Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

CHAPTER NINE

The exposome in the community

In the aftermath of Washington, D.C., I knew that something like Flint was inevitable.

Marc Edwards, Virginia Tech

9.1 Community matters

Environmental health tragedies, such as the water crisis that occurred in Flint, Michigan, reveal breakdowns in our governmental structures and infrastructures. Communities know that something is amiss, but it can be exceedingly difficult for government officials to accept that their systems are not working. Often it takes the outcry of the community, in combination with concerned and knowledgeable scientists, to reveal the problem. This was illustrated with the crisis in Flint (and similarly in Washington, D.C. years earlier). What worries me, though, is that there are numerous instances of unintended exposures that do not rise to the level of what was seen in Flint, are not detected by the community or government, and are summarily ignored. Exposome research should help close this gap as it promotes widespread surveillance of the environment, including untargeted analyses that can detect unknown contaminants. A more systematic way of evaluating the environmental impacts on health should allow the examination of the health impacts of our environment at national and international scales. This will require engagement with our communities, inclusion of citizen scientists, and a democratization of exposome data and knowledge.

As noted in the preceding chapters, the challenges facing data analysis for the exposome are daunting, some may say impossible. I ask the reader to set the thoughts of impossibility aside for a moment. There is one aspect of the exposome that is not complex or fraught with challenges and scientific danger. It is my view that the exposome is a superb educational vehicle to promote the importance of the environment in health

The Exposome.
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and disease. The exposome is an accessible mental model that can be used by students and citizens alike. Each day we are bombarded by a dizzying amount of exposures and influences from our environment. We are aware of many of these exposures through our senses and intuition, and also through information coming from news outlets, social networks, advertisers, and our colleagues and family members, but we generally lack a framework to organize all of the information.

Recall that human intuition fails miserably at dealing with complex data. Most people cannot keep track of the various controllable environmental factors they face every day. Keeping track of a diet is difficult, but possible, yet remembering to not exercise during rush hour or near crowded highways, to avoid the stress of overscheduling, to avoid mixing certain household chemicals, to thoroughly wash fruits and vegetables, and to take any necessary prescriptions can be exhausting. Most people throw up their hands in defeat and just focus on what they perceive to be the most important. Unfortunately, their perceptions—shaped by the often well-meaning, but often misinformed media, friends, and family—are can be shaky from a scientific perspective. The exposome, especially charted as the modifiable version shown later, is an excellent way of organizing these multiple influences in a way that brings clarity to the morass of information. The development of an expanded, personalized, and easy-to-understand version of this could become an interactive tool to be used with one's physician, as a guidepost for home eating habits and as a blueprint for overall health.

9.2 Sensory and technical overload

The dizzying amount of information to which we are subjected is only increasing. Coming from multiple directions and sources, these data can blur our thinking and hinder our ability to make sound decisions. In business circles the term "systems thinking" has been proposed as the future of decision-making. I have never been a fan of the term "systems thinking" which may be a bit hypocritical given my admiration of the field of systems biology. I believe that thinking is a deeply complicated process. All thinking should be conducted at a systems level. Indeed, I like to define systems thinking as merely thinking. Reacting without thinking is by definition not thinking. That said, the concept of systems

thinking is the type of true contemplation and analysis of downstream effects that is needed to understand our health, manage our environment, and make good decisions.

The foundation of systems thinking is to consider implications and impacts of actions beyond the first order. That is, most people have a short-term view in their decision-making process and do not consider second- and third-order consequences. I will use a rather apropos example here. Consider cigarette smoking. A smoker knows that lighting up a cigarette will bring them pleasure. Even if they do not know how the nicotine activates nicotinic receptors that lead to the release of dopamine in the reward systems of their brains, the user can appreciate the pleasurable sensation. Unless they live under a proverbial rock, they also know that smoking has adverse health consequences. Smoking increases the risk of throat, neck, and lung cancers. It impairs breathing capacity. It makes clothes smell like smoke. Those are the primary effects. Over the past few decades, we have become much more aware of the second- and third-order consequences. The most obvious example is the aptly named second-hand smoke. When a person smokes a cigarette, the lit end releases tobacco smoke into the air as does the smoker's exhalation of the inhaled smoke. Thus, the smokers who assume the risk of their habit on their own health introduce a second-order effect on the people and pets in close enough proximity to come in contact with the second-hand smoke.

Unfortunately, the downstream effects of smoking continue. Third-hand smoke represents a less intuitive event. If you have ever entered the home of a smoker, it smells like smoke even if nobody is actively smoking. This means that chemical residues from the smoke must reside in the house. Odors are chemical in nature. Therefore, if the chemicals that are responsible for the odor of burnt tobacco remain in the house, it is certain that other chemicals in cigarette smoke are also going to remain in the home. Cadmium, polycyclic hydrocarbons, and many carcinogens will be in the carpets, upholstery, curtains, and even the paint on the walls. Much of this can also be transferred into dust. Thus, if you purchased the home of a smoker, you will be exposed to the chemicals the smoker deposited all over the house. Our actions have downstream consequences, and few put much thought into this. However, the downstream consequences of our everyday activities can have lasting impact on the individual and those around us.

I find it instructive to consider one's habits and activities in this mindset. It is not as if you have to conduct this analysis every time you engage

in any activity. Just spend some time thinking about your daily activities and how they impact yours and your family's health in the short and long term. Once you map out these major drivers of your health, you can make decisions about them in a holistic way. New data that come your way can then be plotted onto your exposome graph. It should fall within one of the major domains you have already identified, providing a way to filter the new information. Individuals may need input from professionals or experts. This could be a physician, nurse, dietician, or public health professional. Although physicians generally do not have a great deal of time, they can react to a diagram that maps out your current health state.

