NDCAD Commentary

Environmental Contaminants and Child Development: Developmentally-Informed Opportunities and Recommendations for Integrating and Informing Child Environmental Health Science

Alison L. Miller

University of Michigan
School of Public Health

1415 Washington Street

Ann Arbor, MI 48109

Contact: alimill@umich.edu

Acknowledgements: Thank you to Olivia Halabicky, PhD and Sara Stein, PhD, for their helpful comments

Environmental Contaminants and Child Development: Developmentally-Informed Opportunities and Recommendations for Integrating and Informing Child Environmental Health Science

Abstract

Child environmental health (CEH) science has identified numerous effects of early life exposures to common, ubiquitous environmental toxicants. CEH scientists have documented the costs not only to individual children but also population-level health effects of such exposures. Importantly, such risks are unequally distributed in the population, with historically marginalized communities and the children living in these communities receiving the most damaging exposures. Developmental science offers a lens and set of methodologies to identify nuanced biological and behavioral processes that drive child development across physical, cognitive, and socioemotional domains. Developmental scientists are also expert in considering the multiple, hierarchically-layered contexts that shape development alongside toxicant exposure. Such contexts and the individuals acting within them make up an overarching "child serving ecosystem" (Miller et al., 2022) spanning systems and sectors that serve children directly and indirectly. Articulating how biobehavioral mechanisms and social-ecological contexts unfold from a developmental perspective are needed in order to inform CEH translation and intervention efforts across this child-serving ecosystem. Developmentalists can also benefit from integrating CEH science findings in their work by considering the role of the physical environment, and environmental toxicants specifically, on child health and development. Building on themes that were laid out by Trentacosta and Mulligan in 2020, this commentary presents recommendations for connecting developmental and CEH science and for translating such work so that it can be used to promote child development in an equitable manner across this child-serving ecosystem. These opportunities include: 1) Using Developmentally-Informed Conceptual Models; 2) Applying Creative, Sophisticated, and Rigorous Methods; 3) Integrating Developmentally-Sensitive Intervention Considerations; and 4) Establishing Interdisciplinary Collaborations and Cross-Sector Partnerships.

Environmental Contaminants and Child Development: Developmentally-Informed Opportunities and Recommendations for Integrating and Informing Child Environmental Health Science

Over the past few decades, the field of child environmental health (CEH) science has identified powerful effects of early life exposures to common environmental toxicants widely spread through air pollution (Perera, 2017), water (Hanna-Attisha et al., 2016), soil (Simcox et al., 1995), pesticides and other chemicals (Boucher et al., 2014; Eskenazi et al., 2013; Lanphear et al., 2005; Whyatt et al., 2012). CEH scientists have also documented that risk is unequally distributed in the population (Morello-Frosch & Shenassa, 2006; Persico et al., 2016; Sampson, 2022). Childhood exposures are costly not only for individual children but for society given burdens of long-term disease, disability, and loss of productivity over the lifespan (Landrigan et al., 2002; Lanphear et al., 2005). Guided by Developmental Origins of Health and Disease (Gluckman et al., 2016) and lifecourse health development theories (Halfon et al., 2014), CEH science has highlighted how the impacts of environmental toxicants can vary by type and timing of exposure across sensitive developmental periods (Golub, 2000; Rice & Barone, 2000). Methods used in this work have included large epidemiological studies, natural experiments, and mechanistic animal and human studies, and CEH research has resulted in actionable findings by, for example, lowering the threshold at which blood lead levels are deemed to be harmful (Ruckart et al., 2021).

Despite such findings, there remain gaps in translating CEH knowledge to promote child health (Birnbaum, 2018; Trentacosta et al., 2016; Trentacosta & Mulligan, 2020). One reason for such gaps is a lack of a developmental framework to characterize CEH impacts across a range of outcomes, inform intervention strategies, and help families understand and respond to CEH findings and changing guidance. The importance of working with communities to translate environmental health science has been described (Finn & Collman, 2016; Israel et al., 2005; O'Fallon & Dearry, 2002), but limited work has integrated developmental expertise into CEH translation efforts. The National Institute of Environmental Health Sciences (NIEHS) strategic plan (Birnbaum, 2018) endorses a lifespan perspective, a focus on individual differences in susceptibility, and overlapping contexts of exposure, all of which are core developmental science constructs. Developmental science offers a lens and set of methodologies to study nuanced biological and behavioral processes that drive child development across physical, cognitive, and socioemotional domains. Furthermore, developmental scientists are expert in considering the contexts that shape development alongside toxicant exposure. Articulating how mechanisms and social-ecological contexts unfold from a developmental perspective may help inform CEH translation and intervention efforts.

Developmentalists can also benefit from integrating CEH science findings in their work. In recent decades, developmental scientists have focused less on how physical (e.g., chemical exposures, air pollution) compared to social environments (e.g., psychosocial adversity) shape development. Yet, "riskscape" (Ugarte et al., this issue) and "exposome" frameworks (Buck Louis et al., 2017; Trentacosta & Mulligan, 2020) highlight how physical and psychosocial (or chemical and non-chemical) exposures influence child development. Determining how to mitigate such impacts is urgent considering that children who are growing up in historically marginalized communities experiencing systemic structural disadvantage and racism are often exposed to chronic and high levels of co-occurring social adversities and environmental injustices (Morello-Frosch & Shenassa, 2006). These populations are the focus of some papers in this Special Issue of *New Directions for Child and Adolescent Development*, and social and racial justice are appropriately and increasingly at the forefront of developmental science (Cooper et al., 2022). Applying developmentally-informed conceptual models and sophisticated methods to better understand nuanced impacts of such exposures on child development—and point to avenues for intervention—is thus both timely and of great public health importance.

Trentacosta and Mulligan (2020) identified four research themes emerging from CEH science regarding impacts of environmental exposures on child development. These were 1) disparities in exposures; 2) complexities of exposures; 3) mechanisms linking exposures to child outcomes; and 4) protective factors that mitigate exposure risks. Many of these themes appear in this Special Issue. Some studies concern populations who experienced disproportionately high exposures, including an Inuit (Bastien et al) and two Mexican birth cohorts (Merced-Nieves et al, Robledo et al). Others address complexity by examining specific mixtures (e.g., Merced-Nieves et al, Robledo et al, Schildroth et al) or broad exposures (e.g., Ugarte et al), and some study candidate bio-behavioral explanatory mechanisms (e.g., inflammation, Parenteau et al; ANS reactivity, Ugarte et al; learning tasks, Merced-Nieves et al). Finally, some studies identify possible protective factors that moderate the impact of exposure (e.g., weight status, Robledo et al; hippocampal volume; Miller et al). This issue thus begins to illustrate how developmental scientists are contributing to CEH science. Building on the themes laid out by Trentacosta and Mulligan, I reflect on four opportunities and recommendations to connect developmental and CEH science and move such work forward to promote child development in an equitable manner. These are outlined in Table 1 and include: 1) Using Developmentally-Informed Conceptual Models; 2) Applying Creative, Sophisticated, and Rigorous Methods; 3) Integrating Developmentally-Sensitive Intervention Considerations; and 4) Establishing Interdisciplinary Collaborations and Cross-Sector Partnerships.

1. Developmentally-informed conceptual models

<u>Social-Ecological Nesting: The Child-Serving Ecosystem (CSE)</u>

Trentacosta & Mulligan (2020) note how developmentally-informed conceptual models include multiple social-ecological contexts in which children are embedded. Such contexts can be hierarchically nested (e.g., the prenatal environment is nested in mother's social and environmental exposure histories) or somewhat independent (e.g., home vs. school settings). Social-ecological contexts also change over individual/developmental and historical time, or chronosystem (Bronfenbrenner, 1979). An example of developmental change is when children are exposed to new peer groups and activities during adolescence. Historical changes include events that impact a cohort distinctly as a function of their developmental stage (e.g., infants during the Flint Water Crisis; adolescents during the COVID-19 pandemic) or broader socio-cultural shifts, such as maternal employment changes. Finally, social-ecological contexts interact to shape development. For example, recent federal policy changes noting no safe levels of lead exposure have driven local changes in blood lead testing protocols, and, in combination with the COVID-19 pandemic, reduced capacity to detect and treat child lead poisoning (Woolf & Brown, 2022). Developmentally-informed conceptual models that articulate the contexts in which children are embedded and how they interact can aid in 1) detecting impacts of environmental exposures and 2) developing intervention strategies to prevent and/or mitigate impacts of exposure.

It can be further helpful to characterize these contexts and the individuals acting within them as an overarching "child serving ecosystem" or CSE (Miller, Stein, et al.). The CSE spans systems and sectors that serve children directly and indirectly. Individuals in the CSE include parents and caregivers, educators, and clinical care providers who *directly* shape child health and development, as well as (among others) the public health workforce and policymakers who shape child health *indirectly* (Miller, Stein, et al.). Indirect influences are particularly important for CEH considerations, as regulation of toxicants is driven by both local and higher-level policies, which are often siloed from each other and from systems meant to protect the public's health (Korfmacher, 2020). Developmentally-informed conceptual models that articulate connections across the CSE can help identify and leverage opportunities to intervene in key contexts to protect CEH threats (Bachrach, 2010; Miller, Stein, et al.).

Focus on Process and Patterns of Growth

Another feature of developmentally-informed conceptual models is their focus on detailing processes, or mechanisms, within an individual and in interaction with the environment as they unfold across the lifespan (Lerner, 1991). Such mechanisms can be nuanced; carefully phenotyping expected or "normative" developmental trajectories is thus critical in order to understand how toxicants may disrupt them. Furthermore, what may appear "adaptive" in one context or at one point in development may become a liability later, or vice versa. Two studies in the current issue grappled with such findings. Miller et al found that a smaller hippocampus, which has been associated with exposure to early adversity (Hanson et al., 2015), appeared to protect against a negative association between air pollution and telomere length. Ugarte et al found that despite positive associations between housing burden and air and water pollution, housing burden was associated with adaptive responses to stress in a laboratory task, whereas water and air pollution were associated with less adaptive responses. These examples of nuanced associations highlight the need for conceptual models that articulate complex routes of transmission from environmental exposure(s) to child outcomes.

