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Biosocial “Science Talk”: Using Informal Interactive Programs to Help Children Explore the Human Body’s Relationship with the World Around It

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ABSTRACT: This paper describes the application of a “biosocial” approach to informal health and science education. As an engagement between biological and critical social sciences, biosocial theory has sought to re-articulate human bodies as fundamentally the product of interrelationships between the biological and social dimensions of human life. Applying this approach to health and science education, we conducted approximately 200 public demonstrations at a science museum with school-aged participants over a two-year period. These demonstrations were designed to describe cutting edge research into “biosocial mechanisms” such as allostatic load and epigenetics. We examined survey responses and informal conversation with participants in order to characterize key themes that emerged within these interactions. Our analysis identifies a distinct biosocial “science talk” characterized, at varying degrees of complexity, by an emphasis on complex inter-relationships between environments and biology, the mutability of bodies, and the role of social structures and personal experiences in shaping health outcomes. We argue that these forms of science talk reflect the highly individualized and relational functioning of the biosocial mechanisms. We contend that this approach is not only accessible and easily adaptable to informal science education, but of increasing relevance given the impact of the COVID-19 pandemic.

INTRODUCTION

Scientific inquiry and education have traditionally been premised on notions of a fixed, self-contained, and “default” human body. More recently, a growing field of research in both biological and social sciences have challenged these staid notions, instead emphasizing the myriad ways in which our biology and our environments interrelate. A “biosocial” approach, then, is one in which bodies are understood as permeable and fluid, never fixed and perpetually subject to change, even at the molecular level. These changes are mediated both by environmental and structural forces located outside of the body, and through processes of experience and emotion within. Understanding these interrelations and their impact on health and well-being means not only reframing “the body” as an open and dynamic object of study, but developing new epistemological, methodological, and ethical tools to support multiple and diverse audiences in engaging with this paradigm shift in cutting-edge science.

Examples of emerging biosocial inquiry in the life sciences range from the individual genome to population-level health disparities. In molecular biology, research into epigenetics—changes in phenotype without corresponding changes in the underlying DNA—has given rise to a “post-genomic moment” in which the fixed nature of genes and heredity is being revisited (Landecker and Panofsky, 2013). Our understanding of neuroplasticity, the process by which the brain continues to change and develop over the lifespan, has pushed the inquiry of how developmental and environmental factors influence brain structure and function (Meloni et al., 2018). Mechanisms such as allostatic load, the long-term physiological cost of chronic stress (McEwen and Steller, 1993), are direct evidence of the concrete interrelations between molecular, neurological, and social dimensions. These advances have fostered new research into, and conceptualizations of, social determinants of health, which seek to understand the role of factors such as economic stability, physical environment, education, food, gender and racial discrimination, and healthcare systems in shaping health outcomes (Artiga and Hinton, 2018).

The COVID-19 pandemic and the renewed movement for racial justice has brought the intersection of health and structural inequalities to the forefront of public conversation in the United States. Racial and ethnic minority communities have been disproportionately hit hard by COVID-19 (Tai et al., 2020), not as a result of any intrinsic, genetic disposition, but as a product of structural inequalities such as residential and labor market segregations. Meanwhile a movement countering police violence against Black Americans has forced a public reckoning with the myriad ways in which racial ideologies pervade and shape daily life, including within the practices of health and medicine (Evans et al., 2020). These current crises illustrate the limitations of conceptualizing the social and biological as separate realms and indicate the need for a biosocial approach to scientific research and practice. Addressing such current and future challenges in health and medicine also demands a biosocial approach in science education.

Towards a Biosocial Informal Science Education. Informal science education, with its embrace of both cognitive and sociocultural theories of learning, offers an ideal framework in which to develop new models for biosocial engagement. Biosocial research within both the life sciences and the social sciences has consistently emphasized the role of subjective experience, including experienced racism and inequity (e.g., Krieger, 2012; Metzl and Roberts, 2014; Mansfield, 2012). Similarly, informal learning applies a "people-centered" frame, foregrounding personal motives, interests, and identities, to "place-centered" experiences involving specific materials, tools, and artifacts (Bell et al., 2009). Informal learning institutions, such as libraries and museums, can also be community hubs that promote social wellbeing and contribute to collective impact (Norton and Dowdall, 2016). Not only does a biosocial approach to life science education offer a comprehensive and more accurate approach to understanding human biology, it also facilitates the construction of reciprocal relationships with community members and organizations who actively improve science through their participation.

A central challenge in developing biosocial science education is addressing the multiple and dynamic ways in which a human body's biology is intertwined with the world around it. Scientific perspectives alone are insufficient, and novel partnerships with social scientists can help bridge this gap. In particular, a biosocial approach can be informed by the rich work across the critical social sciences, and feminist scholarship in particular, to better understand the human body as socially constructed. For example, theoretical efforts aimed at articulating the boundaries between sex and gender (de Beauvoir, 1953; Rubin, 1975; Butler, 1990) have challenged notions of the body as purely biological and illuminated the disparate means by which they are produced (Longhurst, 2005). Other work has focused on representations of the human body to explore the bodily implications of social and cultural practices (Grosz, 1994; Weiss, 2013). Moreover, it is essential to acknowledge here the largely overlooked lineage of anti-racist and anti-eugenicist medical science which actively confronted the biological theory of race, including but not limited to the work of Hosea Easton (1837), W.E.B. Dubois (1906), and Alice Hamilton (1925). Importantly, such studies have been used to describe the ethical implications of recent biosocial life science, particularly the concern that attention to the potentially damaging effects of poverty, racism, trauma, and stress could (re)inscribe assumptions of inferiority on particular bodies or sub-populations (Meloni, 2016; Roberts, 2016).