The illustration in Fig. 9.1 shows some ways that the Example family can improve their exposome; however, there are also behaviors that can worsen their situation. If one of the members of the Example family were to start smoking in their home, all of their family members and Sparky and Whiskers would be exposed to the second-hand smoke and all of the associated toxicants. There is substantial evidence that family members of smokers who smoke inside the house have an increased risk of pulmonary disease. Veterinarian pathologists will tell you that it is very obvious to identify pets whose owners are smokers. Postmortem, the lungs of dogs and cats look very much like those of a smoker. It is safe to say that the

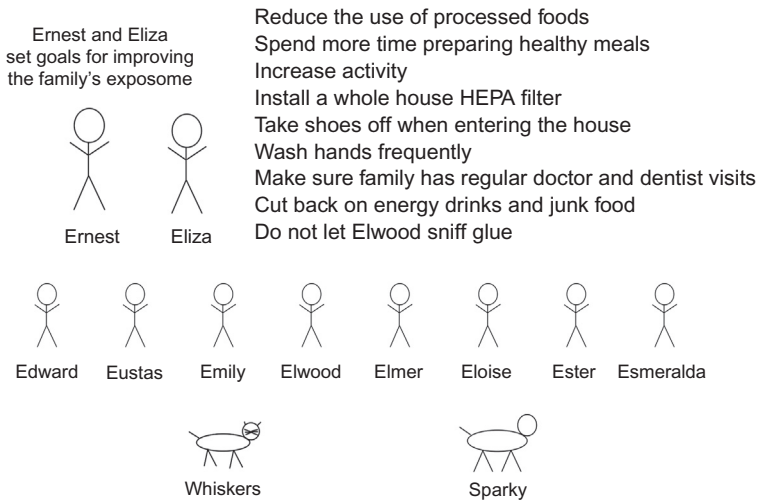

Figure 9.1 ***Improving the Example family's exposome.*** The Example family can take several steps to improve their exposome. Some steps require planning, some take time, and some may require some financial investment. However, most of the improvements are based upon improving behaviors.

average smoker is not considering the impact that their smoking will have on their own pets, or even the young family that moves into their house when they sell it in the next year.

9.3 The modifiable exposome

There are major national and international policy implications for the exposome, but some of the most rapid opportunities occur at the individual, family, and community level. Here we will examine how the exposome can be modified at a local level. The components of the exposome display varying degrees of impact on one's health. Cigarette smoking is much more deleterious than the injestion of the occasional hot dog. Some components are very much under our control (smoking and physical activity), while some are influenced more at a population or societal level (air pollution and healthcare access). Fig. 9.2 illustrates the relative

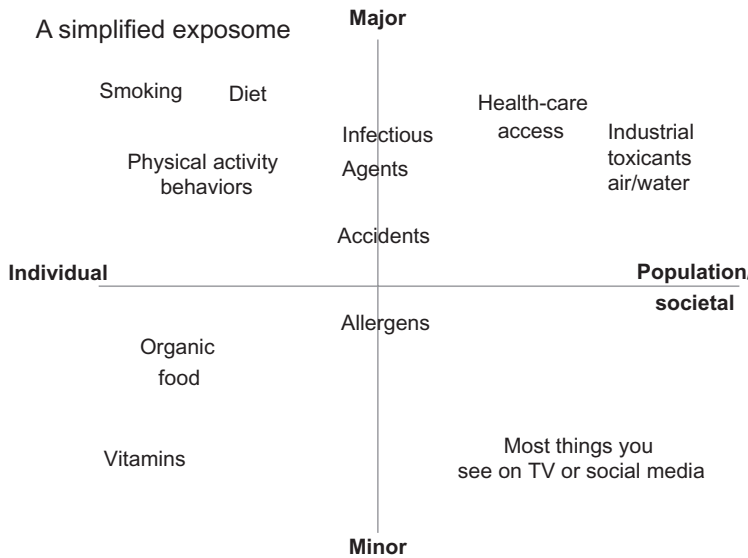

Figure 9.2 ***The simplified exposome.*** The exposome provides a useful mental model to organize the multiple influences on our health. By using an intentionally broad definition of environment, nearly all of the external factors that influence one's health are included in the exposome. It is then possible to plot these various factors along axes that include the importance to health (minor to major) and the ability to control said factors at the individual, community, or societal/population levels.

contribution based on these two scales. The *y*-axis shows the relative degrees of influence, while the *x*-axis displays the level of control from individual to population. Items in the upper half of the diagram have major influences on health and we should be taking steps to minimize their negative impact or to enhance their benefits. Items on the bottom can certainly influence health; they just take a lower priority. The items on the left are under the control of the individual or the community to some degree, while those on the right are more on a population or societal level. The top right quadrant contains the major issues that must involve governments and healthcare systems. Improving healthcare access, reducing air pollution, and improving water supplies all require some intervention on a large scale that involves populations, governments, and regulations. Of course the individual has a role in voicing concerns to their elected officials, but the ultimate solutions come from the larger organizations. Climate change was left out of this graph. This was not intended to minimize its importance, but because the timeframe of the graph is relatively short. The idea is to explore how people can modify their exposome in a positive way on the scale of days, months, and eventually years. This may be temporally naïve, but it allows the reader to focus on the more immediate future from a personal health standpoint. The proper care and maintenance of our planet is essential and the exposome concept certainly includes climate effects, but focusing on the immediate impacts of our exposome on health is easier to consider and it enhances one's appreciation of the environment.

Eating organic foods is listed in the bottom left. This is not meant to downplay the importance of minimizing chemical exposures but to take a broader view of the topic. Overall, the judicious use of chemicals increases crop production and keeps disease and pest damage in check. From a global perspective, organic produce is a luxury. Certainly, if one can afford it, it is best to minimize one's exposures to pesticides and other agricultural chemicals, but eating organic is not as important as eating a healthy diet rich in fruits and vegetables, and for that reason it is viewed as minor. The benefits of eating an organic diet may be as much about the quality of the food itself and less about the lack of pesticide residue. A move toward lower pesticide use across the entire agricultural sector would be of greater benefit than the expansion of the organic industry (although the latter may be helping drive the former). From a food quality perspective, processing and packaging may be a better way to evaluate the potential exposure to chemicals. It is my view that eating fewer processed

foods is a higher priority than eating organic (although doing both would be ideal). Processed foods contain many more chemicals and fewer nutrients. More packaging means more plastics, phthalates, and preservatives. The modern diet with its focus on convenience has increased the delivery of chemicals and decreases the quality of nutrients. This must be reversed. It is tempting to opt for the inexpensive convenient food, but it comes at a price: higher caloric density, higher fat content, higher sodium content, and more unnecessary synthetic chemicals. Fewer people want to spend their time in kitchens, and that is not good for the health of our society. Foods prepared at home with moderately healthy practices are superior in nutritional quality and lower in chemical residues. As adults, one of the most important health lessons we can provide children is to teach them how to prepare healthy foods. There are too many teenagers and college students whose cooking skills limit them to ramen noodles and fast food. This leads to terrible habits that can persist into adulthood.