Luckily, developmentally-informed conceptual models can help contextualize such findings. These models can describe both continuous linear growth patterns and discontinuous, non-linear transitions that involve hierarchical reorganization and consolidation before moving to the next stage (Cicchetti & Toth, 2009; Lerner et al., 2011). Non-linear developmental models can address "sleeper effects", such that children and youth may appear to be protected against harmful impacts during some phases of development but puberty-related biological and/or social changes, for example, may reveal the impacts of toxicants in a manner that appears discontinuous (Mayes, 2003; Spear, 2007). Differential susceptibility models of development describe how organisms can be differentially impacted by an external event such as an environmental exposure as a function of individual characteristics such as genetic makeup (Belsky et al., 2019; Roisman et al., 2012). Such models (along with "biological sensitivity to context" or "vantage sensitivity" models) are increasingly invoked in the child maltreatment and psychological treatment literatures in an effort to explain differential responses to intervention (Bakermans-Kranenburg & van IJzendoorn, 2015; de Villiers et al., 2018; M.H. et al., 2020). Although policies aimed at toxicant exposure prevention are critical, using models to inform the design of post-exposure interventions tailored to specific individuals (e.g., based on pubertal stage, sex, protective factors) could help mitigate the impact of prior exposures. Some studies in the Special Issue apply such models by testing moderators of association between exposure and outcome, as recommended by Trentacosta & Mulligan (2020). For example, Robledo et al found that associations between metal exposures and fat accumulation were stronger among adolescents with obesity. Miller et al found that air pollution was associated with shorter telomere length only among youth with larger hippocampal volumes. As with many models seeking to test moderation, sample sizes were relatively small, limiting power to detect effects, so future work should examine associations in larger samples.

Data Requirements

To test developmentally-informed models, it is important to examine associations longitudinally as well as within developmental periods. Only half of the studies in this issue included longitudinal assessments, and only one had more than two data points (Bastien et al). Future work using longitudinal designs with multiple data points could employ more sophisticated modeling techniques to capture complex patterns of association and change over time. Developmental systems and cascade models, for example, specify how within-person systems adapt over time in response to dynamically shifting external contexts and seek to model these pathways as they shape the developing organism (Masten, 2021). Testing such models requires not only longitudinal data but also specialized analysis techniques such as system dynamics modeling. Although not explicitly developmental in nature, recent examples from the CEH literature illustrate how to apply complex systems thinking and analysis to address environmental impacts on child health and development (Hubal et al., 2022; Payne-Sturges et al., 2021).

2. Creative, Sophisticated, and Rigorous Methods

<u>Assessing Developmentally-Meaningful Outcomes</u>

CEH science has historically focused on the impact of exposures on health outcomes such as asthma rather than social-emotional or behavioral functioning (Davis et al., 2019). Measuring the impact of exposures across multiple outcomes or nuanced indicators of bio-behavioral functioning can be challenging. Studies in the current issue assessed various bio-behavioral processes in relation to exposures. Two studies examined complex memory (Bastien et al.) and learning (Merced-Nieves et al.) tasks. Two others assessed physiological responses that are considered to index integrated bio-behavioral responses to stress (Parenteau et al.; Ugarte et al.). Still another study examined telomere length, considered to index chronic stress exposure (Miller et al.). These are exciting directions that illustrate the power of studying nuanced bio-behavioral processes as explanatory mechanism(s) of transmission from environmental exposures to a broader range of child developmental functioning and outcomes.

Of note, none of the studies in this issue tested outcomes in children younger than age 5 years. Yet, early childhood is a critical period for brain and organ development and vulnerability to chemical exposures (Bennett et al., 2016; Rice & Barone, 2000). Interventions to mitigate impacts of exposures may also be more effective in early compared to later childhood (Barouki et al., 2012; Bennett et al., 2016; Braun, 2017; Hirtz et al., 2017). Yet, deleterious effects of varied toxicant exposures on behavior, learning outcomes, and/or biological stress responses may be subtle and thus difficult to identify in young children (Konijnenberg, 2015; Lewis et al., 2014; Mayes, 2003). A recent review documented associations between environmental exposures and young children's social and cognitive development (prior to age 7), although few of these studies examined multiple or postnatal exposures (Davis et al., 2019). As early childhood is characterized by rapid change, using developmentally-appropriate and valid measures to capture these changes is important. As such, developmental expertise may be needed to conceptualize meaningful areas of early childhood functioning. Identifying the impacts of toxicant exposures on rapidly emerging and potentially subtle bio-behavioral processes is essential in order to identify developmentally-sensitive targets for intervention, and provides a natural and important point of connection between developmental and CEH scientists.

Assessing Complexity of Exposure(s)

CEH science has been critiqued for examining exposure to one toxicant at a time, as multiple exposures are more common than not (Buck Louis et al., 2017; Davis et al., 2019; Payne-Sturges et al., 2021). For example, cumulative risk assessments have been proposed to systematically examine cumulative and interactive impacts of both chemical and non-chemical (e.g., psychosocial stressors) environmental exposures (Payne-Sturges et al., 2018). Measuring and assessing the impact of exposure even to a single toxicant can be complex, however. Over half of the papers in this issue considered exposure to heavy metals, either singly or in combination. Robledo et al analyzed lead and mercury exposure individually and found they were differently associated with fat deposition patterns but only among adolescents with obesity. Studies that used sophisticated statistical methods to model combined exposures (e.g., Bayesian Kernel Machine Regression; Schildroth et al., Weighted Quantile Sum [WQS] regression; Merced-Nieves et al.) found that interactions among heavy metals were associated with multiple indicators of iron deficiency (Schildroth) and that prenatal exposure to metal mixtures–specifically lead, cadmium, and arsenic–was associated with poorer accuracy and response rate on a learning task (Merced-Nieves). Bastien et al. considered exposures to mercury, lead, or polychlorinated biphenyls [PCBs] across 3 developmental periods and found specificity related to type and timing of exposure on performance in a spatial memory task. Together, findings suggest that even when considering the role of a single toxicant, there are nuances to measurement, analysis, and interpretation. Developmental scientists are practiced at modeling such complexities, identifying where and how they are likely to occur within the CSE, and how associations may change with development.

Measuring the complexities of developmentally-salient exposures and outcomes is complicated. Yet, measurement challenges present opportunities for collaboration among CEH and developmental scientists. Matching administrative data on neighborhood or community-level environmental exposures to individually-assessed outcomes is one option, although there are limitations to the precision of this method, as noted by the authors who used this approach. A benefit of using administrative data is that results can be replicated across studies, a key goal for developmental science (Shrout & Rodgers, 2018). As methods to assess environmental exposures become more sophisticated and "light touch" we may also be poised to make great strides in assessing individual levels of exposure on a large scale. For example, although none of the studies in this Special Issue employed personal exposure monitors, research using such devices suggests exposure biomarkers vary by individual (Liang et al., 2019). Indeed, technologies are being marketed commercially and conducting research using individual-exposure measurement approaches may soon be more cost-effective, feasible, and acceptable (Caplin et al., 2019; Steinle et al., 2013; Xie et al., 2021).

Using Measurement Innovations for Change

Innovations in measurement have the potential to be used to effect change as well as prompt new research collaborations. Guidelines for conducting research where results are “reported back” to participants are emerging in the CEH field (Boronow et al., 2017; Haynes et al., 2016; Ohayon et al., 2017). This is important as individual and community-level exposure data can be used by community members to advocate for environmental policy changes (Caplin et al., 2019; Castner et al., 2022; Commodore et al., 2017; Wong et al., 2019). Mapping technologies that integrate community and individual-level exposure data—particularly as relevant to children—can be important tools for researchers and community members alike (Hartley et al., 2021; Stieb et al., 2019; Wong et al., 2019). Visual illustration of the complex systems involved in the pathways from exposure to impact can also be a helpful way to explain the mechanisms of transmission from exposure to child outcomes, and a potential tool to use in advocacy efforts (Hubal et al., 2022; Payne-Sturges et al., 2021).

3. Developmentally-Informed Intervention Considerations: Periods of Risk and Opportunity

Developmental science can also inform strategies to prevent and mitigate toxicant exposures. Perhaps most clearly, developmentally-informed research on the mechanisms of effect, as reviewed above and in this Special Issue, can and should be used to identify new intervention targets and pinpoint developmental risks. For example, using differential susceptibility models to identify moderators may lead to targeted interventions to mitigate exposures based on “what works best for whom”. Exposures also have different implications for children than adults as they tend to take in more of a given toxicant for their body weight, have organs and metabolic systems that are still developing, and may engage in behaviors that can place them at risk (Bearer, 1995). Although prevention of exposure is ideal, many children and youth, particularly in under-resourced contexts experiencing adversities, are not reached by prenatal or even early intervention. Thus, identifying when, how, and where to intervene across different developmental periods is essential for designing and implementing effective interventions.

