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Creating a Female-Responsive Design Framework for STEM exhibits

by
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Abstract

This paper describes the development of a Female-Responsive Design Framework for Informal Science Education (ISE). The FRD Framework translates ideas from Culturally Responsive Pedagogy to discover and recommend pedagogical strategies that apply to females and design. This paper describes our synthesis of prior research about females' social, historical, and cultural practices in STEM learning from a variety of fields. The paper further details our process of developing the FRD Framework with the help of museum practitioners, female youth, researchers, and experts from the fields of design, gender, and museums. We discuss four female-responsive strategies, and suggest multiple STEM exhibit design attributes that support each of these strategies. This framework contributes to a growing movement to more thoughtfully consider females when designing STEM exhibits. We hope that the museum field will expand, evolve, and deeply explore the FRD Framework.

Key words: females, girls, equity, gender, Culturally Responsive Pedagogy, Culturally Sustaining Pedagogy, designed learning environments, STEM, engagement, museums, informal science education, exhibits

Creating a Female-Responsive Design Framework for STEM exhibits

Introduction

The past half century has seen growing national and global efforts to address gender inequity in science, technology, engineering, and math (STEM) participation (Ceci and Williams 2007, Hill, Corbett, and St Rose 2010, National Center for Education Statistics 2003, National Science Board 2008, President's Council of Advisors on Science and Technology 2010). While significant gains have been made, imbalances persist, particularly in females' interest and engagement (Brotman and Moore 2008, Scantlebury and Baker 2007). For example, national surveys indicate that fewer girls than boys report liking math and science; fewer females take AP exams in math and science; fewer females pursue science or engineering degrees in college; and women are still underrepresented in STEM careers, particularly those in physics, engineering, and computer science (Girls Inc. 2004, Hill, Corbett, and St Rose 2010, National Research Council 2009, National Science Board 2008, 2016, National Science Foundation and National Center for Science and Engineering Statistics 2013).

As the Exploratorium began to design a new 5000-foot geometry exhibition, we learned about these inequities in females' interest and engagement in math and science. Faced with the possibility that these issues could affect how women and girls responded to the new exhibition, we began to investigate how issues of gender inequity related to science and technology museums. At first, we found some encouraging signs that museums had the potential to help improve females' participation in STEM. Informal science centers contribute to STEM interest and engagement (Falk and Dierking 2010, National Research Council 2009, National Science Board 2008, Salmi

2001, 2002), and studies show that the hands-on interactivity and playful exploration afforded by museums can foster scientific thinking and engagement (Hamilton et al. 1995, Humphrey and Gutwill 2005, National Research Council 2009, Randol 2005). Further, people with science careers frequently credit memorable museum visits for their initial interest in STEM (Cosmos Corporation 1998).

Despite their promise, however, informal STEM learning environments suffer from gender imbalances similar to those found elsewhere in STEM. For example, females have fewer opportunities than males to participate in informal STEM activities and experiences that spark engagement (Alexander, Johnson, and Kelly 2012, McCreedy and Dierking 2013, National Science Foundation 2003). Some researchers have found that compared to boys, girls are less likely to visit science museums (Borun 1999, Hamilton et al. 1995, Lee and Burkam 1996, National Science Foundation 2003). In fact, the Exploratorium's own visitor data revealed a similar disparity in visitation. More importantly, we determined that the Exploratorium's disparity was driven by return visitors (rather than first time visitors): they were significantly more likely to be family groups with just boys, rather than family groups with girls or even boys and girls.

Getting girls in the museum door is not the only problem. Experiences throughout the museum may also be less appealing to girls. For example, certain exhibits, particularly exhibits in physics and engineering, have been found to attract girls less and engage them for less time (Diamond 1994, Girls Inc. 2004, Greenfield 1995, Hill, Corbett, and St Rose 2010, Kremer and Mullins 1992, Lee and Burkam 1996, National Science Foundation 2003, Ramey‐Gassert 1996, Verheyden 2003). These findings underscored the need to identify designs that could better engage females.