Accidents straddle the line between individual and population control because there are individual steps (seatbelts, protective eyewear, safe practices, and common sense) and societal steps (OSHA regulations, highway safety interventions, and workplace practices) that can be taken. Notably, according to the Centers for Disease Control and Prevention (www.cdc.gov/injury), unintentional injury is the leading cause of death in the U.S. for all ages between 1 and 44! While we tend to think about the importance of heart disease and cancer, of the risk factors that do start at an early age, it is accidents that are most dangerous for most people until middle age. Although we rely on government to provide regulations, we should heed the advice of safety professionals. Alluding back to Chapter 2, Genes, Genomes, and Genomics: Advances and Limitations, when the late Francis Crick was asked about the key to a long healthy life he stated, "Always use the handrail!" Simple advice from an extraordinary scientist. Instead of referencing DNA, he was talking about his exposome (he just did not know it at that time).

Allergens are listed below the *x*-axis because for the majority of people allergens have a minor effect. Of course for individuals with severe allergies, the allergens may pose a much greater effect, and may even be one of the most significant drivers of health. Obviously, if such a graph were personalized and accounted for the individual susceptibilities and vulnerabilities, the layout could look much different. The ultimate goal of this exercise is to develop a personalized assessment and plan for optimizing one's exposome.

It is important to remember that each axis is a continuum. We have some level of control over our exposure to toxicants in the air or water—for example, maintaining vehicles, not exercising near highways, using home air purifiers, HEPA-filtered vacuum cleaners, and using water purifiers depending on water source. However, the major drivers (pun intended) are at a higher level. The number of vehicles on the road, exhaust regulations, and industrial pollution controls must be addressed at the regulatory and societal level. It is unfortunate that important targets for vehicle emission standards can fall victim to political power. That said, we do exert some level of control over our own transportation habits. While cigarette smoking is on the left side, we know that community and societal issues are also at play. From a societal standpoint, cigarettes should not be available to children and teenagers. We know that the sooner people start smoking, the more likely they are to become addicted. While raising the drinking age to 21 in the United States was a slow process and required significant governmental intervention, it did occur and has had a positive impact on the rates of accidents and injury. Had the U.S. tobacco settlement included a similar raising of the legal smoking age to 21 (phased in over several years at the same time that they distributed funds for various programs), it would have done more to improve the health of the U.S. than all of the billions of dollars that were poured into state coffers (even with a predictable prohibition-like black market). In the U.S. we were greeted with some unexpected news on this front in 2019 when the national age for the purchase of tobacco products was raised to 21 and this included electronic cigarettes. Although it will take some time for the effects to be realized, this legislation will likely have a major impact on public health by reducing tobacco and nicotine use in young adults. Unfortunately, the e-cigarette industry had a substantial head start and through aggressive marketing has produced thousands of addicted future customers.

The "most things on TV" description in Fig. 9.2 is only partially tongue in cheek and should also include social media. Most of the news stories related to health are sensationalist. They often focus on obscure, but newsworthy exposures. Decades ago I recall seeing a television news piece on the Marlboro man that included a critical assessment of the tobacco industry. This was when information regarding the cover-up of adverse effects by the industry was becoming public. Today, it is rare to find anything on television that is remotely educational concerning environmental factors in health. An unfortunate example about a lack of societal control is the use of e-cigarettes and vaping mentioned previously. On the

surface, shifting from high-temperature burning of tobacco to nicotine delivery systems that contain few contaminants is a good idea. It is reasonable to conclude that vaping is safer than traditional cigarette smoking, but it is not without risks; the metal coils and flavorings can expose the user to a host of chemicals and the dose of the addictive nicotine can be higher than in cigarettes. More important, the lack of regulation created a public health travesty by allowing the industry to create a new generation of nicotine addicts. Adult cigarette smokers should have access to tools to reduce their exposure to tobacco smoke. Children and teenagers should not have legal access to tobacco or nicotine delivery systems and the new legislation in the U.S. is welcome news. Similar consideration should be given to "energy drinks" with high levels of caffeine. Moderate doses of caffeine, like those found in tea, do not appear to have adverse health effects, but the higher doses found in strong coffee and energy drinks should not be consumed by children and teenagers. In high school, I conducted a science fair project that examined the effects of caffeine on the development of turkeys [this was conducted in a scientific setting at the US Department of Agriculture (USDA)]. Suffice it to say, caffeinated coffee stunted growth, while decaffeinated coffee merely stained the turkeys' feathers (they are messy drinkers; Miller, unpublished observations). I was fortunate to learn this lesson over 30 years ago, but now I witness increased access to highly-caffeinated beverages that are undoubtedly marketed to children.

Infectious agents are listed very close to the top of the graph in Fig. 9.2. Of the items in our environment, infectious agents have the potential to have the biggest immediate impact on health. While many factors involved in the spread and contraction of disease are outside our control, the individual can be sure to obtain recommended vaccines, including seasonal flu vaccines, minimize contact with sick people, and follow appropriate hygiene practices. Not only has the misinformation about vaccines caused outbreaks of measles and other diseases, but I posit that it has also suppressed uptake of season influenza vaccines. This creates considerable challenges to governments and healthcare systems that are trying to protect the public from these diseases. Communities must work to encourage these important activities, and professionals must continually work to counter the pseudoscientific claims that pervade the public thinking. The COVID-19 pandemic has illustrated the need for an improved understanding of the external threats that infectious agents pose. Nearly every action we can take to improve our health is a result of a change in

our exposome. Let us explore how we can view these changes through the exposome lens.