<u>Developmental Periods of Risk</u>

Prenatal, Infancy and Early Childhood. The prenatal period is critical for intervention as many toxicants cross the placental barrier and affect fetal growth and development through organ damage and placental changes (Dugershaw et al., 2020). Breastfeeding during infancy is generally protective but can also transmit some risk depending on maternal exposures and diet (Rebelo & Caldas, 2016; Weisglas-Kuperus et al., 2004). Early childhood is important not only given rapid brain and organ development but also changes in child behaviors that can increase risk. For example, improved fine motor skills can increase pica, or eating of non-food items (Leung & Hon, 2019). New abilities to stand and “cruise” on furniture can result in a child mouthing windowsills that contain lead paint, and the onset of crawling and walking to independent play where a child may access contaminants in their home or in outside soil (Black et al., 2005; Mielke & Reagan, 1998). It is important to consider how these developmental achievements may also result in increased risk for exposures. Physical contexts in the CSE can also carry developmentally-specific risks, such as the use of toxic cleaning products in daycares (Alkon et al., 2022; Querdibitty et al., 2022) or poor indoor air quality (Gilden et al., 2021).

Adolescence. Unique risks emerge in adolescence due to increased autonomy to engage in behaviors that elevate toxicant exposures such as drinking, smoking and vaping (Rubinstein et al., 2018), increased cosmetic use (Madrigal et al., 2016), and/or direct workplace exposures to pesticides, heavy metals, and/or solvents (Golub, 2000; Woolf et al., 2001). Adolescents are also at biological risk due to rapid changes in their reproductive system, brain and other organs across this period (Golub, 2000; Spear, 2007). Identifying the nature of behavioral as well as biologically-driven risks for environmental exposures at specific periods of development, including adolescence, is essential in order to embrace a lifespan approach to prevention, as recommended in the NIEHS strategic plan (Birnbaum, 2018).

Opportunities for Intervention across the CSE

Risk factors have historically been the focus of much CEH and often developmental scientific research. Yet, identifying factors and processes that function to mitigate risk is equally if not more important, especially for children who have already been exposed to toxicants (Trentacosta & Mulligan, 2020). Such protective factors are also often developmentally "located" and thus identifying CEH-relevant protective factors across the CSE may benefit from developmental science contributions.

Parenting. Early caregiving relationships are foundational for healthy child development. Conceptualized broadly as "early relational health", positive parent-child relationships are recognized for their potential to protect against numerous social-contextual stressors by supporting child abilities to cope with stress, develop trust in others, and engage in learning and exploration opportunities (Garner et al., 2021; Willis & Eddy, 2022). Establishing early relational health–which, importantly, includes supporting caregivers to care for their children (Willis & Eddy, 2022)–could thus be an important tool for mitigating effects of toxicant exposure. Relationship-focused interventions for young children who have experienced significant psychosocial adversities such as foster care can positively impact child biological stress responses (Welch et al., 2020) and behavioral and cognitive outcomes (Grube & Liming, 2018). As well, nurturing care interventions to enhance relational health during the first 1000 days (0-3 years) of life are suggested as essential for counteracting the effects of poor nutritional and socioeconomic environments and promoting healthy development on a global scale (Lancet, 2016; Organization, 2018).

Child Care. Early care and education contexts are critical CSE settings for preventing exposure to toxicants and mitigating their impacts. In the United States, federally-funded early education programs (e.g., Head Start) are mandated to provide quality nutrition and cognitive stimulation, which are recommended as strategies to counteract the effects of toxicant exposure (Binns et al., 2007; Engle et al., 2007; Hennig et al., 2012). High-quality childcare is characterized by positive relationships between young children and childcare providers and thus has the potential to mitigate impacts of exposures through early relational health pathways (Ettinger et al., 2019; Hanna-Attisha et al., 2022; Schnur & John, 2014). Specialized early intervention (EI) services for young children may also be more successful when families trust and feel supported by their providers, reflecting relational health between families and providers (Jimenez et al., 2012; Miller, Stein, et al.). A recent analysis found that EI services, which entail individualized service plans tailored to child and family needs, mitigated the impact of lead exposure on later math and reading scores (Stingone et al., 2022). Thus, in addition to identifying and eliminating the physical sources of environmental exposures when possible (e.g., as with the Flint Water Crisis), providing individual, developmentally-tailored interventions—including those that address relational health across CSE contexts during early childhood—may be promising strategies for addressing impacts of exposure.

Caregiver Environmental Health Literacy and Community Advocacy. Empowering caregivers to act collectively on behalf of children is a component of early relational health (Willis & Eddy, 2022). Children are at unique risk for environmental threats, and collective action can be critical in advocating for policies to reduce impact of exposures, such as ensuring access to high-quality childcare and/or EI services (Hamp et al., 2018; Hanna-Attisha et al., 2022). Environmental health literacy, or the knowledge and skills needed to take action based on environmental health data, is a foundational step toward advocating for community and policy changes to protect CEH (Finn & O'Fallon, 2017; Gray, 2018; Nutbeam, 2008). Although parents and other CSE stakeholders can be deeply informed regarding child development, they are not typically informed regarding the role of environmental exposures or how to influence local CEH-relevant policies. For example, recent studies assessing environmental health literacy among EI specialists (Zimmerman et al., 2018) and childcare providers (Koester et al., 2021) found that these early childhood professionals had low environmental health literacy and low confidence regarding this topic. Environmental health literacy and confidence around managing patients' environmental concerns have been found to be lacking even among health care professionals (Brown et al., 2019; Kilpatrick et al., 2002; Zajac et al., 2020).

Environmental health literacy has been recognized as an important intervention lever (Claudio et al., 1998). Engaging and educating parents and providers who work with children across the CSE on local environmental exposures, risk factor screening, and the role that such exposures may play in the life of a child offer important developmentally-informed intervention opportunities (Bennett et al., 2016; Miller, Varisco, et al., 2022). Parents may express concerns but be uncertain about how to address them (Green et al., 2022). Some studies suggest that arming parents with environmental health literacy and personal exposure data can change individual behavior and create powerful community advocates (Commodore et al., 2017; Perovich et al., 2018; Ramirez-Andreotta et al., 2016; Wong et al., 2019). For example, providing feedback to parents around indoor toxicant exposures resulted in families making changes at home and becoming more aware of the need for policy-level change (Perovich et al., 2018; Ramirez-Andreotta et al., 2016). Using personal monitoring to identify child exposures in other CSE settings such as childcare could also yield actionable data. Interventions to increase environmental health literacy among childcare providers (Aurora O. Amoah, 2016; McKeon, 2021), train-the-trainer methods to promote eco-healthy childcares (Gilden et al., 2018), and efforts to promote environmental health literacy among health care providers have shown promise (Miller et al., 2016). Engaging parents to promote environmentally friendly childcares may also be a way to connect home and school contexts (Evans-Agnew, 2018). All of these approaches may benefit from involving developmentalists who have expertise working with parents and other CSE stakeholders.

Youth-Focused Interventions. Compared to early childhood, the adolescent CSE can involve different settings and stakeholders and more direct youth participation. Early adolescence (~10-15 years depending on pubertal status (Dorn et al., 2006)) is a powerful time for intervention as this is an age when new experiences and opportunities can provide inspiration and youth are open to envisioning their future (Crone & Dahl, 2012). Interventions that respectfully engage and empower youth to change their environments can establish new norms for sustained impact (Yeager et al., 2018; Zimmerman et al., 2013). CEH issues may appeal to youth given concerns around climate change (Lee et al., 2020) and related racial inequities (Roy et al., 2019). As youth environmental health literacy can be low (Bogar et al., 2017), youth may benefit from learning about their own exposures (Brickle & Evans-Agnew, 2017; Cardarelli et al., 2021). Studies have sought to engage adolescents using methods described earlier including personal monitoring and mapping of environmental exposure data. For example, Madrigal et al increased youth environmental health literacy regarding exposures to endocrine-disrupting chemicals in cosmetics, resulting in youth advocating for changes in local stores and creating social media campaigns (Madrigal et al., 2016). In other work, youth "citizen scientists" used portable air monitoring devices and videos to collect data across their CSE during a typical day, creating maps and increasing their environmental health literacy and capacity for advocacy (Johnston et al., 2019). A recent study engaged 13-18 year-old farmworkers in creating infographics based on research findings about their exposure to excessive heat (Quandt et al., 2022). Another study trained American Indian pre-adolescents in water pollution concepts and how to be advocates for change, increasing youth environmental health knowledge and enthusiasm for taking care of their environment (Simonds et al., 2019). Multiple studies in the current issue concerned the preadolescent and early adolescent periods (Miller et al., Parenteau et al., Robledo et al., Schildroth et al.); engaging youth in processing and acting on such findings would be an exciting direction for future work. Finally, as adolescents are entering their childbearing years, interventions that involve educating youth about the impacts of prenatal toxicant exposures (Buck Louis et al., 2017; Buck Louis et al., 2013) could have powerful intergenerational impacts.

Connecting the CSE to Promote CEH. The interconnected nature of chemical and non-chemical exposures is challenging for researchers trying to document specificity of effects (Buck Louis et al., 2017). Yet, because the child exists within overlapping physical and social environments, coordinated efforts across the CSE could address multiple exposures. Unfortunately, as with environmental health systems (Korfmacher, 2020) CSE systems and stakeholders are often siloed; they are not designed to function together, they communicate infrequently or ineffectively, and may even work at cross-purposes (Miller, Stein, et al.). Educating stakeholders across the CSE–families, pediatricians, educators, landlords, policymakers, product manufacturers, youth, and even researchers—about CEH may be a way to promote child health and development broadly (Bachrach, 2010). In addition to the above suggestions for working directly with parents, educators, and youth, connecting CSE stakeholders to regional CEH experts such as the Pediatric Environmental Health Specialty Units (PEHSUs) may yield collaborative opportunities to address CEH in CSE settings that do not primarily focus on environmental health concerns – for example, well-child pediatric visits or preschool orientation days (Zajac et al., 2020).