The team committed to creating a math exhibition that would engage females, rather than excluding them; effectively joining a worldwide movement for science museums to better engage females in STEM topics (Achiam and Holmegaard 2015, J. Brown, Huerta Migus, and Williams 2012, Cardella, Svarovsky, and Dorie 2013, Chatman et al. 2008, Laursen 2011, National Science Foundation 2003, 2007, National Science Foundation and National Center for Science and Engineering Statistics 2013, Roughneen 2011, Verheyden 2003, Munley and Rossiter 2013). To that end, we conducted a literature review aimed at identifying effective approaches for engaging females at STEM exhibits. These initial efforts unearthed several promising leads. Some ideas were gleaned from best practices and case studies of female-focused informal education projects (National Science Foundation 2003, 2007). Promising strategies also came from the few qualitative and quantitative research studies that had explored ways of engaging women or girls at exhibits. However, those encouraging studies tended to be limited in scope: they focused on a single STEM topic, and only a handful of design features or interactive exhibits (Cardella, Svarovsky, and Dorie 2013, Crowley et al. 2001, Crowley 2007, Munley and Rossiter 2013, Sinkey, Rosino, and Francisco 2014).

In discussing these approaches with the team and practitioners from other museums, it became clear that we were unsure of the broad applicability of these prior findings and did not have confidence that those ideas would generalize to the specific exhibition being developed. In particular, many practitioners voiced concerns about basing designs on small or single-topic studies, especially when the ideas were counter to their own expertise, or if the designs ran the risk of unintentionally reinforcing stereotypes. The team, and the field, needed a more compelling, and better-supported case for designs that could engage females.

Mobilized, we determined to build on what we had learned to develop a more comprehensive framework for engaging females at STEM exhibits, while actively working to address practitioners' concerns. This became the focus of a large-scale NSF-funded project, supported by a team of contributors and advisors, including practitioners, researchers, a group of female youth, and experts from the fields of design, gender, and museums. We were able to expand the initial literature review into the theory-driven Female-Responsive Design (FRD) Framework described in this paper. This framework is part of a larger mixed methods project which also explored a specific application by investigating which of the FRD-derived exhibit design attributes best engaged 8-13 year-old girls at STEM exhibits (Dancstep and Sindorf 2018b this issue), and explored that narrowed set of attributes in-depth via focus groups (Garcia-Luis and Dancstep, In review).

Grounding our Framework in Theory

As we learned from our initial literature review, current STEM pedagogy—both formal and informal—is often failing to engage females effectively. Various researchers agree that more inclusive practices are needed in order for STEM education to successfully engage women and girls (Archer et al. 2012, Cheryan et al. 2009, Good, Woodzicka, and Wingfield 2010, Hill, Corbett, and St Rose 2010, Master, Cheryan, and Meltzoff 2016, Murphy, Steele, and Gross 2007, Sadker and Sadker 1994). By developing exhibits that better resonate with females' preferred patterns of engaging in STEM, we posit that museums can expand their pedagogical approach to be more inclusive of females. However, efforts to prioritize feminine learning preferences and interests must be advanced with care: a narrow or prescriptive approach risks stereotyping and essentializing females, and may alienate learners who do not share these preferences and interests (Achiam and Holmegaard 2015). Our adaptation of Culturally Responsive Pedagogy works to address these issues.

Culturally Responsive Pedagogy (CRP) takes a sociocultural perspective on education, acknowledging that learning occurs within a social, historical, and cultural context (Gay 2010, Vygotsky 1978). Because learners' cultural backgrounds and histories inform their learning processes, challenges may arise when dominant educational culture is not aligned with learners' home cultures. Culturally Responsive Pedagogy addresses this issue by identifying cultural-historical patterns of learning for non-dominant groups and utilizing those patterns in its pedagogy to create educational approaches that are meaningful, appealing, and effective (Gay 2010, Ladson-Billings 1995). While CRP is more commonly used when exploring ways to engage learners of marginalized racial, ethnic, or language groups, we posit that gender, too, is socially constructed, and is interconnected with cultural-historical practices. The idea that gender is socially constructed and enacted in communities of practice aligns with aspects of post-modern feminism (Achiam and Holmegaard 2015, Butler 1990, 1993, Fenollosa, Achiam, and Holmegaard 2016, Paechter 2007). Females' STEM learning practices are similar to those of other non-dominant groups, in that they too have the potential for marginalization by dominant education systems (National Research Council 2009).