Imagine if you were to visit your general practitioner and share this graph (see Fig. 9.3). Each point represents a health factor that you and the physician deem to be important for your health. It is remarkable that all of these are part of the exposome. Even though you may note a particular family risk factor, all of the behaviors going forward are components of the exposome. Each factor is mapped onto the diagram to indicate its relative importance and the evaluation of where you are in these measures. For example, your total cholesterol may be high. It shows in the upper left quadrant as being important to your health but being in need of improvement.

Now that each of these factors is mapped, we can color code them to reflect their dynamic state. If you see an improvement in your cholesterol status, it would shift to green and move to the right (see Fig. 9.4). Thus it becomes easy to see how alterations in your exposome (as reflected in

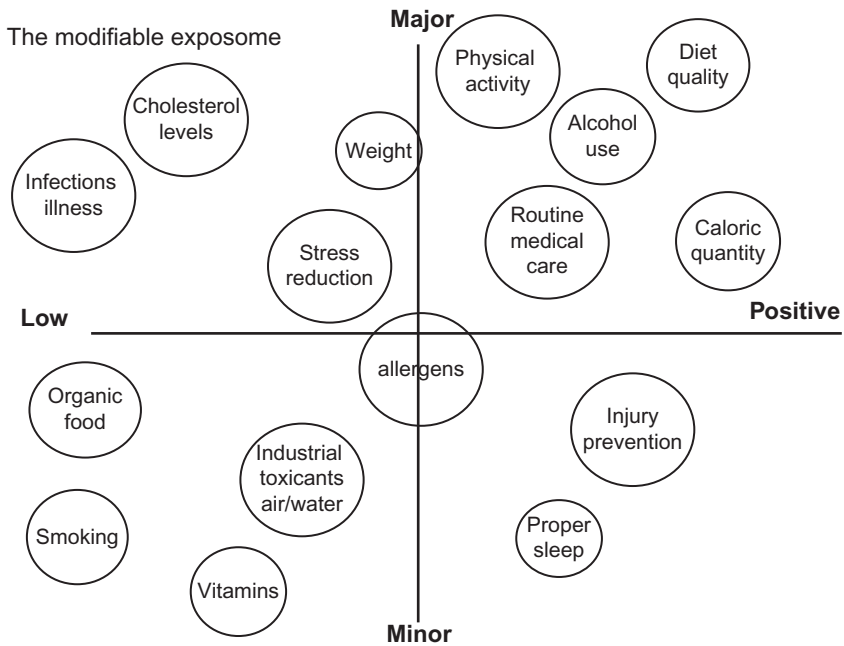

Figure 9.3 ***The modifiable exposome.*** Several major factors are plotted on this graph. Your graph may appear different depending on your background and activities. It is relatively easy to see how changes in each of these items can lead to an improvement in health.

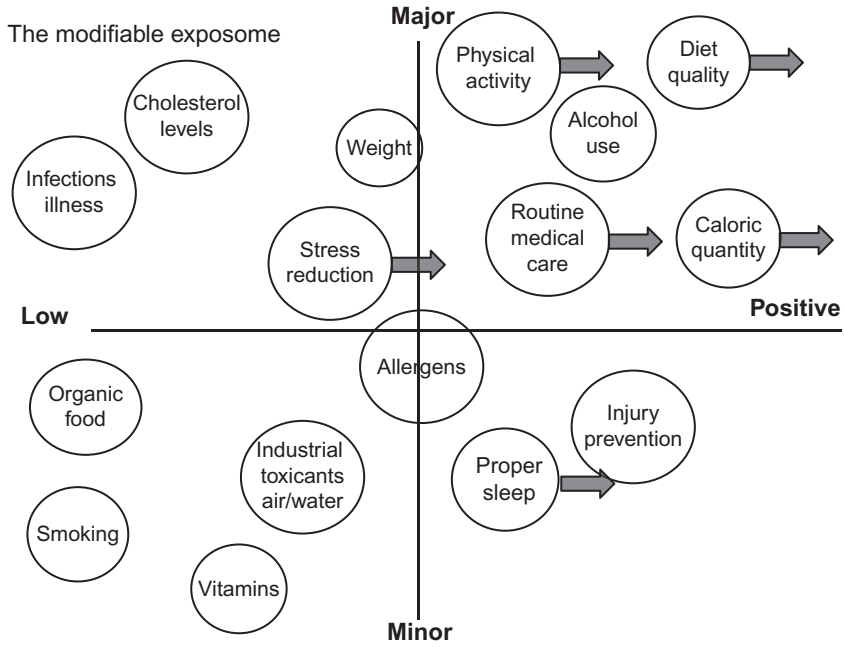

Figure 9.4 ***The modified exposome.*** This figure shows how one could plot the positive changes that have been made to improve one's exposome. Improved dietary habits, increased activity, and avoidance of negative behaviors can cause fairly dramatic changes in one's exposome and health. Imagine reviewing this plot on a weekly or monthly basis to evaluate overall health status.

lifestyle changes) shift your health status into a positive direction. But it is also mapping more than the singular item that you may be considering. Body weight or body mass index, diet, and exercise are interconnected and could be merged into a single unit. The vector could change based on changes in of the three components. Indeed, with a simple app, it should be possible to track these health factors over time—even provide a historical perspective. This becomes an exercise in data visualization as was discussed in the previous chapter. Making data understandable makes them more actionable. When people consider relocating, they do not generally think in these terms. They will evaluate job potential or salary, but not how that new environment will impact their health. Will it become easier or hard to exercise? Will pollen levels or particulate matter levels in the air change? Does the work environment promote health activities? Does the city provide reasonable public transportation? Are their positive commuting options? Will the environment be more or less

healthy? Will there be new exposures? Will the quality of their diet increase or decrease?