4. **Partnering Across Disciplines and Sectors**

To achieve the goal of combining developmental and CEH science to protect child health, particularly for children in structurally disadvantaged communities who experience the compounded impacts of psychosocial stressors and environmental risks (Leech et al., 2016; Morello-Frosch & Shenassa, 2006), we urgently need to translate CEH knowledge into action(s). To do so, we need interdisciplinary collaboration among CEH scientists, developmental scientists, and others. We also need cross-sector partnerships that center individuals whose environments are most impacted and include those who have the power to change exposures across the CSE (e.g., policymakers, industry polluters, politicians (Bachrach, 2010)). Indeed, CEH scientists have been leaders in this type of approach by requiring community engagement in NIEHS funded centers (Birnbaum, 2018; Lichtveld et al., 2016; O'Fallon et al., 2000; O'Fallon & Dearry, 2002). Each of these types of collaborative work are discussed in turn.

Interdisciplinary Collaborations

Interdisciplinary collaborative research can facilitate translating CEH findings, often based on animal models, to in vivo studies and beyond, to children in their natural environments. Effects of certain neurotoxicants that have been well-established in animal models are difficult to translate to the reality of child health and development (Bailey et al., 2016; Harry et al., 2022; Spear, 2007). This is understandable as emerging findings can lead to new concerns and changing guidance (Organization, 2010) and relative lack of control over human (particularly child) compared to animal lab environments (Bachrach, 2010; Bennett et al., 2016; Korfmacher, 2020; Korfmacher et al., 2016).

This is an area where developmental scientists can contribute, having considered such complexities for decades. For example, research on the impacts of early life stress and maternal behavior based on studies of "licking and grooming" rats (Beery & Francis, 2011; Orso et al., 2019) has prompted wide interest in translating findings from animal models to counteract the impacts of early life stress in humans (Heim et al., 2019; Nelson & Gabard-Durnam, 2020).

Interdisciplinary work takes time and effort and can face barriers, which can be especially daunting for early-career scientists (Gauvain, 2018). For example, simply the terminology used by CEH and developmental scientists to describe the prenatal to early childhood period varies (e.g., "first 1000 days", "first three years", "zero to three"), resulting in historically limited cross-fertilization of these literatures. There are many opportunities to build familiarity, however. Joint data collection efforts are an effective way to establish interdisciplinary collaborations. Including developmentally sensitive, nuanced assessments in cohorts with environmental exposure data is a critical step. Studies in the current Special Issue used the ELEMENT, Nunavik Child Development Study, and PROGRESS birth cohorts to do so, and the value of—and challenges in—conducting such work has been highlighted by CEH scientists (Eskenazi et al., 2005) and others (LeWinn et al., 2021). Creating synergistic models across human and animal cohorts is an excellent way to identify and test mechanisms, particularly when timing and level of exposures cannot be specified in human work. Industry or technology sector partnerships could facilitate use of personal exposure monitors to test mechanistic hypotheses regarding individual differences in susceptibility. Finally, connecting with risk communication scientists is essential in determining how to represent data and translate findings in a manner that is meaningful to key audiences, including families, communities, and policymakers (Raphael, 2019).

Partnerships with Communities

Community-based participatory research frameworks are central to CEH work focused on Environmental Justice (Israel et al., 2005; Korfmacher et al., 2016; Lichtveld et al., 2016; O'Fallon & Dearry, 2002; Raphael, 2019). Although less common in traditional developmental science, such approaches are increasingly recognized and appreciated (Mulvey et al., 2020; Rivas-Drake et al., 2016). Community partnerships are essential for translating research findings to foster positive outcomes for children. Engaging community stakeholders across the CSE is necessary not only to identify CEH threats and training needs, but also barriers and opportunities for developmentally-informed, community-relevant implementation of CEH findings. For example, if contaminants are discovered in a childcare or community playground, how can we ensure children continue to gain socialization and other benefits of childcare attendance and outside play without risking additional exposures? Developmental and CEH scientists could also connect with communities to advocate for CEH-informed policy recommendations regarding manufacture of child- and family-facing products in order to reduce toxicant exposures (Bachrach, 2010; Korfmacher et al., 2016).

Respectful community partnerships can guide meaningful research questions, connect systems, and create policy change. Communities who are most impacted by environmental toxicant exposures often have the least power or access to policymakers and limited time for advocacy, so it is important for both CEH and developmental scientists to support communities to engage in collective action and advocacy to protect their children and ensure that community voices are heard (Haynes et al., 2016; Lichtveld et al., 2016; Miller, Varisco, et al., 2022; Raphael, 2019). Given the history of racist policies and mismanagement of environmental pollution, it is essential to build trust among historically marginalized communities (Binder et al., 2022). Citizen science approaches provide a way to partner with community members to gather data and inform study designs that are community-oriented (Sandhaus et al., 2019). Key elements of successful partnerships include dedicating time and resources to build partnerships, addressing interdisciplinary and cross-sector issues, ensuring community representation, co-developing and exchanging knowledge, actively participating, and maintaining collaborative activities over time (Wine, 2017). Taking an Environmental Justice perspective is particularly important in the context of an environmental disaster, as communities know their own priorities and what will and will not work in their setting (Hanna-Attisha et al., 2022; Lichtveld et al., 2016; Raphael, 2019). A potential additional contribution of a developmental perspective could be an explicit focus on listening to the needs of children and families, centering those needs, and advocating for services that may be helpful to them (Hanna-Attisha et al., 2022; Mulvey et al., 2020; Rivas-Drake et al., 2016).

Takeaways for developmental scientists

This is an exciting and important time to apply developmental thinking and methods to study environmental toxicant exposures and learn how to mitigate the effects on children. Risks to healthy development can emerge not only as a result of direct exposure but also climate change-related impacts on access to clean water, clean air, and adequate nutrition on a global scale and the physical and psychosocial stressors this creates (Nations, 2014). CEH and developmental science researchers are increasingly examining the nuances of different levels, timing, mixtures, and types of exposure to risk and protective factors, rather than broad main effects, which should inform interventions (Trentacosta & Mulligan, 2020). Using developmentally-sensitive conceptual models and methods to guide research on the mechanisms of association between exposures and developmental outcomes and to model the contexts of child development will allow for more effective translation of CEH science findings to improve child health and development across the CSE. Developmental scientists are practiced at conceptualizing, measuring, and modeling complex and interconnected social-contextual influences on nuanced aspects of development. Given the urgency of CEH risks and increasing appreciation for the value of interdisciplinary and collaborative work, there should be ample opportunity and motivation for developmental scientists to reach out to CEH colleagues to engage with these issues in order to promote healthy development in children and across the lifespan.

References

Alkon, A., Gunier, R. B., Hazard, K., Castorina, R., Hoffman, P. D., Scott, R. P., Anderson, K. A., & Bradman, A. (2022). Preschool-Age Children's Pesticide Exposures in Child Care Centers and at Home in Northern California. *Journal of Pediatric Health Care, 36*(1), 34-45.

Aurora O. Amoah, N. O. W., Joanne Pérodin, Jerome A. Paulson. (2016). Findings from a pilot environmental health intervention at early childhood centers in the District of Columbia. *Journal of Public Health, 38*(3), e209-e217.

Bachrach, A., Higgins, L. B., & Stagman, S. M. (2010). Environmental Health in Early Childhood Systems Building: Opportunities for States. *National Center for Children in Poverty, Brief, Columbia University*. https://doi.org/https://doi.org/10.7916/D85D90TW

Bailey, K. A., Smith, A. H., Tokar, E. J., Graziano, J. H., Kim, K. W., Navasumrit, P., Ruchirawat, M., Thiantanawat, A., Suk, W. A., & Fry, R. C. (2016, Feb). Mechanisms Underlying Latent Disease Risk Associated with Early-Life Arsenic Exposure: Current Research Trends and Scientific Gaps. *Environ Health Perspect, 124*(2), 170-175. https://doi.org/10.1289/ehp.1409360

Bakermans-Kranenburg, M. J., & van IJzendoorn, M. H. (2015, Jan 3). The hidden efficacy of interventions: gene×environment experiments from a differential susceptibility perspective. *Annu Rev Psychol, 66*, 381-409. https://doi.org/10.1146/annurev-psych-010814-015407

Barouki, R., Gluckman, P. D., Grandjean, P., Hanson, M., & Heindel, J. J. (2012). Developmental origins of non-communicable disease: implications for research and public health. *Environmental Health, 11*(1), 1-9.

Bearer, C. F. (1995). How are children different from adults? *Environmental health perspectives, 103*(suppl 6), 7-12.

Beery, A. K., & Francis, D. D. (2011, 2011/06/01/). Adaptive significance of natural variations in maternal care in rats: A translational perspective. *Neuroscience & Biobehavioral Reviews, 35*(7), 1552-1561. https://doi.org/https://doi.org/10.1016/j.neubiorev.2011.03.012

Belsky, J., Pokhvisneva, I., Rema, A. S. S., Broekman, B. F. P., Pluess, M., O'Donnell, K. J., Meaney, M. J., & Silveira, P. P. (2019, May). Polygenic differential susceptibility to prenatal adversity. *Dev Psychopathol, 31*(2), 439-441. https://doi.org/10.1017/s0954579418000378

Bennett, D., Bellinger, D. C., Birnbaum, L. S., DABT, ATS, Bradman, A., Chen, A., Cory-Slechta, D. A., Engel, S. M., & Fallin, M. D. (2016). Project TENDR: targeting environmental neuro-developmental risks the TENDR consensus statement. *Environmental health perspectives, 124*(7), A118-A122.

Binder, A. R., May, K., Murphy, J., Gross, A., & Carlsten, E. (2022, Feb 25). Environmental Health Literacy as Knowing, Feeling, and Believing: Analyzing Linkages between Race, Ethnicity, and Socioeconomic Status and Willingness to Engage in Protective Behaviors against Health Threats. *Int J Environ Res Public Health, 19*(5). https://doi.org/10.3390/ijerph19052701

Binns, H. J., Campbell, C., Brown, M. J., & Prevention, f. t. A. C. o. C. L. P. (2007). Interpreting and Managing Blood Lead Levels of Less Than 10 µg/dL in Children and Reducing Childhood Exposure to Lead: Recommendations of the Centers for Disease Control and Prevention Advisory Committee on Childhood Lead Poisoning Prevention. *Pediatrics, 120*(5), e1285-e1298. https://doi.org/10.1542/peds.2005-1770

Birnbaum, L. S. (2018). Moving NIEHS Forward for the Next Five Years.