Within the realm of informal science education, science centers and museums have begun to explore topics at the interface of human biology and social systems through interactive exhibits and programs. For example, the Science Museum of Minnesota's *RACE: Are We So Different?* exhibition challenges visitors' perceived connections between the social construct of race and human variation (Goodman and Garfinkle, 2007). *Heureka Goes Crazy*, an exhibition on mental health developed by the Finnish science center Heureka, creates immersive environments to depict the intersection of mental disorders and social relationships (Rosenström, 2015). A recent installation at Questacon – The National Science and Technology Centre of Australia explores the effectiveness of a simple exhibit model with facilitation in communicating social determinants of health (Phiddian et al., 2019). Each of these topical efforts has benefited from collaboration between life scientists, social scientists, educators, designers, and/or peer experts with lived experience.

In considering the construction of a broader framework for applying biosocial thinking to informal science education, transdisciplinary partnerships allow active integration of diverse perspectives at the earliest stages of design. As a challenge, a more concrete framework means the intentional design of materials and conceptual tools that help learners understand these complex interrelations, recognize the origins of forces impacting their bodies, and provide them with means of managing personal and environmental conditions for healthier living. As an opportunity, the benefits of a biosocial approach should reflect the best contributions of each discipline: 1) it more accurately accounts for the complexity of human bodies and health, 2) it is primed to address new ethical considerations that emerge from the complex interrelations of science and social systems, and 3) it assigns value to the lived experience of learners, increasing relevance and deepening engagement.

In this program description, we ask how a biosocial framing of science might help children in informal learning environments to understand the function of particular physiological mechanisms and to think with more complexity about their own bodies and their relationships to broader social systems. Drawing on the combined expertise of biologists, social scientists, and museum educators, we developed four short, facilitated museum floor programs designed to communicate various emerging science concepts of biosocial mechanisms while simultaneously fostering conversations that emphasized the connections between the social and the biological. Through observations and interviews with participants, our analysis shows that a biosocial approach is effective in helping children grasp scientific concepts of human biology and physiology, while generating conversations characterized by an understanding of systemic and relational dimensions at varying degrees of complexity.

PROGRAM DEVELOPMENT AND DESIGN

Facilitated programs at science centers and museums, typically guided by an educator with opportunities for visitors to engage in hands-on interaction with physical materials and open-ended conversation, offer a flexible format to explore biosocial concepts in an informal learning environment. The set of programs described here were developed as part of the Bio-Social Partnerships project, a National Science Foundation-funded graduate education project connecting researchers in the departments of Biology and Geography and Urban Studies at Temple University with museum education staff at The Franklin Institute, a science museum in Philadelphia, PA. The principal goal of the project was to pilot and test a model for cross-disciplinary collaborative learning and communication to produce knowledge about the human body as simultaneously biological and social. The project was based on a studio model, in which both academic papers and museum programs were developed in cross-disciplinary teams of graduate students from the life and social sciences, designed to prepare graduate students to communicate with each other and with public audiences.

Topics for the museum programs were selected through an iterative process in which students brainstormed and defined "fuzzy" problem areas which lent themselves to a biosocial approach as opposed to traditional biological or social scientific research methods. The physical materials for each program were designed to communicate both the functioning of a specific biosocial mechanism (e.g., allostatic load or epigenetics) in line with a more traditional concept-driven approach to science education, but also to spark conversation and increase understanding of how these mechanisms serve to mediate between the "social" and "biological" realms in everyday life. To this end, special attention was paid during the design process to fostering connections between the key science concept of the program and the personal experiences and knowledge of participants. Regular critique sessions ("design crits") were a key component to the design process, with the intention of promoting continuing refinement and iteration of the designs. These crits were held among the courses' students and faculty, as well as approximately 20 external guest critics, including social science, biology and design faculty, along with museum educators and science communication professionals.

The programs were designed to be housed in mobile carts and led by team members acting as facilitators, rather than as stand-alone exhibits. For hands-on materials, this flexible format allowed rapid prototyping and modification during the development process. For the visitor experience, facilitated "no-conflict" conversational approaches and inclusive environments have been shown to support informal science learning, especially when addressing science topics tied to social and cultural identity (e.g., Schoerning, 2018). Aligned with this evidence-based framework, The Franklin Institute's "core four" facilitation techniques—asking questions, making connections, encouraging scientific thinking, and cultivating rich dialogue—were embedded into the program design. This inquiry-driven approach encouraged learners to construct their own knowledge and articulate their understanding, thereby also creating opportunities to reveal, and correct, potential misconceptions. Similar to the development of physical materials, an iterative process was instituted in developing a "biocentric" (i.e., aligned with a traditional biomedical approach) script for each program as well as a "biosocial" version (see Appendix A for an example). These scripts guided facilitators' interactions with participants at The Franklin Institute and allowed for a comparative analysis across programs.