The previous discussion was very much focused on the individual, but what happens when a person does not have control of many of these factors? What if the only apartment you can afford is located near a train station that has a power plant nearby? The increased noise and pollution become unavoidable. One may be able to mitigate the impact of noise on sleep by using earplugs or sound machines, but what about the pollution? Will indoor air purifiers reduce the in-room air pollutants? Can the person afford such luxuries, especially considering the cost of replacement HEPA filters? This is where policy comes into play. Governments have the authority to alter train traffic, to require antipollution devices on power plants, and to rezone areas to not allow housing near such sites. The challenge is getting the government to make thoughtful decisions to support their citizens.

Let us look at the modifiable exposome at a population scale (Fig. 9.3). For example, consider a community that is located near a factory. The factory provides jobs for many people in the town, but it also may produce a high level of emissions. Most people in the town cannot remember when the factory was not the major driver of the town's economy. Let us place our Example family in this town. Eliza's mother worked here for four years after college, but before she went back to graduate school for nuclear physics. The Example family lived here for six years. It was discovered that the factory was exceeding its emissions by 200 percent. This was not discovered by the regulatory body for two years. So the Example family was exposed to elevated levels of emissions for two years. Could this have contributed to the increased asthma and allergy symptoms the family had observed? Will there by long-lasting consequences of these exposures?

Ideally, we prevent these exposures before they occur, but it is almost impossible to prevent all of them. Not to be fatalistic, but governments do not tend to work on a timescale that is terribly useful for the individual's health. Changes in government policy can take years and implementation can add onto that time. However, these changes are essential for those who follow us, whether they be younger siblings or future generations. Therefore, as we continue to improve the conditions in our community and world, we must also take steps that to protect us from those issues that are immediately impacting us. One of the most important concepts to health is that of resilience.

9.4 Resilience and the exposome

As the conditions around us are constantly changing in predictable and unpredictable ways, we must prepare ourselves to resist or adapt to these conditions. There is a large body of health literature on the concept of resilience. We understand what it means to bounce back from a challenging event or life circumstance, but what does resilience mean in an exposome context? Can we develop resilience to exposures? It is obvious that when we do not get enough sleep, do not eat well, and engage in unhealthy activities, we increase the likelihood of getting sick. That is an example of decreased resilience or resistance to infection. It is reasonable to assume that this simple analogy is scalable. How does one become more resilient to exposome-based challenges?

Table 9.1 provides steps one can take to improve one's exposome. Most of these steps are obvious and do not require the exposome concept, but there is not generally a single source for this information. Rarely would a physician address each of these areas. A dietician or nutritionist would only address some. A mental health professional would address anxiety, stress, and cognition, but likely not mention diet. A fitness coach would address one's physical health and may address nutrition, but would not discuss safety practices, water quality, or cognitive activity. This leaves the individual as the only likely person capable of considering and integrating all of these external forces.

The exposome model is also a useful way to address health disparities. Variations in the factors that contribute to the exposome are far more influential than the genetic factors when one looks at various populations within a particular region. Poorer areas tend to be in closer proximity to hazardous waste sites and farther from parks and healthcare facilities. Juarez and his research group are using an exposome-based approach to evaluate such disparities and how they may impact health (Juarez et al., 2017). Layering rich exposome-type data on top of census and other socioeconomic data can help one to reveal trends among various exposures. The addition of comprehensive biological data could bolster these analyses, but it will be necessary to maintain a strong geospatial component to exposome data collection to facilitate the layering of these data. Eliminating health disparities is ultimately about modifying the exposome in the vulnerable and underserved populations. Genomics and precision medicine do not address the public health structures that help one to improve a person's exposome.

Table 9.1 Creating your enhanced exposome.

Intake

Reduce caloric intake (unless you are already at an ideal weight and body mass index and will lose weight by reducing intake)

Minimize intake of processed food. Recall that more processing and more packaging means low nutrient content and higher chemical content, including plasticizers and preservatives

Eat fresh vegetables and fruits. First priority—wash them. Second priority, buy organic if it does not impact your ability to purchase large quantities of vegetables. If it does, fresh nonorganic produce is better than processed food

Minimize alcohol usage (<1 drink per day preferably wine). Consuming large amounts of alcohol is associated with many adverse health consequences

Avoid the use of tobacco products (only use e-cigarettes if it is for smoking cessation)

Activity

Reduce injury risk—occupational setting, falls, gunshots, knife wounds, high-risk activities—wear proper protective equipment, get proper training for high-risk activities

Engage cognitive circuits—be sure to challenge yourself mentally throughout the day

Maintain relationships—avoid isolation—develop structures to avoid loneliness

Develop strategies to minimize stress—yoga, meditation, exercise, quite time. The most important part is identifying strategies that reduce your stress

Practice safe driving and transportation (safety belts, speed limits, and helmets)

Disengage from technology on a regular basis—cell phones computers have become fixtures in our modern lives. It can be hard to function in their absence, but it is necessary to disconnect. Identify spans of time where you are not looking or responding

Be active. Engage in cardiovascular and strength conditioning on a regular basis. Use the stairs, park farther away from the store, take vigorous walks, go to the gym, and participate in recreational sports

9.5 Engineering communities to optimize the exposome

Community members live within a physical environment that includes roads, parks, streets, houses, schools, and other buildings. This built environment has a major impact on our well-being and exposome. The built environment tends to be relegated to engineers and urban planners. Historically, health was not a major priority in urban planning. This is unfortunate because improving the built environment is one of the most effective ways of improving one's exposome. However, the built

environment is increasingly being recognized to be crucial in creating healthy and productive communities. The proximity of housing and sidewalks to roads and associated traffic-related pollution can be a major driver of exposures. The buildings in which we live and work can impact our air quality and influence exposures to volatile substances and airborne materials. The materials used for the construction of our work-related buildings and offices, apartments, houses, and furnishings can have significant effects on our exposures. Many chemicals are used to increase the lifespan of counter surfaces, carpeting, and paints, such as the wood preservatives formaldehyde or arsenic. The most obvious example is lead-based paint. Lead allowed paint to last longer. It prevented peeling and chipping and reduced the time interval between repainting. However, we now know that the lead in paint was a major source of lead exposure and harmful health consequences. The paint was the vehicle for a major public health crisis. This suggests that all of the materials in our built environment have the potential to pose a risk to our health. As noted previously, health is generally not a priority in these decisions (arguably, it is not even considered except for avoiding using components banned by industrial standards). We know that fires can be devastating, so minimizing the flammability of building materials has been a high priority. This led to the widespread use of flame retardants in all sorts of furnishings and clothes. We are now learning that these materials, fluorinated and brominated flame retardants, have adverse effects on health and they are ubiquitous and persist in our environment. Reducing the immediate risk of fire-related injury was the goal, but long-term consequences were not considered.