To discover meaningful and effective ways of reaching females, CRP explores commonalities that women and girls may share in the ways they experience and prefer to participate in STEM learning. However, CRP also avoids making the stereotyped assumption that all females are the same. Rather, we use inclusive definitions of "females," "women," and "girls," following the recommendations put forth by related theorists Gutiérrez and Rogoff (2003), and Paris (2012) to explicitly recognize that there are many ways to be female: preferences and behaviors related to femininity and gender vary across individuals and communities (Achiam and Holmegaard 2015, Fenollosa, Achiam, and Holmegaard 2016, Francis and Paechter 2015, Paechter 2007, Shibley Hyde 2007). For example, one study found African-American and Hispanic girls were more interested than Caucasian girls in certain STEM content, such as designing a video game (Modi, Schoenberg, and Salmond 2012). Because of this variability, culturally responsive practices for females should include a broad, flexible set of strategies, rather than a narrow, stereotyped prescription. The FRD is not expected to be a static, "one size fits all" approach to designing exhibits with universal female appeal—rather, it includes a toolkit of diverse recommendations that should evolve over time.

Because a CRP approach acknowledges variability within and across genders, it also helps to address the concern that female-friendly pedagogy will emphasize stereotypical extremes that may alienate some learners. Instead, CRP strategies should advocate for an inclusive approach. While current inequities in STEM suggest that there is a particular need to more fully attend to and integrate females' interests specifically (Francis et al. 2016, Francis and Paechter 2015), we should anticipate that these interests cover a broad range, and may have more widespread appeal. For example, researchers have found that physics content that is interesting to girls typically interests boys as well (Osborne and Dillon 2008); others have identified content areas of interest to both boys and girls, such as the possibility of life outside earth (Haste 2004, Sjøberg and Schreiner 2010). Ultimately, broadening STEM inclusivity will mean decreasing binary and stereotypical thinking, and instead seeking out practices which engage people across the gender spectrum.

CRP offers a further opportunity for inclusion by acknowledging that learners can change and develop their preferences over time (Gay 2010, Paris 2012). Thus, introducing learners of all genders to strategies that are mindful of females' preferences may support them in expanding their repertoires of engaging with STEM, ultimately incorporating both more masculine and more feminine practices (Banks et al. 2007, Bell et al. 2012, Taub 2006, Thorne 1993). In the end, the goal is not to stereotype, alienate, or exclude any learners, but rather to add new strategies to our pedagogical approach that represent females' needs, resulting in their inclusion, rather than marginalization, from STEM learning (Dawson 2014).

Development Process

The FRD Framework was developed with two sources: 1) a review and synthesis of the literature, and 2) input, expansion, and validation from various advisors throughout the development process. We drew on these two sources iteratively, each informing and broadening the other. From these two sources, we sought to understand commonalities in females' social, historical, and cultural repertoires of STEM learning that could suggest female-responsive strategies. We then identified ways to adapt those strategies to exhibit design. In some cases, our process identified design attributes from the field of exhibit design, which could be applied directly, with no adaptations needed. In other cases, when the female-responsive strategies came from fields such as web design or ISE programming, we identified design-based adaptations that could translate into exhibit design attributes. Because the goal of this framework was to broadly identify as many promising female-responsive exhibit design attributes as possible, we included numerous avenues for exploration, and weighted them equally. This approach, detailed below, will allow us, and the museum field, to draw from an extensive list and deliberately test the ideas in specific contexts.

Literature Review

Our literature search leveraged in-depth qualitative research studies, various case studies, and a few quantitative studies; we drew on work from the fields of psychology, education, museum learning, gaming, and web design, to identify successful and familiar learning practices in females' formal and informal education experiences. To create a more inclusive and intersectional framework, our synthesis included any research supporting females' engagement across multiple dimensions, including race, ethnicity, socioeconomic status, age, and geographic location (across North America and Western Europe). This literature review is summarized below and described in more depth in Dancu (2010).

As we synthesized our findings, four strategies emerged as recurring themes. We then conducted a focused search of the education and design literature, identifying ways to adapt these strategies to design in order to identify exhibit design attributes that would help achieve each of the four emergent strategies. This was an expansion phase where we incorporated any and all ideas that had merit for aligning with females' ways of learning and knowing.

Advisor Contributions

Alongside a review of the literature, we developed the framework by incorporating interviews and conversations with advisors chosen for their expertise. These advisors included informal learning practitioners; learning science researchers; gender and equity experts; and authorities in the broader field of design. Each group of advisors helped develop the framework by suggesting supplemental literature, refining the female-responsive strategies, recommending adaptations to design and specific exhibit attributes, and providing face validity for our strategy and attribute definitions and assessments.

Two separate avenues for input from informal science education practitioners were established. First, we convened four open sessions seeking input from various practitioners at the Exploratorium between 2009 and 2014, with a special focus on expanding the list of design approaches for each strategy. Additionally, a team of five exhibit developers and graphic designers was integral to the project, contributing to all aspects of the framework throughout the project's four years.