Black, K., Shalat, S. L., Freeman, N. C., Jimenez, M., Donnelly, K. C., & Calvin, J. A. (2005). Children's mouthing and food-handling behavior in an agricultural community on the US/Mexico border. *Journal of Exposure Science & Environmental Epidemiology, 15*(3), 244-251.

Bogar, S., Szabo, A., Woodruff, S., & Johnson, S. (2017). Urban youth knowledge and attitudes regarding lead poisoning. *Journal of Community Health, 42*(6), 1255-1266.

Boronow, K. E., Susmann, H. P., Gajos, K. Z., Rudel, R. A., Arnold, K. C., Brown, P., Morello-Frosch, R., Havas, L., & Brody, J. G. (2017). DERBI: a digital method to help researchers offer “right-to-know” personal exposure results. *Environmental health perspectives, 125*(2), A27-A33.

Boucher, O., Muckle, G., Jacobson, J. L., Carter, R. C., Kaplan-Estrin, M., Ayotte, P., Dewailly, É., & Jacobson, S. W. (2014). Domain-specific effects of prenatal exposure to PCBs, mercury, and lead on infant cognition: results from the Environmental Contaminants and Child Development Study in Nunavik. *Environmental health perspectives, 122*(3), 310-316.

Braun, J. M. (2017). Early-life exposure to EDCs: role in childhood obesity and neurodevelopment. *Nature Reviews Endocrinology, 13*(3), 161-173.

Brickle, M. B., & Evans-Agnew, R. (2017, Apr-Jun). Photovoice and Youth Empowerment in Environmental Justice Research: A Pilot Study Examining Woodsmoke Pollution in a Pacific Northwest Community. *J Community Health Nurs, 34*(2), 89-101. https://doi.org/10.1080/07370016.2017.1304148

Bronfenbrenner, U. (1979). *The ecology of human development: Experiments by nature and design*. Harvard university press.

Brown, P., Clark, S., Zimmerman, E., Valenti, M., & Miller, M. D. (2019). Health professionals’ environmental health literacy. *Environmental Health Literacy*, 195-227.

Buck Louis, G. M., Smarr, M. M., & Patel, C. J. (2017). The exposome research paradigm: an opportunity to understand the environmental basis for human health and disease. *Current environmental health reports, 4*(1), 89-98.

Buck Louis, G. M., Yeung, E., Sundaram, R., Laughon, S. K., & Zhang, C. (2013, May). The exposome--exciting opportunities for discoveries in reproductive and perinatal epidemiology. *Paediatr Perinat Epidemiol, 27*(3), 229-236. https://doi.org/10.1111/ppe.12040

Caplin, A., Ghandehari, M., Lim, C., Glimcher, P., & Thurston, G. (2019). Advancing environmental exposure assessment science to benefit society. *Nature communications, 10*(1), 1-11.

Cardarelli, K. M., Ickes, M., Huntington-Moskos, L., Wilmhoff, C., Larck, A., Pinney, S. M., & Hahn, E. J. (2021, Feb 23). Authentic Youth Engagement in Environmental Health Research and Advocacy. *Int J Environ Res Public Health, 18*(4). https://doi.org/10.3390/ijerph18042154

Castner, J., Huntington-Moskos, L., & May, A. (2022). Generating Data Visualizations of Longitudinal Cohort Ambient Air Pollution Exposure: Report-Back Intervention Development in Participatory Action Research. *CIN: Computers, Informatics, Nursing, 40*(1), 44-52.

Cicchetti, D., & Toth, S. L. (2009). The past achievements and future promises of developmental psychopathology: the coming of age of a discipline. *Journal of Child Psychology and Psychiatry, 50*(1-2), 16-25. https://doi.org/https://doi.org/10.1111/j.1469-7610.2008.01979.x

Claudio, L., Torres, T., Sanjurjo, E., Sherman, L. R., & Landrigan, P. J. (1998). Environmental health sciences education--a tool for achieving environmental equity and protecting children. *Environmental health perspectives, 106*(suppl 3), 849-855.

Commodore, A., Wilson, S., Muhammad, O., Svendsen, E., & Pearce, J. (2017, 2017/07/06). Community-based participatory research for the study of air pollution: a review of motivations, approaches, and outcomes. *Environmental Monitoring and Assessment, 189*(8), 378. https://doi.org/10.1007/s10661-017-6063-7

Cooper, S. M., Hurd, N. M., & Loyd, A. B. (2022). Advancing scholarship on anti-racism within developmental science: Reflections on the special section and recommendations for future research. *Child Development*.

Crone, E. A., & Dahl, R. E. (2012, 2012/09/01). Understanding adolescence as a period of social–affective engagement and goal flexibility. *Nature Reviews Neuroscience, 13*(9), 636-650. https://doi.org/10.1038/nrn3313

Davis, A. N., Carlo, G., Gulseven, Z., Palermo, F., Lin, C.-H., Nagel, S. C., Vu, D. C., Vo, P. H., Ho, T. L., & McElroy, J. A. (2019). Exposure to environmental toxicants and young children's cognitive and social development. *Reviews on environmental health, 34*(1), 35-56.

de Villiers, B., Lionetti, F., & Pluess, M. (2018, 2018/06/01). Vantage sensitivity: a framework for individual differences in response to psychological intervention. *Social Psychiatry and Psychiatric Epidemiology, 53*(6), 545-554. https://doi.org/10.1007/s00127-017-1471-0

Dorn, L. D., Dahl, R. E., Woodward, H. R., & Biro, F. (2006). Defining the boundaries of early adolescence: A user's guide to assessing pubertal status and pubertal timing in research with adolescents. *Applied Developmental Science, 10*(1), 30-56. https://doi.org/10.1207/s1532480xads1001_3

Dugershaw, B. B., Aengenheister, L., Hansen, S. S. K., Hougaard, K. S., & Buerki-Thurnherr, T. (2020). Recent insights on indirect mechanisms in developmental toxicity of nanomaterials. *Particle and Fibre Toxicology, 17*(1), 1-22.

Engle, P. L., Black, M. M., Behrman, J. R., Cabral de Mello, M., Gertler, P. J., Kapiriri, L., Martorell, R., & Young, M. E. (2007, 2007/01/20/). Strategies to avoid the loss of developmental potential in more than 200 million children in the developing world. *The Lancet, 369*(9557), 229-242. https://doi.org/https://doi.org/10.1016/S0140-6736(07)60112-3

Eskenazi, B., Chevrier, J., Rauch, S. A., Kogut, K., Harley, K. G., Johnson, C., Trujillo, C., Sjödin, A., & Bradman, A. (2013). In utero and childhood polybrominated diphenyl ether (PBDE) exposures and neurodevelopment in the CHAMACOS study. *Environmental health perspectives, 121*(2), 257-262.

Eskenazi, B., Gladstone, E. A., Berkowitz, G. S., Drew, C. H., Faustman, E. M., Holland, N. T., Lanphear, B., Meisel, S. J., Perera, F. P., & Rauh, V. A. (2005). Methodologic and logistic issues in conducting longitudinal birth cohort studies: lessons learned from the Centers for Children's Environmental Health and Disease Prevention Research. *Environmental health perspectives, 113*(10), 1419-1429.

Ettinger, A. S., Leonard, M. L., & Mason, J. (2019). CDC's Lead Poisoning Prevention Program: A long-standing responsibility and commitment to protect children from lead exposure. *Journal of public health management and practice: JPHMP, 25*(Suppl 1 LEAD POISONING PREVENTION), S5.

Evans-Agnew, R. A., Postma, J., Ochoa Camacho, A., Hershberg, R.M., Trujilio, E., & Tinajera, M. . (2018). Development and Pilot Testing of a Bilingual Environmental Health Assessment Tool to Promote Asthma-friendly Childcares. *Progress in Community Health Partnerships: Research, Education, and Action, 12*(1), 35-44. https://doi.org/doi:10.1353/cpr.2018.0004

Finn, S., & Collman, G. (2016). The pivotal role of the social sciences in environmental health sciences research. *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy, 26*(3), 389-411.

Finn, S., & O'Fallon, L. (2017). The emergence of environmental health literacy—from its roots to its future potential. *Environmental health perspectives, 125*(4), 495-501.

Garner, A., Yogman, M., Child, C. o. P. A. o., & Health, F. (2021). Preventing childhood toxic stress: partnering with families and communities to promote relational health. *Pediatrics, 148*(2).

Gauvain, M. (2018). From Developmental Psychologist to Water Scientist and Back Again: The Role of Interdisciplinary Research in Developmental Science. *Child Development Perspectives, 12*(1), 45-50. https://doi.org/https://doi.org/10.1111/cdep.12255

Gilden, R., Friedmann, E., Spanier, A., & Hennigan, C. (2021). Indoor air quality monitoring in Baltimore City, MD head start centers. *International Journal of Environmental Science and Technology*, 1-8.

Gilden, R., McElroy, K., Friedmann, E., Spanier, A., Son, H., Witherspoon, N. O., & Pauk, H. (2018). Train-the-Trainer Approach in the Eco-Healthy Child Care® Program. *Health Behavior and Policy Review, 5*(2), 59-65.

Gluckman, P. D., Buklijas, T., & Hanson, M. A. (2016). The developmental origins of health and disease (DOHaD) concept: past, present, and future. In *The epigenome and developmental origins of health and disease* (pp. 1-15). Elsevier.