9.6 Behaviors, mandates, and nudges

The concept of nudge, which garnered widespread attention with the publication of *Nudge: Improving Decisions about Health, Wealth, and Happiness* by Richard Thaler and Cass Sunstein, is to gently guide people into positive behaviors by making it easier to make the right decision (Thaler & Sunstein, 2008; Sunstein, 2013). The decisions that people make regarding their environment are based on a combination of factors. First, the individual can know what is best for him or her and pursue that particular action. Second, the individual can know what is best for him or her and choose not to pursue that particular action. Third, the individual

can be ignorant of what is best for them and may or may not pursue the appropriate activity. For each of the dozens of choices to be made in a single day, there will be various combinations of the aforementioned decisions. Often the poor choices we make in maintaining a healthy exposome are based upon our own laziness. We may well know what is best, but because such decisions can require more effort, money, and energy, we choose not to make them. The conservation of energy may appear to be a positive adaptation from a bioenergetic standpoint, but it leads to small negative consequences that can build up over time to weaken the individual. Thus, there is an advantage from a policy, regulatory, and organizational perspective to make good choices the default option. We see this sort of strategy used in many life settings. For example, the opt-out setup of a company 401k or retirement plan makes the default to save money. One must consciously choose not to participate in a retirement plan. When participation in such a program is opt-in, the participation rates are much lower.

Antismoking policies are designed in a similar manner. The default behavior in settings with such restrictions is not smoking. While the basis of such programs is often framed in the manner of reducing second-hand smoke, which is a good thing, it also forces behavioral changes in the smoker. With the majority of the world population being nonsmokers, antismoking policies are well accepted by the general public. The general population notices that there is less smoke in their presence and there is no downside. Things get trickier when we try to encourage behaviors that include the majority of people.

A recent example of this was the school lunch initiative in the U.S. to improve the quality of the food served in public schools. It made perfect sense. As noted previously, our children need to eat healthier food. If only healthy choices are made available, the children will have no choice but to eat healthier food (in general, the healthier choices have lower levels of preservatives and higher levels of nutrients). The USDA has control over the school lunch program, so instituting broad changes was easy. The result was a major pushback by children and school systems due to the swift and dramatic implementation (due to the children's unfamiliarity to the healthier choices and the impact on school system budgets). A more staggered implementation could have led to broader adoption and slowly shifted children's eating patterns and also muted the pushback from the organizations that were affected by these changes. The concept of nudge in the hands of a politician or a federal government can be

interpreted or perceived as a shove, but that does not mean that prohealth policies should not be pursued. New York City's laws that restricted the size of sweetened beverages were initially received as an infringement on personal freedom. Although reduction of sugar intake is good for health, creating rules and laws that make swift and dramatic changes in behavior does not go over well. It should be noted that New York City's anti-tobacco laws faced similar resistance, but led to dramatic health improvements and served as a model for many other cities. Fortunately, consumers do adapt, and over time the new polices become part of daily life and support improved decision-making.

Building upon his work in *Nudge*, Cass Sunstein highlighted his accomplishments regarding the development of easy-to-understand government policies during his term in a subsequent book *Simpler*, although he did not acknowledge that the Affordable Care Act, which was introduced while he was still overseeing the release of regulations as director of the White House Office of Information and Regulatory Affairs, was an example of precisely the opposite of what he claimed to be doing. The lack of broad support for the legislation led to an onslaught of challenges that have been undermining a program that addressed a problem that the majority of the population agreed needed to be fixed. Perhaps I am naïve to think that competing political parties can agree on anything, but one party legislation always faces dramatic opposition when the other party regains power. Although it seems obvious, policies that involve a broader range of supporters are much more likely to be sustained even if they result in compromised goals.

9.7 The exposome in the classroom

If offered as a stand alone course or as a component of several courses, the exposome could impact students throughout their education, starting in elementary schools by providing an analogous construct to the genome allowing the nature—nurture comparison to be made in a systematic way. The exposome could also be included in biology and health classes. In high school, it would help one to frame the variables in our complex world to link earth science courses with those that address health. For college courses the exposome provides a key biological and health principle to nonscience majors. For science majors, it helps faculty

connect the challenges students hear about with climate change, psychological stressors, and diet with their chemistry, biochemistry, and biology classes. Later, I will examine how the exposome can be integrated at multiple levels of education.

Concerning the field of public health, most schools have very little basic science in their curriculum. Basic concepts in biochemistry and physiology are often overlooked because it is not clear why students need this information. A course that examines the balance of genetic and environmental contributors to disease can provide an excellent introduction to many of the important scientific concepts in public health that make it easier to understand the various drivers of health. The exposome provides an organizational structure to understand the complex exposures that impact health, exposes students to cutting-edge science from multiple disciplines, and forces them to think in a holistic manner. It reminds them of the rapidity of scientific advancement and serves as a reminder to keep up with the literature. We experimented with a course called Genome, Exposome, and Health several years ago at Emory University. By providing information on both the genetic and environmental influences on health, the students could appreciate the balance between the two and recognize where their actions have the greatest effects.

While medical students learn about human physiology *ad nauseam*, they hear little about air pollution and atmospheric chemistry, environmental and occupational health, and physical activity. For the most part, the medical field has been dismissive of holistic medicine practitioners, such as homeopaths and chiropractors, based on the tenuous scientific foundations of their disciplines, but these practitioners try to treat the entire patient. Individuals in the general population yearn to be treated as a whole person, and these aforementioned practitioners give them what they want. Traditional (also referred to allopathic) medicine has missed this point to some degree. The average person does not want to be looked at as a renal system, a digestive system, and a cardiovascular system. They know that certain activities in one area of their life can impact another. Sending a person to four different specialists pretty much ensures that they no longer understand the causes and effects of their actions to their health. It is critical to distill the complicated medical minutia into structures the general medical consumer can understand and appreciate. Since the exposome encompasses all of the malleable components of our health, it can serve as an excellent rubric to understand health, and the behaviors and actions that improve health or contribute to disease.