Over the course of two years, four programs were developed and tested with children visiting The Franklin Institute. The programs covered four individual topics: *allostatic load, epigenetics, melanin and race*, and *learned reward* (Figure 1).

The *allostatic load* program was designed as a game that would illustrate the potential for negative health impacts associated with chronic stress. Allostatic load is a conceptual framework used to explain how frequent or chronic activation of the body's stress response (brought on by exposure to violence, trauma, poverty, etc.) can result in overexertion of physiological systems and the cumulative strain on cardiovascular, immune, and metabolic systems. The game involved a visitor playing the role of a white blood cell tasked with preventing infection from a flu virus. A ball (the flu virus) was rolled down a ramp, and the visitor (in the role of the white blood cell) tried to catch the ball before it crossed a line on the ramp (i.e., infected the body). As the game progressed, more and more balls representing hypothetical "stressors" were added, necessitating a heightened neuroendocrine response and making the visitor's job in defending the body progressively more difficult. The biosocial approach to this program probed participants to consider everyday factors that could activate a stress response and how their impact might build up over time.

The *epigenetics* program aimed to guide participants in

Figure 1. Biosocial programs at The Franklin Institute. Clockwise from top left: allostatic load, epigenetics, melanin and race, and learned reward.

thinking about the distinction between traits that can be predicted by DNA sequence alone versus those in which environmental factors affect gene expression to produce greater variability. A physical model was designed to represent variability in heart disease, a health condition known to be influenced by epigenetic mechanisms. The starting point of a ball at the top of a vertical wooden box represented the genotype, i.e., the "starting condition." Potential phenotypes were represented by five compartments at the bottom of the model, which acted as a probability scale of developing heart disease. To simulate changing gene expression, participants could direct the path of the ball through the model to different compartments by adding wooden ramps. These ramps represented different epigenetic triggers, conveying the notion that DNA can predispose someone to heart disease but that social and behavioral factors play a role in determining health outcomes. The biosocial approach here prompted participants to identify potential environmental factors and consider their individual or structural basis.

The goal of the *melanin and race* program was to help participants disassociate race and skin color by exploring the biological function of melanin. Participants were first asked to turn five beakers of water into progressively darker shades of brown, using an eyedropper and caramel food coloring. Next, the facilitator demonstrated how melanin absorbs ultraviolet (UV) radiation, using an iPad app to measure light reflectivity with color swatches matching different skin tones. Finally, participants analyzed a world map of UV intensity to understand the geographic and historical context for differences in skin melanization. In the biosocial approach, the demonstration of UV absorption used faces of people with various skin tones instead of color swatches without faces, priming participants to think about how the biological basis of skin color impacts people in a societal context.

The *learned reward* program was designed to illustrate how past experiences and memories influence our brain's perception of novel stimuli. The brain's reward system is a network of regions that release the neurotransmitter dopamine and elicit a feeling of reward or pleasure when exposed to a positive stimulus. The positive or negative valence of a given stimulus can be learned and reinforced through experience. Participants were given three sensory stimuli (olfactory, auditory, and tactile) asked to rate their reaction to each stimulus. One visitor then "visualized" the brain activity of their reward center on a pathway network model, constructed from an acrylic panel with a laser-etched MRI image of the brain and backlit with LED strips of variable brightness. By lighting up each sensory pathway with a brightness matched to their rating of the corresponding stimulus, the visitor could see an additive color effect representing the combined activation of their reward center. In the biosocial approach, participants were asked to discuss their ratings and the group compared the brain visualizations of two participants, prompting consideration of individual and shared experiences.

DATA COLLECTION AND ANALYSIS

We present data from a prospective, mixed-methods evaluation of programming for children and accompanying adults who visited The Franklin Institute between 2017 and 2018. The Temple University IRB determined that this data collection, designed to evaluate only these particular programs, did not meet the criteria for human subjects research as defined in the regulations and was therefore exempt. Data to refine and evaluate the facilitated programs were collected both in the form of observations recorded during program interactions and in the form of surveys conducted with single participants before and after the activity. Observational data was collected pertaining to participants' experiences and behavioral and verbal reactions to the program, their understanding of science concepts, and conversations with facilitators about personal experiences and knowledge as they related to the activity. Program-specific survey instruments were designed for each of the four programs and included questions pertaining to the demographics of the group, pre- and post-program multiple choice questions designed to measure conceptual understanding, and open-ended questions pertaining to participants' understanding of the concepts as well as connections made to relevant personal experiences and knowledge (see example in Appendix B).