Two avenues were also created to gather input from learning science researchers who specialize in informal education. Initially, we held phone interviews with four museum researchers, asking them to provide examples of exhibit designs that were successful or unsuccessful for fulfilling each of the strategies (Benne 2007, Borun 2007, Koke 2007, McCreedy 2007, 2008). A second group of learning science research advisors contributed via three meetings (two of which were multi-day) and email communication to all aspects of the framework. This latter research advisor group focused especially on operationalizing the four emergent strategies, recommending additional literature, and providing face validity for our design attributes and their measurement.

Two experts from the broader field of design contributed to all aspects of the framework, exchanging email feedback as well attending two in-person daylong meetings. Our design experts especially focused on honing the strategies, adding to the list of attributes, and identifying important variations on those attributes.

Beyond educational design and research expertise, we sought to develop a framework that was conscious and thoughtful in its identification of shared experiences and ways of learning while also careful to avoid stereotyping or overgeneralization. Aligning with the Exploratorium's existing commitment to better engage the Latinx community, we created space for Latina voices whenever possible, including high-level team members and expert advisors. We held four half-day meetings with cultural-historical theory and equity experts that centered on responsivity, and avoiding potential bias, in our research. Two multi-day advisor meetings with experts in gender and equity in museums contributed to the framework, with a special focus on identifying additional attributes that addressed each of the strategies, and further sharpening our strategy and attribute definitions.

Finally, we created a Girl Advisory Committee (GAC), comprised of Latina girls ages 10-13, who informed the development of the FRD Framework. The GAC provided feedback on the research design, contributed to the framework, described their experiences with exhibits at the Exploratorium, and discussed issues museums are facing with inclusivity. They provided feedback on the exhibits that they felt achieved the emergent strategies, which helped us review our list for additional attributes; the GAC also suggested attributes for consideration.

In summary, the framework we present below builds on prior research, and is also the result of many valuable voices and perspectives. While this framework is a first step, we expect it will evolve with the museum field and the broader culture surrounding girls in STEM.

The Female-Responsive Design Framework

Female-Responsive Strategies

The Female-Responsive Design Framework identifies four pedagogical strategies that build on females' preferences in order to better engage and support their STEM learning.

The strategies are:

- Enable Social Interaction and Collaboration;
- Create a Low-Pressure Setting;
- Provide Meaningful Connections; and
- Represent Females and their Interests.

These strategies should not be seen as mutually exclusive, nor should they be taken as a static prescription. Rather, the groupings serve to focus our efforts to unearth potentially important exhibit designs.

Enable Social Interaction and Collaboration

Learning is socially mediated regardless of learners' gender (Miller 1993, Vygotsky 1978); however, studies suggest that collaborative social interactions may be more important for females. Historically, females have preferred, been more engaged in, and performed better in academic and everyday STEM situations that are social, cooperative, and support their active participation. For example, females frequently report positive experiences with cooperative math and science activities, and negative experiences when the activities are competitive (Rosser 1991, Taylor 2005). These attitudes reflect performance: girls' achievement scores in math have been positively related to their participation in cooperative learning activities, and negatively related to their participation in competitive activities (Peterson and Fennema 1985). In museums, females tend to work together on exhibits and support one another in the process (Diamond 1994, National Science Foundation 2003, Taylor 2005). Research suggests that pedagogy that aligns with females' preference for social interaction and collaboration may be effective for improving females' engagement and skills practice in STEM.

Create a Low-Pressure Setting

Researchers have found that females often underestimate their STEM abilities, experience "science anxiety," or doubt that they can succeed at STEM challenges (Britner 2008, Chatman et al. 2008, Hill, Corbett, and St Rose 2010, Nix, Perez-Felkner, and Thomas 2015). Studies have found that some girls dislike competitive activities (Taylor 2005) while others avoid exhibits that seem difficult (Sinkey, Rosino, and Francisco 2014). Safe, comfortable, playful, or open-ended experiences have been shown to support girls' preference for participating in low-pressure STEM activities (e.g., Baker 2013, Gontan 2013, Sammet and Kekelis 2016, Vossoughi et al. 2013).