When I initiated my work on the exposome, I was fearful that the general public would bristle at such an esoteric scientific concept, but I have found quite the opposite response. It has more been along the lines of "Well, duh, we know this; we have just been waiting for the scientists to figure it out." The vast majority of people want to understand the various factors that affect their health, but we need to work on our delivery of the information. With environmental health not being taught in most U.S. medical schools, we cannot currently rely on the medical field to deliver this message.

An example of a misunderstanding of the external factors that influence our health is the use of nutritional supplements and vitamins. A story in the monthly magazine *The Atlantic* by Paul Offit not only heaped praise upon Linus Pauling, one of the greatest chemists of all time (another one of those double Nobel winners, although one was for Peace so he has nothing on Sanger, Curie, and Bardeen), but also delivered equally biting scorn for his promotion of high doses of vitamins (Offit, 2013). Current research suggests that such vitamin regimens have no positive effect on health, but the general public has a view of "if vitamins are good then more must be better," and the health practitioner does little to counter this way of thinking. Most people cannot fathom that supposedly healthy vitamins could be worse than exposure to low levels of pesticides (I am not saying it is, just that it could be). Swallowing gram quantities of vitamins that obviously enter our body with ease may well be worse than exposure to pesticide drift. An old health adage is that once there is adequate caloric and nutrient uptake, removal of factors has a greater effect on health outcomes than adding them. Removing a deleterious influence typically trumps adding a positive influence. To put it another way, eliminating bad habits is likely to have a greater benefit than adding good habits, and it is possible that ingestion of megadoses of vitamins may be one of those bad habits. In addition, such vitamins and supplements may interfere with the proper absorption and metabolism of key nutrients and pharmaceuticals.

It is the proper management of one's exposome that is key. People put so much literal and figurative stock into the vitamin industry, but much of this is due to misperception and aggressive marketing. In the context of the exposome, the use of vitamins may be an important part of one's health regimen, but if the nutrient level in one's diet is already high (because they are eating a proper diet), it is more likely than not to be introducing a deleterious iatrogenic effect. A recent review showed no

beneficial effects of vitamin supplements on major health outcomes (Khan et al., 2019). By looking at all of the sources of chemical exposure in one's life, the individual exposures can be placed in the appropriate biological context. In fact, removal of excessive nutrients and pesticides would be the best outcome. The limited oversight that the U.S. Food and Drug Administration has over the vitamin industry has led to massive consumption of these products that are not only a waste of money, but also a source of uncharacterized exposures. This is one of the areas in which precision medicine could have a great benefit. If we analyzed an individual's diet, exposures, etc. and determined that they would benefit from a nutritional supplement, then they could be recommended to take that specific supplement, but if their nutritional status was good there would be no need for the introduction of vitamins. It is important to note that the ingredients in vitamins are not inert. The fat soluble vitamins can accumulate in the body and raise to toxic levels. The trace metals contained in vitamins also pose a concern. There is evidence that the recommended daily allowance of manganese may have adverse consequences on the regulators of oxidative stress. That said, except for the daily multivitamin that provides the RDA levels of vitamins and minerals, the potential adverse consequences of megadoses of vitamins, at least the fat-soluble ones, likely outweigh the often dubious potential positive effects. A sound understanding of how the exposome influences health may allow the consumer to make more judicious decisions about health habits.

9.8 Building a healthy exposome for the community

Another area in which the exposome can help one frame health effects is the built environment. Urban planners know how to design a community that includes walking trails and parks. Architects know how to design buildings that have minimal impacts on the environment. They know how to utilize more environment-friendly building materials. They know how to make the use of mixed-use developments. It is unfortunate that governments do not do more to reward more intelligent community and housing developments. Leadership in Energy and Environmental Design (LEED) certification promises users that future cost savings will offset the increased building costs, but communities also benefit from this

type of thoughtful construction. The private organization has been instrumental in getting more environment-friendly building to occur and more recently has introduced the concept of LEED communities that encourage more expansive activities, such as redevelopment of sites in need of remediation from past toxic waste exposures.

As more people move from rural areas into cities and metropolises, this will become increasingly important. LEED also has a less-appreciated effort on human health. The environmental quality category focuses on how the materials used impact air quality. This category includes issues around ventilation, acoustics, reducing off-gassing of building materials, and the use of more natural lighting. LEED emphasizes research that shows that improving these areas can boost worker productivity, but there is also evidence that they improve health. However, this is an area that needs more research. There are few rigorous biology-based studies that examine the impact of building materials on health. Currently, LEED certification is a wholly voluntary activity. There is no doubt that many of the steps in LEED construction have higher costs, but many of these costs are offset over a relatively short period of time in energy or other utility savings. For example, improved natural lighting can decrease electricity use, and low- or no-flow toilets can provide substantial savings on water usage. However, it is not easy to make the larger upfront investments required for these improvements, and this is where building codes or tax incentives can promote the construction of buildings that support human health rather than antagonize it.

9.9 Teaching the exposome concept outside of the classroom

Academic investigators, well trained in the art of dissemination among their colleagues, often fall short when it comes to explaining their research to the general public, and this statement may even be too generous. When one looks at recent stories regarding environmental factors in health, one sees more sensation than information. How valuable is it to dribble out information on environmental health exposures to the general public? Given the current state of environmental health knowledge in the public, one could argue that it is a terrible approach. The public will remember the sensational story about one type of chemical and then

irrationally never use nonstick cookware (but instead continue to use oil, suboptimal for health, on a traditional pan for decades). The public is fickle. A particular food is associated with a decreased risk of cancer and it becomes the trend du jour. Would not it be preferable to teach a mental construct that allows a person to frame a particular exposure in its proper context? Fresh fruits and vegetables are a key part to a healthy diet, and it does not matter if a study shows that broccoli or blueberries reduce cancer—you should be eating them (because they were part of a healthy diet, but don't forget to wash them to remove pesticide residues and infectious agents). If a person learned to look at the current health report and weigh it against their modifiable exposome, they may be more likely to place it in the proper context.