Golub, M. S. (2000). Adolescent health and the environment. *Environmental health perspectives, 108*(4), 355-362.

Gray, K. M. (2018, Mar 2018

2022-01-06). From Content Knowledge to Community Change: A Review of Representations of Environmental Health Literacy. *International journal of environmental research and public health, 15*(3), 466. https://doi.org/https://doi.org/10.3390/ijerph15030466

Green, R., Lanphear, B., Phipps, E., Goodman, C., Joy, J., Rihani, S., Flora, D., & Till, C. (2022). Development and Validation of the Prevention of Toxic Chemicals in the Environment for Children Tool: A Questionnaire for Examining the Community's Knowledge of and Preferences Toward Toxic Chemicals and Children's Brain Development. *Front Public Health, 10*, 863071. https://doi.org/10.3389/fpubh.2022.863071

Grube, W. A., & Liming, K. W. (2018). Attachment and Biobehavioral Catch-up: A systematic review. *Infant Mental Health Journal, 39*(6), 656-673.

Halfon, N., Larson, K., Lu, M., Tullis, E., & Russ, S. (2014, 2014/02/01). Lifecourse Health Development: Past, Present and Future. *Maternal and Child Health Journal, 18*(2), 344-365. https://doi.org/10.1007/s10995-013-1346-2

Hamp, N., Zimmerman, A., & Hoffen, J. (2018, Oct 1). Advocating for Automatic Eligibility for Early Intervention Services for Children Exposed to Lead. *Pediatr Ann, 47*(10), e413-e418. https://doi.org/10.3928/19382359-20180924-01

Hanna-Attisha, M., Hamp, N., & O'Connell, L. (2022). Promise of Early Intervention for Children Exposed to Lead. *JAMA pediatrics, 176*(5), 446-448.

Hanna-Attisha, M., LaChance, J., Sadler, R. C., & Champney Schnepp, A. (2016). Elevated blood lead levels in children associated with the Flint drinking water crisis: a spatial analysis of risk and public health response. *American journal of public health, 106*(2), 283-290.

Hanson, J. L., Nacewicz, B. M., Sutterer, M. J., Cayo, A. A., Schaefer, S. M., Rudolph, K. D., Shirtcliff, E. A., Pollak, S. D., & Davidson, R. J. (2015). Behavioral problems after early life stress: contributions of the hippocampus and amygdala. *Biological psychiatry, 77*(4), 314-323.

Harry, G. J., McBride, S., Witchey, S. K., Mhaouty-Kodja, S., Trembleau, A., Bridge, M., & Bencsik, A. (2022). Roadbumps at the Crossroads of Integrating Behavioral and In Vitro Approaches for Neurotoxicity Assessment. *Front Toxicol, 4*, 812863. https://doi.org/10.3389/ftox.2022.812863

Hartley, J. M., Lobatos, S., Daniel, J. L., & Lung, T. (2021). Empowering Environmental Justice Decision Makers: Increasing Educational Resources for US Environmental Protection Agency's Mapping Tools. *Environmental Justice, 14*(5), 383-390.

Haynes, E. N., Elam, S., Burns, R., Spencer, A., Yancey, E., Kuhnell, P., Alden, J., Walton, M., Reynolds, V., Newman, N., Wright, R. O., Parsons, P. J., Praamsma, M. L., Palmer, C. D., & Dietrich, K. N. (2016). Community Engagement and Data Disclosure in Environmental Health Research. *Environmental health perspectives, 124*(2), A24-A27. https://doi.org/10.1289/ehp.1510411

Heim, C. M., Entringer, S., & Buss, C. (2019, Jul). Translating basic research knowledge on the biological embedding of early-life stress into novel approaches for the developmental programming of lifelong health. *Psychoneuroendocrinology, 105*, 123-137. https://doi.org/10.1016/j.psyneuen.2018.12.011

Hennig, B., Ormsbee, L., McClain, C. J., Watkins, B. A., Blumberg, B., Bachas, L. G., Sanderson, W., Thompson, C., & Suk, W. A. (2012, Jun 2012

2013-03-07). Nutrition Can Modulate the Toxicity of Environmental Pollutants: Implications in Risk Assessment and Human Health. *Environmental health perspectives, 120*(6), 771-774.

Hirtz, D., Campbell, C., & Lanphear, B. (2017). Targeting environmental neurodevelopmental risks to protect children. *Pediatrics, 139*(2).

Hubal, E. A. C., DeLuca, N. M., Mullikin, A., Slover, R., Little, J. C., & Reif, D. M. (2022, Feb 15). Demonstrating a systems approach for integrating disparate data streams to inform decisions on children's environmental health. *BMC Public Health, 22*(1), 313. https://doi.org/10.1186/s12889-022-12682-3

Israel, B. A., Parker, E. A., Rowe, Z., Salvatore, A., Minkler, M., López, J., Butz, A., Mosley, A., Coates, L., & Lambert, G. (2005). Community-based participatory research: lessons learned from the Centers for Children’s Environmental Health and Disease Prevention Research. *Environmental health perspectives, 113*(10), 1463-1471.

Jimenez, M. E., Barg, F. K., Guevara, J. P., Gerdes, M., & Fiks, A. G. (2012, 2012/11/01/). Barriers to Evaluation for Early Intervention Services: Parent and Early Intervention Employee Perspectives. *Academic Pediatrics, 12*(6), 551-557. https://doi.org/https://doi.org/10.1016/j.acap.2012.08.006

Johnston, J. E., Juarez, Z., Navarro, S., Hernandez, A., & Gutschow, W. (2019, Dec 21). Youth Engaged Participatory Air Monitoring: A 'Day in the Life' in Urban Environmental Justice Communities. *Int J Environ Res Public Health, 17*(1). https://doi.org/10.3390/ijerph17010093

Kilpatrick, N., Frumkin, H., Trowbridge, J., Escoffery, C., Geller, R., Rubin, L., Teague, G., & Nodvin, J. (2002). The environmental history in pediatric practice: a study of pediatricians' attitudes, beliefs, and practices. *Environmental health perspectives, 110*(8), 823-827.

Koester, B. D., Sloane, S., Fujimoto, E. M., Fiese, B. H., & Leona Yi-Fan, S. (2021, 2021). What Do Childcare Providers Know about Environmental Influences on Children's Health? Implications for Environmental Health Literacy Efforts. *International journal of environmental research and public health, 18*(10), 5489. https://doi.org/https://doi.org/10.3390/ijerph18105489

Konijnenberg, C. (2015). Methodological Issues in Assessing the Impact of Prenatal Drug Exposure. *Subst Abuse, 9*(Suppl 2), 39-44. https://doi.org/10.4137/sart.s23544

Korfmacher, K. S. (2020, Nov). Bridging Silos: A Research Agenda for Local Environmental Health Initiatives. *New Solut, 30*(3), 173-182. https://doi.org/10.1177/1048291120947370

Korfmacher, K. S., Pettibone, K. G., Gray, K. M., & Newman, O. D. (2016). Collaborating for systems change: A social science framework for academic roles in community partnerships. *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy, 26*(3), 429-457.

Lancet, T. (2016). Series advancing early childhood development: From science to scale. *Retrieved from www.thelancet.com/series/ECD2016*.

Landrigan, P. J., Schechter, C. B., Lipton, J. M., Fahs, M. C., & Schwartz, J. (2002). Environmental pollutants and disease in American children: estimates of morbidity, mortality, and costs for lead poisoning, asthma, cancer, and developmental disabilities. *Environmental health perspectives, 110*(7), 721-728.

Lanphear, B. P., Hornung, R., Khoury, J., Yolton, K., Baghurst, P., Bellinger, D. C., Canfield, R. L., Dietrich, K. N., Bornschein, R., & Greene, T. (2005). Low-level environmental lead exposure and children's intellectual function: an international pooled analysis. *Environmental health perspectives, 113*(7), 894-899.

Lee, K., Gjersoe, N., O'Neill, S., & Barnett, J. (2020). Youth perceptions of climate change: A narrative synthesis. *WIREs Climate Change, 11*(3), e641. https://doi.org/https://doi.org/10.1002/wcc.641

Leech, T. G., Adams, E. A., Weathers, T. D., Staten, L. K., & Filippelli, G. M. (2016, Jul-Sep). Inequitable Chronic Lead Exposure: A Dual Legacy of Social and Environmental Injustice. *Fam Community Health, 39*(3), 151-159. https://doi.org/10.1097/fch.0000000000000106

Lerner, R. M. (1991). Changing organism-context relations as the basic process of development: A developmental contextual perspective. *Developmental Psychology, 27*(1), 27-32. https://doi.org/10.1037/0012-1649.27.1.27 (Canalization of Behavioral Development)

Lerner, R. M., Leonard, K., Fay, K., & Issac, S. S. (2011). Continuity and discontinuity in development across the life span: A developmental systems perspective. In *Handbook of life-span development.* (pp. 141-160). Springer Publishing Company.

Leung, A. K., & Hon, K. L. (2019). Pica: a common condition that is commonly missed-an update review. *Current pediatric reviews, 15*(3), 164-169.

LeWinn, K. Z., Caretta, E., Davis, A., Anderson, A. L., Oken, E., & on behalf of program collaborators for Environmental influences on Child Health, O. (2021, 2021/06/15). SPR perspectives: Environmental influences on Child Health Outcomes (ECHO) Program: overcoming challenges to generate engaged, multidisciplinary science. *Pediatric Research*. https://doi.org/10.1038/s41390-021-01598-0

Lewis, A. J., Galbally, M., Gannon, T., & Symeonides, C. (2014, 2014/02/24). Early life programming as a target for prevention of child and adolescent mental disorders. *BMC Medicine, 12*(1), 33. https://doi.org/10.1186/1741-7015-12-33

Liang, L., Gong, P., Cong, N., Li, Z., Zhao, Y., & Chen, Y. (2019). Assessment of personal exposure to particulate air pollution: the first result of City Health Outlook (CHO) project. *BMC Public Health, 19*(1), 1-12.

