

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(pp. 4-14)

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***From the 2017 Rosa Bruno-Jofré Symposium in Education (RBJSE)**
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Abstract: *This literature review explores the issue of underrepresentation of women in physics by framing the topic as a journey towards equity, with many barriers along the way and which persists, yet at a slow pace. The journey perspective accounts for the long history of the issue and includes various understandings of and approaches to the issue. This review begins by introducing the status of underrepresentation of women in physics education in Canada, which is indicative of the low numbers of women in the field. In recognizing the complex dynamics of the problem of underrepresentation of women in physics, the review asks about the nature of the problem: What is the relationship between gender and science? Is equity in physics education and the field at large important? Based on the review of existing literature on the underrepresentation of women in physics, this literature review presents three arguments. The first argument is that the low number of women in physics is best explained by low participation from young women at the high school level of education. The second argument is that barriers to young women's election and continuation of physics study exist within physics education at the high school level. The third argument is that there is a need for research that aims to understand young women's experiences of barriers in physics education during high school in order to move forward on the journey toward gender equity in physics education and the field.*

Keywords: equity, physics, women, physics education, women in physics

This literature review hones in on the social, cultural, and educational aspects of women's journey towards equity in high school physics education. The term equity is used here to mean the concept of equal opportunity for young women in physics education. The terms social, cultural, and educational are used to portray the sweeping complexity of such a journey; the ability to reach gender equity is dependent on existing social, cultural, and educational dynamics. Such dynamics are reviewed in this literature review as the physics education research community's understanding of the underrepresentation of women in physics, or in analogous terminology, the understanding of our current position on the journey towards equity in high school physics education. Understanding our place on this journey towards equity provides guidance for continued progress.

Before beginning, it is important to present the current status of the underrepresentation of women in physics plainly; in nearly all countries of the world and at all levels of education, physics is failing to recruit and retain women (McCullough, 2002, Naylor, et al., 2017). In Canada, the average percentage of students who are women in Grade 12 physics is only 33% (NSERC, 2010). Women are notably underrepresented at the undergraduate level (20%), as well as the Masters level (24%) and the PhD level (19%) (McKenna, 2011). It is also important to establish a framework for thinking about the issue of underrepresentation of women in physics, which can be achieved by asking the following two questions: What is the relationship between gender and science? Is equity in physics education and the field at large important?

In her *Reflections on Gender and Science* (1985), Evelyn Fox Keller offers insightful perspectives on the nature of science and gender. One perspective offers a key distinction about the issue of underrepresentation of women in physics: the problem lies within physics education itself, not within women. That is, women's lack of progress in physics is not their own doing; it is a result of barriers and inequities existing in their lives, many in the educational setting. Another perspective of Keller's, based on personal experiences as a mathematical biophysicist, is that science has eternally been bound in ideas of masculinity. Keller suggests another pivotal perspective following from her other views, that masculine and feminine categories are not biological necessities; rather, they are created out of complex and interwoven cognitive, emotional, and social forces. To Keller, the dynamic between such forces supports the historic association of masculinity and science, and the equally historic dissociation of femininity and science. This recognition accounts for human-generated inequities and is therefore central to approaching issues of equity. While it is clear that the past and current reality for women in physics has and continues to pose challenges, a solid rationale for the importance of equity in physics is required.

Among the general population in Canada, multiple schools of thought exist on the need for equity in physics. Some suggest a need for equity among genders in physics based on fairness (Baker, 2002). Others suggest that equity among genders in physics is not a prerequisite for advances in physics and therefore is not a pertinent concern (Holden, 2000). One school of thought prioritizes progress for women and the other prioritizes progress for physics; however, the advancement of physics should not be viewed as dependent on gender if assuming a lens of equity (Hazari & Potvin, 2005). The rationale for the importance of equity in physics is two-fold since it assumes the importance of progress for both women and men in physics and for physics as a whole. First, the contributions made to the field when heterogeneity (rather than homogeneity) is assumed could result in progress through unhindered participation. Second, women who choose to study physics should have an accessible path to personal progress in terms of academic and career options.

Despite the substantiation of the importance of equity in physics, systemic barriers to gender equity exist in multiple realms, one of which realms is education. The following components of the literature review examine systematic barriers that exist at the high school level of physics education and contribute to the underrepresentation of women in physics. In doing so, the following three arguments regarding the issue of underrepresentation of women in physics are presented:

1. The low numbers of women in the physics field are best explained by the decrease of physics participation by young women at the high school level of education.
2. Barriers to young women's election and continuation of physics study exist within physics education at the high school level.
3. There is a need for research that aims to understand young women's experiences of barriers in physics education during high school.