While many of the issues and concerns mentioned previously are addressed in the behavioral sciences and risk science, the general public is not so concerned with decision-making processes, biases, and probabilities. We know that most people are not intuitive risk scientists, but rather they are looking for an easy way to frame the complexity of the data with which they are bombarded. The exposome provides this framework and can introduce biological concepts in a context that makes it easier to remember over time. One does not need a college course in biology to understand the key components. When it comes to exposures that affect our health, the exposome stands out as a workable and teachable model that can be used to improve health. As part of the HERCULES Exposome Research Center at Emory University, the Community Advisory Board used the exposome concept to teach people in their neighborhoods about the environment. Michelle Kelger and Melanie Pearson worked closely with the community members to provide the materials and information needed to deliver this information to the communities. At Columbia University, the Columbia Center for Children's Environmental Health, investigators Frederica Perera, Julie Herbstman, and Virginia Rauh, and others have built a decades-long community partnership to address environmental exposures, and this work has led to marked improvements in health and even governmental policy changes. Community-based participatory research (CBPR) strives to involve the affected communities in all stages of research from design to data collection, and delivery of results. While CBPR is useful for university-based research projects, we are also seeing more exposome-based citizen science. Various monitors of pollution are available to the general public and many are using such systems to monitor air or water quality in their

neighborhoods and using that data for personal decisions or to take to politicians to illustrate a community health concern. Simple programmable computers, such as the Raspberry Pi, can be coupled with sensors to create inexpensive and educational monitoring devices.

9.10 Obstacles and opportunities

The transfer of knowledge about the exposome should not be difficult from an educational standpoint. The primary challenge for the field is the general acceptance of the concept itself. Members of the general public are inclined to embrace a holistic view of their health, and the exposome concept fits within this view. However, adoption of the exposome within the halls of academia requires those in the field of environmental health sciences to see the value of a unifying framework that expands beyond their traditional intellectual boundaries. Within the field of environmental health sciences, many of the concepts of the exposome are already being addressed even if the term is not being used, or if the vision is not as broad. Incorporating the exposome, especially the big data–generating approaches, into courses within environmental health sciences is necessary. The explosion of complex datasets is not going to slow down anytime soon. In fact, trainees who ignore this unavoidable truism will be at a significant disadvantage. Integration of the exposome concept into medical education may be a different matter. The medical profession is very thoughtful and careful about alterations in their information-dense curriculum. It may be best to start with continuing education (CE). Developing CE courses that address certain aspects of the exposome could become a useful tool in medical education. However, improving environmental health science education among medical professionals is an important and attainable goal, and those with expertise in environmental health sciences should continue to explore ways of doing so. The field will need to prepare and deliver the appropriate type of materials for education and training for each of the aforementioned areas. The more resources that can be provided to the professor, scientist, or teacher willing to present this material, the more likely the effort will be successful. Ideally, courses that incorporate the exposome theme will become common in academia. With concerted efforts from scientists and public health professionals, the exposome can become a useful vehicle for

teaching the importance of the environment in our health to those in other scientific disciplines and to the general public.

9.11 Discussion questions

1. Create a new version of the modifiable exposome with community on the left side of the *x*-axis and society on the right side. In essence, remove the role of the individual. Conversely, create a new version that plots individual on the left side of the *x*-axis and community or family on the right side. Discuss the differences and similarities among the different exposome plots.
2. Outside of class, explain the concept of the exposome to a scientific colleague and a nonscientific colleague. What was the response?
3. Plot your own exposome on Fig. 9.5. What are the activities, habits, and lifestyle choices that most greatly impact your health? Are these

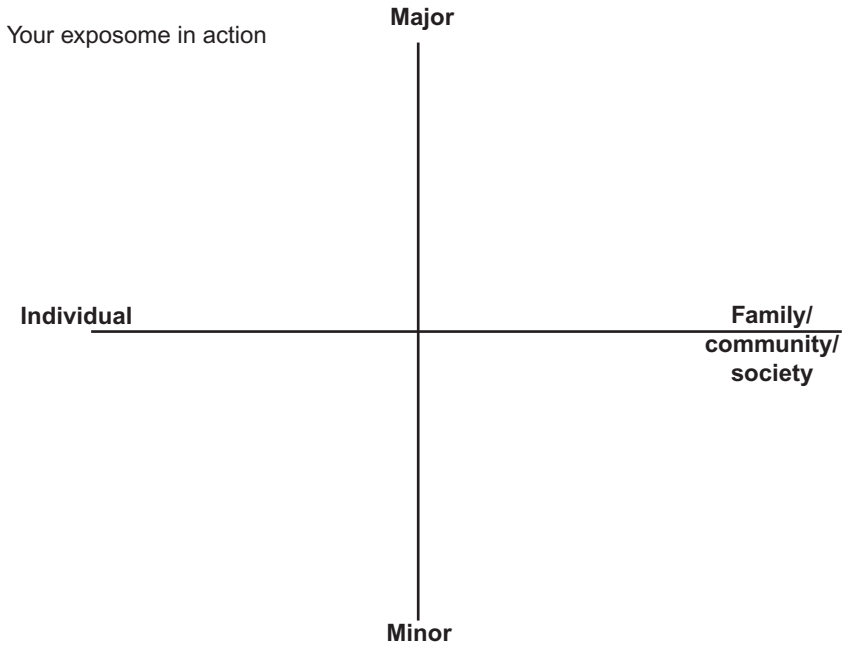

Figure 9.5 ***Your modifiable exposome.*** Use this graph to plot the key aspects of your life that influence your exposome. What changes can you make to drive these items toward the positive side of the graph? Which are the most important factors?

the areas that you think about the most? Set goals on how to shift these areas into a more positive direction.

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