Participant groups were recruited directly at the museum by team members based on the presence of children aged 5-14 within a given group. Given that this study was designed as a proof of concept on the viability of the facilitated programs, we were not able to target specific ages or stratify our design to ensure equal age group representation across conditions. Future research would be designed in order to target specific age groups. After recruitment and consent from an adult member of the group, the adult was asked to complete a survey to collect demographic information, and a child within the target age range was asked to answer the pre-program multiple choice questions. Pre-program and post-program multiple choice questions were conducted only during the *Learned Reward* and *Melanin and Race* programs. During the program, one team member facilitated the hands-on activities and conversation using either the biocentric or the biosocial script, while a second team member recorded observations and transcribed comments. Team members regularly switched roles so as to minimize any influence of a particular facilitator on the outcomes of a given script. Observational notes included characterization of overall group dynamics; instances of knowledge co-construction between group members, especially children and adults; and transcription of relevant quotes, both unprompted and prompted by facilitator questions, during discussion. After the program, the same child participated in a short interview to answer open-ended questions and post-program multiple choice questions.

Participants from twenty groups were recruited and interviewed for each script version of the four different programs (n=160 groups representing 795 observed participants). Participants were randomly assigned to individual scripts, as scripts were scheduled to be tested in advance in order to assure that each facilitator presented the material with an approximately equal frequency. Observational notes and survey data were then combined and analyzed for primary themes. Two members of the research team performed a close reading of a subset of transcripts to identify recurrent descriptive and analytic themes, which were then condensed and clarified through an iterative process conducted by three team members to create a final codebook of twenty-five secondary codes and three primary code groups (see Appendix C). The final code book was used to guide the discussion and interpretation of the data to identify themes that integrated findings across codes. Code groups were then referenced against the exhibit (e.g., allostatic load) and the script version (biosocial vs. biocentric) to identify additional patterns.

RESULTS

Table 1 describes participant demographics derived from the responses of those participants who completed one of the four survey instruments, which represents a subset (n=172) of the overall participants. The majority of participants visited the museum with "Family and/or Friends," with the average group size being 4.5 individuals. Participants were asked to self-report the gender and race/ethnicity of their group members. A majority (57.4%) of participants self-identified and/or identified members of their group as White, a significantly higher percentage than estimated (34.9%) in the most recent American Community Survey 5-Year Estimate for Philadelphia (Census Bureau, 2017). Table 2 shows the total number of visitors (including adults) recorded in the observational notes, broken down by age group and script (n=795). The majority (65%) of the total visitors under 18 years fell within the ranges of 5-9 and 10-14 years of age. While equal numbers of demonstrations were conducted for all scripts, visitor numbers vary by script due to fluctuations

Table 1. *Participant Characteristics, % of total surveyed (n=172).*

Gender*	
Female	61.9
Male	38.1
Age of Children	
0-4	3.3
5-9	52.6
10-14	34.0
15-19	10.1
Race/Ethnicity	
Black/AA	15.7
Asian/Pacific Islander	8.3
White	57.4
Hispanic/Latino	6.7
Native American/Native Alaskan	0.6
Other	1.6
Group Composition	
Family and/or Friends	78.3
Organized group	21.1
Other	0.7

Data for this study was collected prior to The Franklin Institute adding a "other/non-binary" option to the gender question in its standard demographic survey.

in museum attendance, specifically due to variations in attendance of school and camp groups.

Table 3 represents the analysis of the change in scores between the pre- and post-program multiple choice questions. We found no statistically significant difference between the change in scores for the biocentric versus biosocial versions of each program. We therefore focused our analysis on characterizing the nature of the dialogue and interaction during the biosocial programs.

"Science Talk": Connecting Biological Mechanisms to External Factors. Our goal of applying a biosocial approach to informal science learning is to encourage exploration of the complex interrelationships between environments and biology, the mutability of bodies, and the role of social structures and personal experiences in shaping health outcomes. In characterizing this exploration, we define as "science talk" the interactions of and language used by participants during the programs as they shared their understanding, debated concepts, and discussed their own relevant ideas and experiences. While most participants tended to clearly comprehend the functioning of the particular biosocial mechanisms being discussed, we did observe differences in the degree of complexity and personalization expressed in their science talk.

Our analysis of the qualitative data established two broad levels of dialogue and interaction, which we categorize as Level I and Level II science talk (Table 4). In a Level I response, a visitor is able to verbally and nonverbally communicate their understanding of the impact of environmental conditions on a biological phenomenon and can make connections to a personal experience. For example, most participants tended to nod or demonstrate understanding when the concept of melanin was described; one visitor explained:

> *"Pigment is why we have darker skin. We need more melanin to protect us in hotter places."* (melanin and race)

In contrast, Level II science talk demonstrates a greater degree of biosocial thinking, in which the visitor actively and with little prompting makes connections not only to their