Provide Meaningful Connections

Females have historically preferred and been more successful in STEM situations that offer meaningful, contextualized ways to connect to content. Understanding the value and relevance of an educational activity transforms it into a true learning experience (D.L. Brown and Wheatley 1989, Lave 1990, Williams and Burden 1997). While this applies to all genders, context seems particularly important to females. For example, females have expressed greater interest in learning math and science when the topics include practical applications such as solving social problems, improving the lives of people and animals, or exploring environmental concerns (Froschl et al. 2003, Milgram 2005, Rosser 1991). According to several researchers, females often wish to know the context surrounding concepts and phenomena (Ford et al. 2006, Milgram 2005), as well as the purpose of an activity, prior to engaging in it (Rosser 1991). Embedding STEM learning in context may also help connect STEM concepts to learners' prior knowledge, boosting girls' interest and self-confidence (Buechley et al. 2008). These and other studies suggest that pedagogical approaches tailored to females' preference for meaningful connections may enhance their STEM engagement and learning.

Represent Females and their Interests

Some researchers suggest that to learn science effectively, students need to see their own multifaceted identities reflected in science practices and communities (Archer et al. 2012, Brickhouse, Lowery, and Schultz 2000). This may be especially critical for females and members of other communities historically underrepresented in STEM (Dawson 2014, SciGirls Connect 2012), who may be alienated by stereotypically masculine or "geeky" environments

(Archer et al. 2013, Master, Cheryan, and Meltzoff 2016). Research suggests that females have engaged more readily with STEM when the topics, aesthetics, and imagery related to themselves and their interests. For example, developers at MIT discovered that whimsical aesthetics increased their program's appeal for girls (Resnick, Berg, and Eisenberg 2000, Volman and van Eck 2001). A study in a children's museum found that including an image of a character named "Power Girl" on exhibit labels significantly increased the number of science explanations that visiting parents provided to their daughters (Crowley et al. 2001, Schneider and Cheslock 2003). Pedagogical principles that incorporate females' preferred aesthetic and content interests may send an inclusive message that females belong in STEM topics and activities.

Exhibit Design Attributes

Having identified the four strategies in the FRD Framework, we next worked within each strategy to identify adaptations to design. We further delineated specific design attributes that could be applied to exhibits. Table I provides a few examples of our approach to distilling broad female-responsive strategies into specific exhibit design attributes.

Table I. Sample Female-Responsive Design Strategy and Adaptation to Exhibit Design.

Female-responsive strategy	Adaptation to design	Exhibit design attribute
Enable Social Interaction and Collaboration	Provide enough space to accommodate a friend or a group	The exhibit is designed to allow people to experience the phenomenon or do the activity from more than one side
		The exhibit includes more than one station
		The exhibit has a large floorplan that is designed to accommodate three or more people
	Encourage discussion	The label invites visitors to compare with another person
		The label recommends telling/showing others

The strategy, **Enable Social Interaction and Collaboration**, for example, might be accomplished by exhibit designs that have *multiple sides or stations*, thus accommodating multiple users and encouraging conversation (Borun and Dritsas 1997, Humphrey and Gutwill 2005). *Open-ended* exhibit designs have also been shown to foster dialogue (Borun and Dritsas 1997, Humphrey and Gutwill 2005). Exhibit designs might **Create a Low-Pressure Setting** by offering *opportunities to observe others*, boosting females' comfort and engagement as they *preview the experience* (Heath et al. 2002, Meisner et al. 2007, Rosser 1991, vom Lehn, Heath, and Hindmarsh 2001). Similarly, a *use drawing* may promote confidence as females use an exhibit (Fenichel and Schweingruber 2010, Perry 2012, Serrell 2015). Exhibit designs could **Provide Meaningful Connections** by *embedding a story or narrative* (see e.g., Casey, Andrews, et al. 2008, Casey, Erkut, et al. 2008, Ford et al. 2006), or by *incorporating familiar objects and materials* (Perry 2012, Resnick, Berg, and Eisenberg 2000, Vossoughi and Bevan 2014). Finally, to **Represent Females and Their Interests**, exhibit designs might *incorporate representations of women in STEM*, which may bolster females' desire to participate in STEM, and increase the time they spend at exhibits (e.g., Bhatt et al. n.d., Milgram 2011, NASA 2009, Onkka and Bequette 2014).

In total, our process identified 55 female-responsive design attributes that had the *potential* to better engage females at STEM exhibits. Appendix A provides the full list of female-responsive strategies and adaptions to exhibit design, along with references. In this list, each design attribute is grouped under a single female-responsive strategy for ease of presentation; in reality, a single exhibit design attribute might support multiple strategies.