The Critical Period

High participation rates in the physics field depend upon a strong supply of high school students who are well prepared to enter university physics programs (McKenna, 2011). The low numbers of women in the physics field can be expected to remain low if the supply of young women engaging in physics education also remains low. McCullough (2002) has documented women's representation in physics at every stage of education from high school to the doctoral level of study in the United States. She has found that, as the level of education increases, women's representation in physics decreases. This phenomenon is described by many science education researchers as the "leaky pipeline." In physics, though, McCullough describes the leak as more like a gaping hole. Similarly, in Canada, the percentages of women entering university to study physics at the Bachelor's level is a mere 20% (McKenna, 2011). Based on the low numbers of women choosing physics following high school, it can be argued that high school is a critical period for students making decisions about studying physics. When only a small number of women do elect to continue studying physics after high school, underrepresentation of women in the field is a result. According to the International Study of Women in Physics (Ivie, Cuzjko, & Stowe, 2001), most women physicists are attracted to physics and elect to study it during high school. Yet, the largest percentage drop of girls studying physics occurs immediately after high school before post-secondary education. It is of educational concern that most women choose to discontinue studying physics during high school, a critical period in education in which a strong physics interest is most likely to be sparked.

Beliefs and Barriers Inhibiting Young Women in High School Physics

Hazari and Potvin (2005) offer three viewpoints commonly held by physicists, science education researchers, and the broader community about the barriers responsible for the underrepresentation of women in physics. As these individuals broadly comprise the physics field and physics education, their views influence the high school level of physics education at which the underrepresentation of women has been discussed as particularly concerning. The viewpoints reflect different understandings of the issue, ascribe different root causes, and offer various degrees of solutions. They are *inherent differences, socialized differences,* and *the culture bias of physics.*

A person who bears the *inherent differences* perspective would assume that biology is to blame, or, in other words, that there are genetically transmitted tendencies that differ between males and females that cause them to respond differently to physics. This belief is heavily criticized in the literature for its likeness to biological determinism and the way it upholds sexist practices (Lorenzen, 2001). This belief offers no solution to the problem of underrepresentation of women in physics because a solution is thought to be unnecessary and irrelevant since women should participate in physics by will and out of interest, rather than being forced. The *inherent differences* viewpoint does not appreciate that physics is failing women by upholding barriers to their progression; rather, it assumes women are failing to fit into physics by their very nature. The issues with this viewpoint are not hidden in the past or behind political correctness and continue to provide reason for the lack of progress for women in physics.

Upon examination of the literature, the *inherent differences* viewpoint serves as a basis for research that investigates barriers for the gender gap in physics. The literature focuses on barriers to women's enrollment or success in physics as a result of inherent differences between men and women and girls and boys, or as a result of traits that one group possesses and the other does not. For example, literature exists that describes critical differences between the nature of girls who are intending to study physics and those who are not (Mujtaba & Reiss, 2013), differences between girls' and boys' grade achievement and interest in physics (Stadler, Duit, & Benke, 2000), and differences in specific characteristics of students that predict their physics enrollment (Thomson, Wurtzburg, & Centifanti, 2015). Some studies focus on what young women need to inherently possess in order to successfully carry on in physics (Mujtaba & Reiss, 2013).

Studies also question female and male students' understanding of physics due to inherent differences (Stadler, Duit, & Benke, 2000). There are limited solutions offered by proponents of the *inherent differences* viewpoint; interventions in physics education are often not encouraged for the reason that inherent traits may not be altered, and this position maintains existing barriers to women in physics. Such barriers are largely social and cultural; these are discussed below in two other viewpoints.