Table 2. *Participants by program, script, and age (n=795).*

Program	Age	Biosocial n(%)	Biocentric n(%)	Total n(%)
Epigenetics (n=224, Biosocial 101, Biocentric 123)	**Age**			
	0-5	4(4.0)	2(1.6)	6(3.0)
	6-9	38(37.6)	36(29.3)	74(33.0)
	10-13	27(26.7)	44(35.8)	71(31.7)
	14-18	0(0.0)	1(0.8)	1(<0.1)
	18+	32(31.7)	40(32.5)	72(32.5)
Allostatic Load (n=237, Biosocial 136, Biocentric 101)	**Age**			
	0-5	7(5.1)	3(30)	10(4.2)
	6-9	35(25.7)	36(35.6)	71(30.0)
	10-13	61(44.9)	43(42.6)	104(43.9)
	14-18	5(3.7)	2(2.0)	7(3.0)
	18+	28(20.6)	17(16.8)	45(19.0)
Learned Reward (n=162, Biosocial 90, Biocentric 72)	**Age**			
	0-5	3(3.3)	4(5.6)	7(4.3)
	6-9	30(33.3)	23(31.9)	53(32.7)
	10-13	27(30.0)	18(25.0)	45(27.8)
	14-18	7(7.8)	0(0.0)	7(4.3)
	18+	23(25.6)	27(37.5)	50(30.9)
Melanin and Race (n=172, Biosocial 95, Biocentric 77)	**Age**			
	0-5	3(3.2)	3(3.9)	6(3.5)
	6-9	34(35.8)	26(33.8)	60(34.9)
	10-13	22(23.2)	18(23.4)	40(23.3)
	14-18	3(3.2)	3(3.9)	6(3.5)
	18+	33(34.7)	27(35.1)	60(34.9)

Table 3. *Statistical test of changes in program survey scores from pre to post.*

Program	Biocentric			Biosocial			*t*	*p*
	N	*M*	*SD*	*N*	*M*	*SD*		
Learned Reward	20	-0.034	0.214	20	0.016	0.131	-0.97612	.347
Melanin and Race	20	0.11	0.491	20	0.135	0.523	-0.14669	0.8849

Table 4. *Characterizations of Science Talk by Degree of Complexity and Personalization.*

Science Talk	Characteristics	Quotes
Level I	• Basic comprehension, or with some areas of confusion, of the functioning of biosocial mechanisms • Simplified relationships between environment and biology (unidirectional, deterministic) • Connections to individual experiences, especially when prompted	"Air pollution, unclean water. Your DNA gets smaller and smaller and you have less." "Getting sick doesn't happen when you have germs, it happens when you get stressed." "Our skin absorbs, we get tan. More sun at the equator. If you stay in the sun, we have more melanin. Darker skin absorbs more light. We got burned in Jamaica."
Level II	• Clear comprehension of the functioning of biosocial mechanisms • Articulated complexity in the relationship between environment and biology (e.g., mentions of "likelihood" or "probability"/ multidirectional relationship between environment and biology) • Actively make connections to their own life experience and broader social/environmental dynamics especially with little prompting	"Different types of stress affect the body differently and can make you more likely to get sick" "If you live in a city, you're more likely to be exposed to pollution and kids don't have a choice in where they live."

own life experience *but also* to broader social dynamics. A sample observation of a Level II response noted:

> *"[The visitor] made comments about the inaccuracy of racial categories (more or less tan, "I'm in-between"). [They] understood the connection between melanin, sun exposure and skin cancer."* (melanin and race)

Participants overall displayed a high level of science comprehension in all four programs, indicating that the programs were successful in conveying key science concepts accurately. Among the few misconceptions, one emerged as an important consideration for presenting biosocial program content. The concept of probability—for example, that chronic stress might make you *more likely* to become immune deficient—can be difficult for children to grasp. In some cases, participants misinterpreted biosocial connections to conclude that environmental exposures would *necessarily* dictate what happened to the body. Such misconceptions around health and wellness require extra care because they can perpetuate misinformation or lead to misguided decisions with unintended health consequences. The facilitated nature of the programs allowed this misconception to be addressed and corrected when it emerged during conversation, but for some participants, their misconceptions appeared only in the post-program evaluation. These were coded as Level I responses, for example:

> "*Getting sick doesn't happen when you have germs, it happens when you get stressed.*" (allostatic load)
>
> "*You should stay healthy and eat well because your DNA changes if you don't.*" (epigenetics)

Adding explicit conversation prompts to the program about probability, risk, and relevant considerations for personal health may be important for ensuring that participants are integrating accurate information for the future.

The *allostatic load* program, on the other hand, revealed a design challenge in that the gamified nature of the physical model sometimes overshadowed the concept. Some (especially younger) participants tried to prevent all the stressor balls from crossing the line and "entering the body" as a perceived way to win the game, rather than remaining focused on stopping the larger "flu virus" ball. It is unclear the extent to which this design challenge shifts the way that participants understand the information presented.

In addition to science talk, we identified two subcategories of conversation: "systems talk" and "relations talk." As these categories represent fundamental themes in a biosocial science of the body, we explore these themes in greater detail in the following sections.

"Systems Talk": Recognizing Structural Dimensions of Lived Experience. Beyond fundamental understanding of scientific concepts, we found important variations in how participants identified the production of bodily phenomena and health outcomes in relation to social structures. We define "systems talk" as a type of thinking and conversation centered around societal level arrangements or mechanisms

Table 5. *Characterizations of Systems Talk by Degree of Complexity and Personalization.*

Systems Talk	Characteristics	Quotes
Level I	• Allusions to causes of ill health without explicit mention of social systems. • Unidirectional relationships between social systems and biology	"Sometimes people get treated different, but it's not fair." "Things like smoke are bad to breathe."
Level II	• Identifying biosocial mechanism in relation to societal level arrangements and drawing linkages to health outcomes • Participants position themselves or others within societal level arrangements • Multidirectional relationships between structure and biology	"A lot of people live in places with pollution and they can't move from there." "My neighbor has to move because they couldn't pay rent, and my other neighbor is getting divorced. I think this could make them get sick more." "(Race) doesn't affect me but other cultures. Racism... but it's really not fair because it is just melanin."

and their role in producing or determining everyday experiences. Quotes from participants pertaining to social systems included themes such as economics, race and racism, gender, environmental issues, geography, and the built environment. These responses tended to be centered on the structural means by which an individual’s health might be impacted.