We also identified and explored potentially important variations on the design attributes. The first set of variations were related to the location from which a design attribute was detectable, and included whether the design attribute was visible from afar, from up close, or only while using the exhibit. The second set of variations were related to the importance of the design attribute: whether it was central or peripheral to the exhibit experience. The final set of variations consider combinations of similar attributes. For example, when considering the attribute *familiar object*: was the object visible from afar, or only up close? Did it matter whether the object was prominent and central to the experience, compared to being part of the cabinetry; or was it combination of the two?

Discussion

We acknowledge that the Female-Responsive Design Framework is just the beginning of the conversation. In creating the FRD Framework, we adopt a Culturally Responsive Pedagogy approach similar to that of postmodern feminism, acknowledging that gender is a social construct, and recognizing the heterogeneity within and across genders (see e.g., Gay 2010, Ladson-Billings 1995, Paechter 2007, Shibley Hyde 2007). In the long run, we believe that improving inclusivity in STEM will mean looking beyond the needs of girls and women with a more gender-expansive, less binary lens. In the present, however, we posit that the current state of gender inequities in STEM suggests that studying and addressing females' needs is a significant and important step (Francis et al. 2016, Francis and Paechter 2015). The FRD Framework is our response to answering the initial questions raised by the *Geometry Playground* team, and so many designers before and since: *What can we do to ensure that our exhibits* *welcome more females instead of turning them away? How can we design to be more inclusive of females, yet not reinforce stereotypes?*

Grounding our viewpoint within CRP and aspects of postmodern feminism helps address several concerns that practitioners tend to have. First, rather than make unfounded assumptions about stereotypical female interests, we recognize that every museum visitor has a unique set of experiences and STEM interests. The FRD Framework draws on literature, experts and girl advisors to ground the design attributes in the interests and experiences of real-world females, rather than assumptions and stereotypes (Gay 2010, Ladson-Billings 1995). Second, rather than make prescriptive recommendations that serve to perpetuate stereotypical identities, the FRD Framework offers a flexible set of possible design attributes, to represent the interests of a diverse audience (see e.g., Achiam and Holmegaard 2015, Dawson 2014, Fenollosa, Achiam, and Holmegaard 2016). These two cautions suggest that when adopting the FRD Framework, practitioners should not expect any single exhibit to engage every female, nor incorporate every strategy, but thoughtfully draw upon the suite of design strategies to create a more female-inclusive museum experience.

A third concern that this framework seeks to recognize is the danger of setting too narrow a goal for inclusion. Instead of simply bringing girls into current STEM practices, we hope to expand the definition of what counts as science. CRP and postmodern feminist approaches similarly argue that it is not appropriate to expect non-dominant groups such as females to assimilate to traditional STEM practices (Fenollosa, Achiam, and Holmegaard 2016, Gay 2002, 2010, Ladson-Billings 1995, Paris 2012). This is because STEM is not gender-neutral. Rather, many

STEM subjects and practices are associated with traits related to stereotypes of masculinity such as rationality, objectivity, and logic (see, e.g., Achiam and Holmegaard 2015, Archer et al. 2012, Blickenstaff 2005, Fenollosa, Achiam, and Holmegaard 2016). There remains a perception that participation in STEM is for men and boys (Archer et al. 2012, Blickenstaff 2005). At the same time, women are often not seen as serious scientists, and traits or activities related to stereotypes of femininity such as subjectivity, caring, and aesthetics are not seen as important to science (McCreedy and Dierking 2013, Rosser 1991).

Current STEM education practices, including museum exhibit design, often reflect this bias toward the masculine, excluding learners (of all genders) whose interests and experiences are not aligned with masculine ideals (Achiam and Holmegaard 2015, Dawson 2014, Fenollosa, Achiam, and Holmegaard 2016, McCreedy and Dierking 2013). Rather than expect females to adapt themselves to the status quo, the FRD Framework creates an opportunity to challenge and shift current STEM exhibit design (Feinstein 2017). Opening our practices to include, represent, and value a broader variety of female perspectives has the potential to engage many more people across the gender spectrum (Banks et al. 2007, Bell et al. 2012, Calabrese Barton 1998, Taub 2006, Thorne 1993).

While we took care to ground our Female-Responsive Design Framework in theory, prior research, and the expertise of advisors and practitioners, the majority of our 55 specific female-responsive design attributes have not been previously studied in the science museum context for their ability to enhance females' experiences. The FRD Framework was developed in order to identify a set of testable attributes for further investigation, which will help determine how these attributes play out with females in science museums. There are a variety of possible explorations. For example, researchers might identify which of these attributes are most important when exploring different intersectional identities or when focusing on different STEM topics or learning outcomes. Research might also explore the process by which specific attributes support the broader strategies, or seek to understand how various attributes might work together.