Lichtveld, M., Goldstein, B., Grattan, L., & Mundorf, C. (2016). Then and now: lessons learned from community-academic partnerships in environmental health research. *Environmental Health, 15*(1), 1-4.

M.H., v. I., Bakermans-Kranenburg, M. J., Coughlan, B., & Reijman, S. (2020, Mar). Annual Research Review: Umbrella synthesis of meta-analyses on child maltreatment antecedents and interventions: differential susceptibility perspective on risk and resilience. *J Child Psychol Psychiatry, 61*(3), 272-290. https://doi.org/10.1111/jcpp.13147

Madrigal, D. S., Minkler, M., Parra, K. L., Mundo, C., Gonzalez, J. E. C., Jimenez, R., Vera, C., & Harley, K. G. (2016). Improving Latino youths' environmental health literacy and leadership skills through participatory research on chemical exposures in cosmetics: The HERMOSA Study. *International quarterly of community health education, 36*(4), 231-240.

Masten, A. S. (2021, Feb). Resilience of children in disasters: A multisystem perspective. *Int J Psychol, 56*(1), 1-11. https://doi.org/10.1002/ijop.12737

Mayes, L. C., & Ward, A. . (2003). Principles of neurobehavioral teratology. *Neurodevelopmental Mechanisms of Psychopathology*, 3-22.

McKeon, T. P. S., Frances S.; Howarth, Marilyn V. . (2021). Enhancing Environmental Health Literacy about the Asthma- Air Pollution Connection at Childcare Centers in Asthma Prevalent Philadelphia Neighborhoods. *Journal of Health Disparities Research and Practice, 14*(3).

Mielke, H. W., & Reagan, P. L. (1998). Soil is an important pathway of human lead exposure. *Environmental health perspectives, 106*(suppl 1), 217-229.

Miller, A. L., Stein, S. F., Sokol, R., Varisco, R., Trout, P., Julian, M. M., Ribaudo, J., Kay, J., Pilkauskas, N. V., Gardner-Neblett, N., Herrenkohl, T. I., Zivin, K., Muzik, M., & Rosenblum, K. L. (2022, 2022). From zero to thrive: A model of cross-system and cross-sector relational health to promote early childhood development across the child-serving ecosystem. *Infant Mental Health Journal, n/a*(n/a). https://doi.org/https://doi.org/10.1002/imhj.21996

Miller, A. L., Varisco, R., Charles, S., Haan, P., Stein, S. F., Hernandez, J., Riley, H. O., Sokol, R., Trout, P., & Arboleda, L. (2022, 2022). Parenting and Lead Mitigation at Home: A Multifaceted

Community Partnership Model Promoting Parent Engagement in Lead Exposure Prevention. *Health Promotion Practice*, 15248399221092998.

Miller, M. D., Valenti, M., Schettler, T., & Tencza, B. (2016, 2016). A Multimedia E-Book--A Story of Health: Filling a Gap in Environmental Health Literacy for Health Professionals. *Environmental Health Perspectives (Online), 124*(8).

Morello-Frosch, R., & Shenassa, E. D. (2006). The environmental "riskscape" and social inequality: implications for explaining maternal and child health disparities. *Environmental health perspectives, 114*(8), 1150-1153.

Mulvey, K. L., McGuire, L., Hoffman, A. J., Hartstone-Rose, A., Winterbottom, M., Balkwill, F., Fields, G. E., Burns, K., Drews, M., Chatton, M., Eaves, N., Law, F., Joy, A., & Rutland, A. (2020). Learning hand in hand: Engaging in research–practice partnerships to advance developmental science. *New directions for child and adolescent development, 2020*(172), 125-134. https://doi.org/https://doi.org/10.1002/cad.20364

Nations, U. (2014). The millennium development goals report *http://www.un.org/millenniumgoals/2015/MD, New York, NY*.

Nelson, C. A., & Gabard-Durnam, L. J. (2020, 2020/03/01/). Early Adversity and Critical Periods: Neurodevelopmental Consequences of Violating the Expectable Environment. *Trends in Neurosciences, 43*(3), 133-143. https://doi.org/https://doi.org/10.1016/j.tins.2020.01.002

Nutbeam, D. (2008). The evolving concept of health literacy. *Social science & medicine, 67*(12), 2072-2078.

O'Fallon, L. R., Collman, G. W., & Dearry, A. (2000, 2000/11/01). The National Institute of Environmental Health Sciences' research program on children's environmental health. *Journal of Exposure Science & Environmental Epidemiology, 10*(6), 630-637. https://doi.org/10.1038/sj.jea.7500117

O'Fallon, L. R., & Dearry, A. (2002). Community-based participatory research as a tool to advance environmental health sciences. *Environmental health perspectives, 110*(suppl 2), 155-159.

Ohayon, J. L., Cousins, E., Brown, P., Morello-Frosch, R., & Brody, J. G. (2017, 2017/02/01/). Researcher and institutional review board perspectives on the benefits and challenges of reporting back biomonitoring and environmental exposure results. *Environmental Research, 153*, 140-149. https://doi.org/https://doi.org/10.1016/j.envres.2016.12.003

Organization, W. H. (2010). Protecting children's health in a changing environment: report of the fifth ministerial conference on environment and health. . *World Health Organization. Regional Office for Europe.*

Organization, W. H. (2018). Nurturing care for early childhood development: a framework for helping children survive and thrive to transform health and human potential.

Orso, R., Creutzberg, K. C., Wearick-Silva, L. E., Wendt Viola, T., Tractenberg, S. G., Benetti, F., & Grassi-Oliveira, R. (2019, 2019-August-28). How Early Life Stress Impact Maternal Care: A Systematic Review of Rodent Studies [Systematic Review]. *Frontiers in Behavioral Neuroscience, 13*. https://doi.org/10.3389/fnbeh.2019.00197

Payne-Sturges, D. C., Cory-Slechta, D. A., Puett, R. C., Thomas, S. B., Hammond, R., & Hovmand, P. S. (2021, Mar). Defining and Intervening on Cumulative Environmental Neurodevelopmental Risks: Introducing a Complex Systems Approach. *Environ Health Perspect, 129*(3), 35001. https://doi.org/10.1289/ehp7333

Payne-Sturges, D. C., Scammell, M. K., Levy, J. I., Cory-Slechta, D. A., Symanski, E., Carr Shmool, J. L., Laumbach, R., Linder, S., & Clougherty, J. E. (2018). Methods for evaluating the combined effects of chemical and nonchemical exposures for cumulative environmental health risk assessment. *International journal of environmental research and public health, 15*(12), 2797.

Perera, F. P. (2017). Multiple threats to child health from fossil fuel combustion: impacts of air pollution and climate change. *Environmental health perspectives, 125*(2), 141-148.

Perovich, L. J., Ohayon, J. L., Cousins, E. M., Morello-Frosch, R., Brown, P., Adamkiewicz, G., & Brody, J. G. (2018). Reporting to parents on children's exposures to asthma triggers in low-income and public housing, an interview-based case study of ethics, environmental literacy, individual action, and public health benefits. *Environmental Health, 17*(1), 1-12.

Persico, C., Figlio, D., & Roth, J. (2016). *Inequality before birth: The developmental consequences of environmental toxicants*.

Quandt, S. A., Younger, E. C., Arnold, T. J., Zepeda, R., Arcury, T. A., & Daniel, S. S. (2022). Developing Infographics to Present Research Findings from CBPR to Latinx Farmworker Community Members.

Querdibitty, C. D., Wetherill, M. S., Sisson, S. B., Williams, B., Aithinne, K., Seo, H., Inhofe, N. R., Campbell, J., Slawinski, M., & Salvatore, A. L. (2022). Cleaning Products Commonly Used in Oklahoma Family Child Care Homes: Implications for Respiratory Risk and Children's Health. *International journal of environmental research and public health, 19*(7), 4299.

Ramirez-Andreotta, M. D., Brody, J. G., Lothrop, N., Loh, M., Beamer, P. I., & Brown, P. (2016). Improving environmental health literacy and justice through environmental exposure results communication. *International journal of environmental research and public health, 13*(7), 690.

Raphael, C. (2019). Engaged communication scholarship for environmental justice: A research agenda. *Environmental Communication, 13*(8), 1087-1107.

Rebelo, F. M., & Caldas, E. D. (2016, 2016/11/01/). Arsenic, lead, mercury and cadmium: Toxicity, levels in breast milk and the risks for breastfed infants. *Environmental Research, 151*, 671-688. https://doi.org/https://doi.org/10.1016/j.envres.2016.08.027

Rice, D., & Barone, S. (2000). Critical periods of vulnerability for the developing nervous system: evidence from humans and animal models. *Environmental health perspectives, 108*(suppl 3), 511-533.

Rivas-Drake, D., Camacho, T. C., & Guillaume, C. (2016). Chapter Six - Just Good Developmental Science: Trust, Identity, and Responsibility in Ethnic Minority Recruitment and Retention. In S. S. Horn, M. D. Ruck, & L. S. Liben (Eds.), *Advances in Child Development and Behavior* (Vol. 50, pp. 161-188). JAI. https://doi.org/https://doi.org/10.1016/bs.acdb.2015.11.002

Roisman, G. I., Newman, D. A., Fraley, R. C., Haltigan, J. D., Groh, A. M., & Haydon, K. C. (2012, May). Distinguishing differential susceptibility from diathesis-stress: recommendations for evaluating interaction effects. *Dev Psychopathol, 24*(2), 389-409. https://doi.org/10.1017/s0954579412000065

Roy, A. L., Raver, C. C., Masucci, M. D., & DeJoseph, M. (2019, Mar). "If they focus on giving us a chance in life we can actually do something in this world": Poverty, inequality, and youths' critical consciousness. *Dev Psychol, 55*(3), 550-561. https://doi.org/10.1037/dev0000586

Rubinstein, M. L., Delucchi, K., Benowitz, N. L., & Ramo, D. E. (2018). Adolescent exposure to toxic volatile organic chemicals from e-cigarettes. *Pediatrics, 141*(4).