We again categorized systems talk into Level I and Level II responses (Table 5). While a Level I response might identify a structural or systemic factor influencing a biological mechanism, Level II responses go further in illustrating how participants place themselves or other people within a social structure. For example, Level II systems talk might recognize the connection between people and places, health inequities stemming from notions of difference, or economic burdens:

> “*A lot of people live in places with pollution and they can’t move from there.*” (epigenetics)
>
> “*(Race) doesn’t affect me but other cultures. Racism...but it’s really not fair because it is just melanin.*” (melanin and race)
>
> “*Sometimes I cause people in my life long-term stress. But so can paying bills and making sure their families are safe and fed. It can be stressful because you have to put them before you.*” (allostatic load)
>
> “*My neighbors get stressed when people don’t behave nicely or when something happens that affects everyone. Grown-up stress is stuff like taxes, bills, getting tickets.*” (allostatic load)

“Relations Talk”: Integrating Emotions, Behavior, and Relationships. A second subcategory of science talk that emerged in conversations involved the relationships that participants had with other people (e.g., family members, friends, neighbors), relationships participants observed between other people (e.g., teachers’ or parents’ feelings related to children), individual emotional or visceral experiences (e.g., feeling afraid, experiencing stress in a bodily capacity), and individual health behaviors. We define “relations talk” as connections made by participants between individual experience and differences in relation to biology.

Alongside understanding of social systems, participants in the exhibits demonstrated important variations in their understanding of relationships (Table 6). We characterized Level I relations talk by responses that focused narrowly on participants’ personal experience and conceptions of themselves as individuals, and their unique relationship with the world, with sometimes limited connections to biology. For example:

> “*I could be nicer to my brother so he’s not annoying to me.*” (allostatic load)

Table 6. *Characterizations of Relations Talk by Degree of Complexity and Personalization.*

Relations Talk	Characteristics	Quotes
Level I	• Discussion of individual experience and difference but with limited connection to biology • References to visceral experiences • Discussion of the significance of individual relationships with other people/things, yet vague connection to biology and/or broader social circumstances.	“I don’t have the stress myself, my parents do and I can’t always stop them from fighting.” “I don’t like school’s macaroni because I almost threw up on it in 1st grade. I like chicken nuggets because we ate it on the first night of camp and camp is fun.”
Level II	• Discussion of individual experience and difference in relation to biology • References rich depictions of visceral experiences as they relate to biosocial mechanisms • Recognition of individual experiential differences as a mediator between broader circumstances and biology	“We’re different people - different life experiences. What I associated with something is different because we have different experiences.” “Stress is all my feelings bunched up inside me.”

> “*I think it affects people but I’m not sure why. Lighter and darker skin treated differently.*” (melanin and race)

In Level II relations talk, participants were able to extrapolate biosocial connections to other people besides themselves and the relationships they observed between others. Participants discussed the importance of memories and past experiences in thinking about how brain pathways differ between individuals. References to visceral descriptions illustrated how they were thinking about the connections between their emotions and their bodily experience. The programs also prompted people to think about how people treat each other and the influence of those relationships on health, especially with respect to conflict and stress. Examples of Level II relations talk responses include:

> “*Our brains are different in how they react. When you have bad or good experiences, your brain determines how to deal with it.*” (learned reward)
>
> “*Stress is a weight on our shoulders. It makes us not feel as good.*” (allostatic load)
>
> “*Sometimes when people say the mean things, I can’t ignore it and I get stressed out.*” (allostatic load)
>
> “*[People are] treated differently based on skin, so darker skin means treated worse.*” (melanin and race)

While the *melanin and race* program elicited frequent conversations about how people treat each other unfairly, only a small number of those participating in the *allostatic load* and *epigenetics* programs recognized unfair treatment as detrimental to a person's health. As illustrated by the following quote from a participant in the epigenetics activity, responses to these activities tended towards more generalized notions of unfairness.

> *"How and where you grew up, how you get treated by other people."* (epigenetics)

The linkage between experiences of mistreatment and diminished health outcomes has been examined in several studies in the past two decades, particularly as it relates to gender and racial discrimination (Carter et al., 2017; Nuru-Jeter et al., 2009; Kaholokula et al., 2010; Chae et al., 2014). A robust understanding of bodies as biosocial would account for the ways in which social structures shape interpersonal experiences and which ultimately can impact the body. Ideally, a biosocial approach to informal science education would be able to convey this complexity more fully for younger audiences.