Phase two of our project (see Dancstep and Sindorf 2018b this issue, and Dancstep and Sindorf 2016) begins this exploration, working to identify the most promising subset of the FRD's design attributes, within a particular set of topics and with a specific age range. This study suggested that the FRD Framework can help museum staff understand how to design exhibits to better engage females. However, not all of the FRD-derived design attributes showed equal promise for engaging 8-13 year-old girls at physics, engineering, math, and perception exhibits. Attending to such specifics is important as it aligns with the theoretical underpinnings of our framework. Culturally Responsive Pedagogy asserts that educators should pay close attention to the specifics, nuances, and variability in the ways pedagogical approaches manifest in different contexts. That is, the FRD Framework can provide a starting point, but further work is needed to learn about which design attributes work best in specific contexts and with various audiences.

Conclusion

We know that there are many practitioners like the *Geometry Playground* development team, who are passionate about engaging and educating all learners. We seek to support that drive by illuminating principles of good design that consider females' preferences as part of their thoughtful and strategic toolkit. Further, we hope this framework helps provide practitioners with a clear sense that this is a complex topic that cannot employ a "one-size-fits-all" approach and will shift over time. As this is a first step, we encourage the field as a whole to continue striving toward equity and inclusion as we expand the boundaries of STEM.

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Appendix A. Female-Responsive Design Framework: Strategies and Adaptation to Exhibit Design.

Female-responsive strategy	Adaptation to design	Exhibit design attribute	Variations: Afar	Variations: Close	Variations: Use
Enable Social Interaction and Collaboration. See citations (1, 10, 11, 29, 32, 33, 42, 50, 51, 53, 54, 59, 64, 67, 68, 74, 75, 79, 82, 90)	Provide enough space to accommodate a friend or a group (1, 12, 13, 41)	Seating for two or more (1)	√		
		Exhibit has a bench for two or more people (1)	√		
		Can be used from multiple sides (1, 12, 13, 41)	√		√
		Has multiple stations (41)	√		√
		Space to accommodate three or more people (12, 13)	√		
	Create designs that can be experienced by everyone at the same time (1, 12, 13)	Phenomenon can be experienced by two or more people at the same time (1, 12, 13)			√
	Offer opportunities to work with others (1, 12, 13, 41, 68, 73, 84, 90)	Includes two or more required roles (1)			√
		Label invites visitors to work together (73, 84)		√	
		Allows for more than one set of hands or bodies (12, 13)			√
		Designed for multiple players to use without interfering with each other (12, 13, 41)			√
	Encourage discussion (1, 12, 13, 68, 84)	Label invites visitors to compare with others (1)		√	
		Label recommends telling or showing others (1)		√	
		Label asks at least one open-ended question (12, 13, 84)		√	√
Create a Low-Pressure Setting. See citations (1, 6, 10, 15, 24, 35-37, 40, 59, 64, 67-69, 74, 76, 79, 80, 82, 85, 89-91, 96, 97)	Help people know what to do before they approach (from afar) (1, 39, 58, 73, 76, 79, 91, 94)	Visitors can watch others to preview what to do (1, 39, 58, 73, 76, 91, 94)	√	√	√
		Exhibit is designed so one or more interactive elements is visible and understandable from a distance (91)	√		
		Prior visitors' work is visible (1)	√		√
	Provide orientation cues that indicate how to get started (from up close) (1, 30, 39, 58, 73, 76, 79, 83, 91, 94)	Title suggests what the exhibit does (1, 73)	√	√	
		Title and tagline suggest what to do at the exhibit (1, 73)	√	√	
		The form of interactive elements suggests how to use them (1)		√	
		The exhibit is designed to provide feedback when visitors manipulate an aspect of it (1)			√
		Exhibit includes a use drawing (1, 30, 73, 83)	√	√	
	Promote and support open-ended exploration (1, 10, 12, 13, 37, 41, 45, 64, 68, 82)	Exhibit does NOT have a series of predetermined steps (1, 12, 13)			√
		Exhibit allows for a multitude of iterations with a variety of variables (1, 41)			√
		Label suggests three or more distinct activities (1, 41)		√	
		Exhibit provides three or more distinct activities (1, 41)			√
		The exhibit is designed so that many interactions are right (1)			√
		The exhibit is designed so that the outcome of using it is different every time (1, 12, 13)			√
	Avoid competition (1, 45, 67, 74, 79, 80, 90, 97)	The exhibit avoids or minimizes time pressure (1)			√
		The exhibit is designed so that no one can lose (1)			√
		The exhibit encourages team competition (1)			√
		The exhibit avoids or downplays adversarial interactions (1, 90)			√