Ruckart, P. Z., Jones, R. L., Courtney, J. G., LeBlanc, T. T., Jackson, W., Karwowski, M. P., Cheng, P.-Y., Allwood, P., Svendsen, E. R., & Breysse, P. N. (2021). Update of the blood lead reference value—United States, 2021. *Morbidity and Mortality Weekly Report, 70*(43), 1509.

Sampson, R. J. (2022). Legacies of inequality, legacy lead exposures, and improving population well-being. *Proceedings of the National Academy of Sciences, 119*(14), e2202401119.

Sandhaus, S., Kaufmann, D., & Ramirez-Andreotta, M. (2019). Public Participation, Trust and Data Sharing: Gardens as Hubs for Citizen Science and Environmental Health Literacy Efforts. *Int J Sci Educ B Commun Public Engagem, 9*(1), 54-71. https://doi.org/10.1080/21548455.2018.1542752

Schnur, J., & John, R. M. (2014). Childhood lead poisoning and the new Centers for Disease Control and Prevention guidelines for lead exposure. *Journal of the American Association of Nurse Practitioners, 26*(5), 238-247.

Shrout, P. E., & Rodgers, J. L. (2018, Jan 4). Psychology, Science, and Knowledge Construction: Broadening Perspectives from the Replication Crisis. *Annu Rev Psychol, 69*, 487-510. https://doi.org/10.1146/annurev-psych-122216-011845

Simcox, N. J., Fenske, R. A., Wolz, S. A., Lee, I.-C., & Kalman, D. A. (1995). Pesticides in household dust and soil: exposure pathways for children of agricultural families. *Environmental health perspectives, 103*(12), 1126-1134.

Simonds, V. W., Kim, F. L., LaVeaux, D., Pickett, V., Milakovich, J., & Cummins, J. (2019, Apr). Guardians of the Living Water: Using a Health Literacy Framework to Evaluate a Child as Change Agent Intervention. *Health Educ Behav, 46*(2), 349-359. https://doi.org/10.1177/1090198118798676

Spear, L. P. (2007, 2007/01/01/). Assessment of adolescent neurotoxicity: Rationale and methodological considerations. *Neurotoxicology and Teratology, 29*(1), 1-9. https://doi.org/https://doi.org/10.1016/j.ntt.2006.11.006

Steinle, S., Reis, S., & Sabel, C. E. (2013). Quantifying human exposure to air pollution—Moving from static monitoring to spatio-temporally resolved personal exposure assessment. *Science of the Total Environment, 443*, 184-193.

Stieb, D. M., Huang, A., Hocking, R., Crouse, D. L., Osornio-Vargas, A. R., & Villeneuve, P. J. (2019). Using maps to communicate environmental exposures and health risks: Review and best-practice recommendations. *Environmental Research, 176*, 108518.

Stingone, J. A., Sedlar, S., Lim, S., & McVeigh, K. H. (2022). Receipt of early intervention services before age 3 years and performance on third-grade standardized tests among children exposed to lead. *JAMA pediatrics, 176*(5), 478-485.

Trentacosta, C. J., Davis-Kean, P., Mitchell, C., Hyde, L., & Dolinoy, D. (2016). Environmental contaminants and child development. *Child Development Perspectives, 10*(4), 228-233.

Trentacosta, C. J., & Mulligan, D. J. (2020). New directions in understanding the role of environmental contaminants in child development: Four themes. *New directions for child and adolescent development, 2020*(172), 39-51.

Weisglas-Kuperus, N., Vreugdenhil, H. J. I., & Mulder, P. G. H. (2004, 2004/04/01/). Immunological effects of environmental exposure to polychlorinated biphenyls and dioxins in Dutch school children. *Toxicology Letters, 149*(1), 281-285. https://doi.org/https://doi.org/10.1016/j.toxlet.2003.12.039

Welch, M. G., Barone, J. L., Porges, S. W., Hane, A. A., Kwon, K. Y., Ludwig, R. J., Stark, R. I., Surman, A. L., Kolacz, J., & Myers, M. M. (2020). Family nurture intervention in the NICU increases autonomic regulation in mothers and children at 4-5 years of age: follow-up results from a randomized controlled trial. *PloS one, 15*(8), e0236930.

Whyatt, R. M., Liu, X., Rauh, V. A., Calafat, A. M., Just, A. C., Hoepner, L., Diaz, D., Quinn, J., Adibi, J., & Perera, F. P. (2012). Maternal prenatal urinary phthalate metabolite concentrations and child mental, psychomotor, and behavioral development at 3 years of age. *Environmental health perspectives, 120*(2), 290-295.

Willis, D. W., & Eddy, J. M. (2022). Early relational health: Innovations in child health for promotion, screening, and research. *Infant Mental Health Journal*.

Wine, O., Sarah Ambrose, Sandy Campbell, Paul J. Villeneuve, Katharina Kovacs Burns, Alvaro Osornio Vargas. (2017). Key Components of Collaborative Research in the Context of Environmental Health: A Scoping Review. *Journal of Research Practice 13*(2), R2.

Wong, C., Wu, H.-C., Cleary, E. G., Patton, A. P., Xie, A., Grinstein, G., Koch-Weser, S., & Brugge, D. (2019). Visualizing air pollution: communication of environmental health information in a Chinese immigrant community. *Journal of health communication, 24*(4), 339-358.

Woolf, A., Alpert, H. R., Garg, A., & Lesko, S. (2001). Adolescent Occupational Toxic Exposures: A National Study. *Archives of Pediatrics & Adolescent Medicine, 155*(6), 704-710. https://doi.org/10.1001/archpedi.155.6.704

Woolf, A. D., & Brown, M. J. (2022). Old Adversary, New Challenges: Childhood Lead Exposure and Testing. *Pediatrics, 149*(5). https://doi.org/10.1542/peds.2021-055944

Xie, S., Meeker, J. R., Perez, L., Eriksen, W., Localio, A., Park, H., Jen, A., Goldstein, M., Temeng, A. F., & Morales, S. M. (2021). Feasibility and acceptability of monitoring personal air pollution exposure with sensors for asthma self-management. *Asthma research and practice, 7*(1), 1-11.

Yeager, D. S., Dahl, R. E., & Dweck, C. S. (2018, Jan). Why Interventions to Influence Adolescent Behavior Often Fail but Could Succeed. *Perspect Psychol Sci, 13*(1), 101-122. https://doi.org/10.1177/1745691617722620

Zajac, L., Johnson, S. A., & Hauptman, M. (2020, Feb). Doc, can you test me for "toxic metals"? Challenges of testing for toxicants in patients with environmental concerns. *Curr Probl Pediatr Adolesc Health Care, 50*(2), 100762. https://doi.org/10.1016/j.cppeds.2020.100762

Zimmerman, E., Borkowski, C., Clark, S., & Brown, P. (2018, 2018). Educating speech-language pathologists working in early intervention on environmental health. *BMC Medical Education, 18*. https://doi.org/https://doi.org/10.1186/s12909-018-1266-3

Zimmerman, M. A., Stoddard, S. A., Eisman, A. B., Caldwell, C. H., Aiyer, S. M., & Miller, A. (2013, Dec 1). Adolescent Resilience: Promotive Factors That Inform Prevention. *Child Dev Perspect, 7*(4). https://doi.org/10.1111/cdep.12042

Table 1. Recommendations and Opportunities for Developmental Science to Integrate and Inform Child Environmental Health Science

Recommendation / Opportunity	Relevance for CEH	Application Examples
1. Use Developmentally-Informed Conceptual Models	Direct and indirect influences across the Child-Serving Ecosystem (CSE) overlap and interact to shape environmental exposure(s), child health and development	Consider exposures and potential for intervention across the CSE
		Borrow developmental models such as biological sensitivity to context to identify moderators
	Effects of toxicant exposure may differ across individuals and stages of post-natal development; may appear discontinuous	Use longitudinal designs with multiple datapoints to test complex, non-linear models, identify sleeper effects
2. Apply Creative, Sophisticated, and Rigorous Methods	Impacts on early development may be subtle and require specialized assessment of developmentally-relevant constructs and processes	Employ developmentally-sensitive assessments to capture nuanced biobehavioral constructs, and change
	Need novel methods to assess complex and individual exposures	Use personal exposure monitors for children and members of the CSE
	Innovative measurement strategies can engage communities, spark change	Conduct community mapping, in combination with personal exposures data
3. Integrate Developmentally-Sensitive Intervention Considerations	Developmentally-sensitive periods of risk call for developmentally-informed/targeted interventions	Consider how developmental changes in behavior may drive exposure risk
	Environmental Health Literacy is limited	Test behavioral interventions to mitigate risk (e.g., relational health

	among CSE stakeholders	interventions in early childhood)
	Increasing connections across the CSE can provide opportunities to integrate CEH interventions throughout	Engage youth directly as advocates
		Promote Environmental Health Literacy among CSE stakeholders
4. Establish Interdisciplinary Collaborations and Cross-Sector Partnerships	Need to translate CEH findings from animal models to human context	Develop cross disciplinary partnerships
	Must engage cross-sector stakeholders to make change in CEH	Employ citizen science, report back study designs to engage and build community partnerships
	Communities who are most impacted need to be engaged in solutions	Embrace an Environmental Justice orientation