DISCUSSION

Our pilot program sought to examine how a biosocial approach to health and science learning might help young museum visitors and their accompanying social groups better understand how specific mechanisms in human bodies work, and to think more complexly about their own bodies and their relationships to broader social systems. Across all four programs, we found that integrating a biosocial framework effectively conveyed key concepts of human biology and health. We focused our analysis on the discussions and interactions that took place during interactive museum programs as a means of ascertaining how participants understood and applied a biosocial framing. What emerged from this analysis was a distinct biosocial "science talk" in which participants drew from their own personal experiences and understandings of the world to emphasize the mutability of bodies and complexity of interactions between bodies and environments.

The Nature of Biosocial Thinking. Museums and other informal learning institutions foster constructivist learning, where visitors guide their own learning by drawing on prior knowledge, personal experience, and social interaction (Jeffrey-Clay, 1998). A biosocial approach to human biology and health is particularly well-suited to this learning environment because of the emphasis on both individuality *and* interrelationships. The two distinct subcategories of "systems" and "relations" that we identified represent ways in which participants related prior knowledge and life experience to descriptions of biosocial mechanisms as ways of explaining and further exploring the material. By reframing the body as the result of a highly personalized exchange between an individual's biology and the external environment, the science is no longer hypothetical. Rather, learners can now construct their thinking about the actual bodies of themselves and people they know, including the lived experiences and social relations that produce those bodies. Such a biosocial framing is grounded in the functioning of the biological mechanisms themselves, which likely explains why we saw little difference in terms of science talk between the biocentric and biosocial scripts.

While we observed both systems and relations talk across the four programs, the specific topics of the programs encouraged participants to think about different aspects of the interrelations between the social and the biological. For example, the *learned reward* program, in its focus on the brain's reward center, logically led participants to consider their own experiences and the experiences of others, thereby promoting thinking about relationships between individuals and their own personal visceral experiences. Similarly, the *melanin and race* program focused on socially perceived differences between people and therefore sparked conversations centered around interpersonal relations. The *epigenetics* and *allostatic load* programs, on the other hand, encouraged more systemic thinking in that explanations of the mechanisms centered on external conditions impacting bodies, conditions which were then contextualized by participants in terms of social structures.

The Level I and Level II classifications that emerged in our analysis captured differences in the degree of complexity and personalization reflected in participants' responses. Perhaps the most important distinction between these two categories related to how participants conceived the interrelationships between bodies and environments. Understandings of these interrelationships were characterized by two distinct facets: the directionality of the relationship (i.e., unidirectional vs. multidirectional) and the role of probability in shaping the outcomes of these relationships (i.e., deterministic vs. relational). To promote accuracy in biosocial thinking, programs can benefit by directly addressing these interrelationships and model their application to personal decision-making.

Cognitive Development and Biosocial Thinking. Observationally, we found that younger participants tended to understand the relationships between environments and bodies in more unidirectional, deterministic ways (Level I talk). These participants were more likely to suggest, for example, that living near a source of pollution *would* make you sick, while older participants, likely to have more prior knowledge of probability, would suggest that a particular environmental exposure *may* make a person sick. Whereas younger participants tended to focus their comments on how an external environment "gets under the skin," older participants more often discussed the relationship between bodies and environments as multidirectional (Level II talk). For instance, older participants discussed how darker skin is not only the result of a gene-by-environment interaction, but also determines how a person is positioned within a social structure. This conceptualization understands environments as implicated in producing of bodies, which then in turn shape and are shaped by specific social relations.

This observed correlation between age and complexity of reasoning is aligned with theories of childhood cognitive development. Under Piaget's cognitive developmental theory (Crain, 2011), for example, our target range of participants overlaps with the transition between the concrete and formal operational stages. Younger children in the concrete operational stage are able to conceive things from someone else's perspective and generalize based on observations but are limited to applying these skills to physical objects. In contrast, older children in the formal operational stage are able to manipulate abstract ideas and make predictions about the world. We are encouraged to see how these cognitive skills align with different levels of biosocial complexity. Our results suggest that once children develop theory of mind and can process other people's mental states, they are able to make connections between their own bodies and the world around them that then grow more sophisticated over time.

Design and Facilitation of Biosocial Conversations. In a designed environment like a museum, physical space and materials play a key role in a visitor's learning experience (Bell et al., 2009). In particular, the format of a facilitated, small-group program with hands-on interaction has been demonstrated to be successful in guiding visitors to think about the societal impacts of science and technology (Wetmore et al., 2013). We observed that several elements of this model were particularly helpful in creating a positive learning environment for biosocial concepts, which have the potential to be intimidating in their complexity and unfamiliarity or uncomfortable due to their deeply personal nature. The visually interesting program materials and the promise of active participation piqued participants' curiosity and created an approachable space. The hands-on experience provided an opportunity for participants to discover a phenomenon for themselves, while also creating a consistent learning experience (across diverse individual facilitators). As the *allostatic load* program showed, however, physical materials can sometimes be distracting if the dynamics of the user interaction do not fully support the conversation.

With hands-on exploration to ground the interaction, the intentional design of open-ended questions and application of best practices for generating meaningful conversations (Wetmore et al., 2013) encouraged participants to contribute their ideas, opinions, and values at their own level of comfort. Facilitation was critical to helping participants make connections between the biological and social. We had expected some hesitancy in discussing these possibly challenging topics, but in response to the questions many participants were open in sharing their personal experiences with each other and with the facilitator, enriching the conversation.