Female-responsive strategy	Adaptation to design	Exhibit design attribute	Variations: Afar	Close	Use
Provide Meaningful Connections — See citations (1, 7, 8, 10, 16, 18-22, 31, 33, 40, 42-49, 52-54, 56, 59, 62-64, 66-68, 77-79, 82, 85, 87, 90, 93, 95)	Situate the idea in a real-world context (1, 19, 45, 47, 53, 54, 59, 66, 68, 73, 77, 79, 95)	Label describes how the exhibit phenomenon is used or applied in the real world (1)			√
		Exhibit includes at least one familiar object* (1, 73)			√
		Females report that there is something at the exhibit they have seen before (1)			√
		Label provides history of the exhibit or the phenomenon (1)		√	
	Show how the idea connects to people, animals, community, or the environment (1, 8, 10, 19, 33, 40, 42-46, 52, 54, 59, 62-64, 66-68, 77-79, 82, 85, 95)	Label describes how the phenomenon is related to social issues for humans, animals, or the environment (1, 19, 64, 67)			√
		Exhibit includes at least one image of a person (1)	√	√	
		Exhibit includes at least one image of a STEM professional (1)	√	√	
		Exhibit includes any text about a STEM professional		√	
	Provide a story or narrative (1, 2, 18, 20-22, 31, 45, 68, 77, 87, 93, 95)	Exhibit has embedded story or narrative (1)			√
	Enable authorship of objects or narratives (1, 18, 53, 68, 85)	Exhibit involves self-expression or authorship (1)			√
Represent Females and their Interests — See citations (1, 4, 5, 8-11, 14, 23, 25-29, 31, 33, 34, 36-38, 40, 42-46, 49, 50, 52, 55, 57, 59, 61-68, 71, 72, 76-82, 86, 88, 89, 91-93, 95, 96)	Depict females (8, 26, 27, 29, 33, 40, 43, 44, 49, 67, 78, 81)	Exhibit includes at least one image of a female (26, 27, 29, 67, 81)	√	√	
	Represent female role models and STEM professionals (1, 8-10, 29, 33, 40, 49, 60, 65-68, 71, 79, 82, 89)	Exhibit includes at least one image of a female STEM professional (1, 71)	√	√	
		Exhibit includes any text about a female STEM professional (1)		√	
	Include users' own self images (1)	The exhibit is designed to reflect a visitors' self-image (1)	√		√
	Use aesthetics that appeal to females (1, 11, 25, 42-44, 46, 52, 55, 62, 63, 68, 77, 78, 80, 95)	The exhibit has bright, prominent color*	√		√
		The exhibit has some color (but not bright or prominent)*	√		√
		The exhibits' look-and-feel is homey, personal, homemade, or delicate (1)	√		√
	Integrates a sense of whimsy and playfulness (1, 4, 10, 17, 31, 41, 42, 45, 46, 52, 61-63, 67, 73, 77, 82, 93, 96)	The exhibits' look-and-feel is playful, whimsical, or humorous (1, 17)	√		√
		Exhibit uses a familiar object in an unfamiliar way (1)	√		√
		Label text has an informal tone (41, 67, 73)		√	
		Label imagery has an informal tone		√	
	Incorporate females' skills and interests (1, 3, 5, 8, 23, 29, 33, 34, 36-38, 40, 45, 46, 50, 57, 59, 64, 66, 67, 70, 72, 76, 79, 80, 86, 88, 90-92)	Exhibit content has been related to female interests via prior research or evaluation (1, 3, 36, 37, 46, 50, 59, 67, 72, 86, 92)			√
		Exhibit topic has been related to shared male and female interests via prior research or evaluation (1, 34, 37, 70, 72, 86)			√
		Females report that the exhibit relates to their lives or interests (1)			√
		Exhibit interaction involves using small motor skills (1)			√

* A small subset of design attributes included additional variations: whether the attribute was central to the exhibit experience or phenomenon; whether the attribute was peripheral or located in the cabinetry, and whether the attribute was included in the label.

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