The second viewpoint that is held among the science education research community and broader community is *socialized differences*, which suggests that individuals are socialized to have different interests. Through this lens it can be said that females are less inclined towards physics than males due to social transmission of values and behavioural dispositions by influences such as family, education, and other social influences (Hazari & Potvin, 2005). The physicist, science educator, or researcher who holds the *socialized differences* viewpoint believes that women are either trained to feel that studying physics is not for them, or they are trained towards behaviours that lead their interests away from studying physics. Such social training occurs through the education system (e.g., teachers, peers, curriculum focuses) and outside of the education system (e.g., parents, media, social norms; Hazari & Potvin, 2005). The literature synthesized here is research that has focused on negative social influences within educational systems that act as barriers to young women and inhibit their election and continuation of physics. Socialized differences can occur as a result of gender stereotypes (Deemer, Thoman, Chase, & Smith, 2014), less prior physics experience for females (Chambers & Andre, 1996), lack of equitable assessment (Hazel, Logan, & Gallagher, 1997; Hofer, 2015), lack of real world and human perspectives in physics education (Jones, Howe, Rua, 2000), lack of encouragement for young women (Alexakos & Antoine, 2003), lack of self-confidence and self-concept in studying physics for young women (Häussler & Hoffmann, 2002; Sikora & Pokropek, 2012), and lack of relevance and interest of physics for young women (Sadler, Sonnert, Hazari, & Tai, 2012), among other factors.

Both the *inherent differences* and *socialized differences* viewpoints are limited in terms of solutions for the underrepresentation of women in physics since they largely attribute the cause of underrepresentation to women's tendencies (whether inherent or socialized), rather than physics and how it may be failing to support young women. The final viewpoint, *the culture bias of physics*, approaches the underrepresentation of women with the idea that the problem has more to do with the nature of the field of physics than it does with the nature of women (Baker, 2002). *The culture bias of physics* attributes the low numbers of women in physics to cultural bias; it suggests that physics is bound by masculine tendencies and preferences and it is not a gender-neutral subject, meaning that any individual lacking such tendencies could feel deterred from the subject and even alienated within the field. The bias can be transmitted pedagogically, academically, and socially. Research studies have identified the effects of such culture bias on young female students. For example, studies have shown that contextual barriers in educational settings, such as biased teachers and learning materials, are more prominent for individuals who have been historically marginalized, such as ethnic minorities and women (Fouad, Smith, & Zao, 2002; Luzzo & McWhirter, 2001). Specifically, women and ethnic minorities anticipated significantly more career-related barriers than did men and European American students. Such contextual barriers in school settings have been shown to have negative effects on undergraduate students' choice of academic major (Lent et al., 2005). As part of physics' biased culture, stereotypes about science and gender (e.g., that science is masculine) work most strongly against those students who care most about achievement and success, and females who identify most strongly with their gender (Kaiser & Hagiwara, 2011). Logel et al. (2009) showed that gender stereotypes do not need to be made explicit to women to affect their performance and experiences negatively; simply being in an environment that is male-dominated or that is known to relate to gender stereotypes is sufficient to undermine women's performance and motivation. The strength of influence that the *culture bias of physics* has is detrimental to girls and women at all stages in their physics education or careers.

Frost, Reiss, and Frost (2005) believe that as schools work against gender barriers, it is not enough for schools to be isolated islands of good pedagogy. In addition to teaching excellence, biased perceptions must be challenged. Murphy and Whitelegg (2006) agree that current developments for improving physics education that do not challenge the biased gender-science relationship, and therefore the impact on girls' participation, will consequentially be limited in their success in gender equity.

Proponents of the *culture bias* viewpoint offer the most comprehensive solutions; those needed to address the pedagogical, academic, and social issues. For the progress of both women in physics and physics as a science, physics requires revamping from its educational curriculum to culture. Change from within the discipline is necessary in order to "include broad and diverse worldviews, to make physics more accessible to everyone…and to change the social climate towards collaboration instead of competition" (Hazari & Potvin, 2005, Culture Bias section, para. 9).

Moving Forward

The majority of literature reviewed on the underrepresentation of women from an educational perspective shares a common interest to improve the issue of few women in physics. Despite differences in perspectives and the extensive literature on the topic's long history, there is limited information about how women experience their physics education

(McCullough, 2002). The social and cultural changes needed to hold equity to physics demand that the current (mostly quantitative) literature be accompanied by a human understanding of how young women in high school experience physics education. Qualitative research is needed to understand why some women decide to continue in physics and why others reject it (Ivie & Stowe, 2000). A focus is needed on how young women experience and perceive physics during their high school education and use their experiences to make decisions regarding future education and career pursuits (McMahon & Patton, 1997). The voices of young women as physics students are an invaluable resource to aid in the journey towards equity in physics and physics education. Understanding their experiences affords the opportunity to more pointedly address the barriers in physics education that prevent women from enjoying and succeeding in physics.

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