Future Directions. As we consider the development of a biosocial framework for children in informal learning environments, our pilot program suggests multiple questions for future inquiry. First, aside from participants' age, are there specific design or facilitation elements in this program format that can help elicit Level II thinking? One advantage of informal learning is that learners are typically present in social groups, especially as multigenerational families in science centers and museums. Although we only interviewed children, in many cases their adult group members also participated in the program. Understanding the interactions between group members—particularly between adults and children—could help inform how to encourage more complex thinking as a group even if children are in earlier phases of cognitive development.

A second question is how to scaffold what might be considered "Level III" systems thinking, specifically with respect to the aggregative feedback loop between environment and biology. For example, the biosocial devaluation of particular bodies can produce harmful environments that then negatively impact the health of those bodies (e.g., situating environmental hazards in majority Black and brown communities). Or, social marginalization might impact the likelihood of disease occurrence, which then results in further marginalization (e.g., environmentally related chronic disease occurrence negatively impacts labor market participation). In these scenarios, perceptions of difference become embodied, in some cases resulting in physical differences. We did not observe participants taking this next step in their conceptualizations in our analysis, perhaps because it requires an additional level of abstract thinking that was not embedded in the program design.

Third, how do we broaden access to and engagement with biosocial thinking in informal learning environments? A limitation of our pilot program is the disproportionately low representation of participants of color compared to community demographics. While museums and other informal science institutions may be convenient testbeds for developing new learning experiences, their visitorship reflects the nonparticipation and exclusion of many people, especially those from low-income and minority ethnic groups (Dawson, 2014). To explore the potential of biosocial thinking as a promising connection between all people, their health, and their environments, these programs should aim to engage diverse audiences where they already live, work, and play. Community organizations, libraries, neighborhood out-of-school-time youth programs, and local health centers are potential partners who can bring new voices to inform further development of models of informal biosocial science education.

Finally, what is the long-term impact on learners of repeated practice with biosocial thinking? In our study, due to the sequential nature of the program design, participants only interacted with one of the four programs. As described above, we found that different programs elevated different aspects of biosocial science talk. Exposure to multiple programs may provide a more robust and balanced approach to biosocial thinking. A further question of interest is the learner's ability to transfer the framework; after developing skills for identifying and reflecting on biosocial connections in one topic or set of topics, do learners apply those skills to new topics and scenarios? Do they make meaning out of informal biosocial learning experiences that leads them to think differently about their own bodies and environments?

CONCLUSION

Our hope is that this paper offers some insight into how a biosocial framework can contribute to informal science learning about the body and how this type of content might be integrated into informal learning environments. While this approach represents a shift away from traditional health science curricula, the readiness and ease with which participants were able to relate ideas about biosocial mechanisms to their own lives not only illustrates the accessibility of the concepts, but also school-aged children's abilities to act as active partners in producing knowledge about bodies. Intimate, visceral, and embodied knowledge of one's own body is not limited to adults, and children can and should participate in biosocial inquiry. The hyper-individualized nature of bodies in a biosocial framing requires understanding the specific structural and experiential pathways through which bodies are produced, and these pathways may differ between adults and children. Involving children as partners in biosocial research then serves both as a pedagogical tool and as a step towards a more inclusive means of producing knowledge about bodies.

The emergence of COVID-19 in the U.S. has further illustrated the relevancy of a biosocial framing in a number of ways. Tragically, the pandemic has illuminated with extreme clarity how experiences of racial and social marginalization increase the likelihood of the exposure to the virus (Oppel et al., 2020), the severity of symptoms (Azar et al., 2020), and the likelihood of mortality (Kim and Bostwick, 2020). Inequalities in housing, labor segregation, the ability to access healthy food, criminalization and incarceration, stress, and the uneven access to adequate medical care all represent possible modes by which social difference becomes material within living bodies under COVID-19. Perhaps as an artifact of the emphasis on transmission, much of the narrative of COVID-19 has been presented in starkly dualist terms (exposed/unexposed, infected/uninfected, symptomatic/asymptomatic). The reality is often much more relational. The many questions emerging about immune system response, viral load, emergent comorbid conditions and the long-term effects of the disease point to a degree of complexity *within* the body that is shaped by an interplay between the biological and the social, just as complex interrelations *outside* the body shape chains of transmission.

Feminist scholars have long called for "a more adequate, richer, better account of a world" (Haraway, 1991). Embracing a critical social perspective in order to inform our understandings of the inherently non-dualist and relational nature of human bodies (which themselves are situated within complex societal configurations) moves us on the path towards such an account. In parallel, informal science education strives to develop tools and frameworks to not only understand the world around us, but to shape our collective futures for the better. We have described here just one example of how a cross-disciplinary collaboration that brings together these visions can generate concrete strategies for engaging public audiences. We hope that partnering with those publics, guided by a broad framework for participation in cutting-edge research on the biosociality of human life, can be a step towards a better science and towards greater health and justice.

ASSOCIATED CONTENT

Supplemental material mentioned in this manuscript can be found uploaded to the same webpage as this the manuscript.

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ABBREVIATIONS

FLAE: First-Last-Author-Emphasis; UV: Ultraviolet

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