Chapter 12
Tactile Approaches to Help Learners Visualize Key Processes in Environmental Health Sciences

Kathleen M. Vandiver

Abstract This chapter describes how hands-on models, or manipulatives, can be employed to improve the environmental health literacy of a variety of people, from science teachers and students in classrooms, to global audiences in large festival gatherings. Environmental health concepts can be quite abstract. For example, the effect of wood smoke on human lungs. People are concerned about the exposure to toxic molecules from the smoke, but find an explanation of the chemical process by which wood smoke harms human health too difficult to fully understand. Hands-on activities and models are a visual and tactile way of communicating essential molecular environmental health concepts in an inviting way without requiring a technical background.

The MIT Edgerton Center Molecule Set (hereafter referred to as the Molecule Set) is one example of an engaging model set that employs a simple design of differently colored LEGO® bricks to represent atoms. The set was designed to teach chemical principles to middle school students, and has evolved to include new topics with a more environmental health emphasis such as climate change and air pollution. The success of the Molecule Set and corresponding lessons stems from a unique collaboration between MIT scientists and the MIT Edgerton Center. This chapter highlights the Molecule Set and other relevant examples where hands-on models have been used to communicate abstract science concepts and improve environmental health literacy.

Keywords STEM education · Hands-on models · Carbon dioxide · Climate change · Ocean acidification · Air pollution · Environmental health literacy · Mercury contamination · Manipulatives · Chemical models

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Introduction

General observations over the course of history record the usefulness of physical objects to solve problems and share knowledge, as well as the value of experiential learning for vocational training. The abacus used in China and the *quipu* (colorful knotted strings) used by the Incas are examples of such tactile approaches for mathematical calculations and record keeping. In addition, humankind has long relied on apprenticeships where a youth learns by experience, guided by a master of the craft over time. Maria Montessori recognized the importance of learner-centered experiential learning and how it facilitated a greater understanding of abstract concepts. The Montessori approach that utilizes manipulatives for teaching math concepts has been shown to be effective for younger students (Laski et al. 2015). These fundamental learning principles can also be applied to teaching molecular biology or atmospheric chemistry with hands-on manipulatives.

This approach is based on the principle that people learn by doing (Ingmire 2015). In these experiences, the learner's mind is highly engaged with planning what the hands should do. Thus, the mental learning goals can be achieved by manipulating physical objects. Achievement is best when the tasks are mentally consolidated by repetition. Additionally, the challenge of performing any manipulative task can be motivating and affect the learning outcome in a positive way as compared to a passive listening experience. Motivation, the desire to learn more, is the key to processing information (Ormrod 2008). Several researchers have compared knowledge attainment among different pedagogical delivery methods in studies comparing hands-on only lesson delivery with verbal only lesson delivery (Asokanthan 1997; Lipson 2007; Stice 1987). The latter showed that as much as 90% of the knowledge was retained when a concrete experience was given, compared to 20% retention when an abstract concept was provided alone.

A Modelling Set with one Purpose

The set was designed with one purpose – to communicate abstract concepts in concrete ways.

Each lesson is grounded in the use of LEGO bricks and instructional mats. Building tasks using the bricks are guided by pictures on placemats to provide immediate, positive feedback. In the last step of building their model, students place their structures on top of full-scale pictures to check for correctness; this step provides immediate, positive feedback for the tactile experiences. While the target age group in school settings is grade six through grade ten, because the materials summarize key concepts quickly and well, community colleges and colleges have used them successfully for non-scientific audiences. Thus, such kit-based, hands-on approach can help students of different ages and from different backgrounds better understand how environmental exposures affect their health.

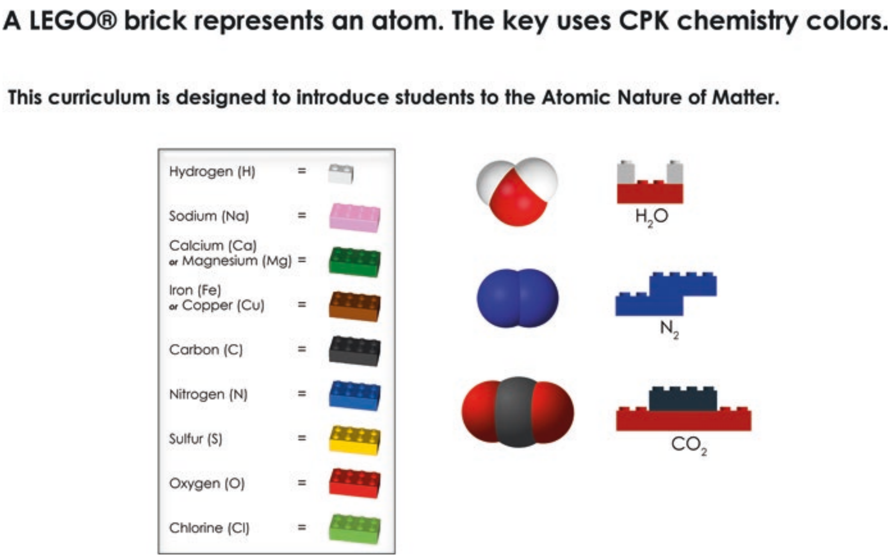


Fig. 12.1 Colors, shapes, and connectivity are important in this model

The sets come with a well-designed teacher guide to help facilitate the classroom activities. The guides enable the teachers to be properly prepared for the classroom activities. Additionally, this guided inquiry approach allows the student to explore and discover the concepts for themselves and may stimulate the students' desire to learn more.

LEGO bricks embody a favorite classroom teaching analogy – elements as the building blocks of nature – but more importantly, the bricks help to convey several key, abstract chemical concepts. Colors represent the atoms of different elements, which helps students become familiar with standardized chemical colors, such as black for carbon, red for oxygen, and white for hydrogen. Brick sizes also have meaning and help students understand the different atom sizes. The bricks connect to each other, just like atoms in nature cling together to form molecules.[1] Students can create molecules by pressing bricks together, rather than using small sticks or springs as in other molecular modeling systems. The simplicity of the bricks keeps the students and teacher focused on the primary instructional goal – using the models to illustrate the essential introductory concepts and definitions for: atoms, molecules, elements, compounds, mixtures, and chemical reactions.

The instructional placemats emphasize that molecules take specific, functional shapes. Students use the placemats to confirm they have assembled the bricks in the correct shape. Although exact chemical bond angles cannot be duplicated with the bricks, each molecular model has a designated, stylized space-filled shape that is consistent across lessons. For example, the CO_2 model has one carbon attached to two separate oxygens (See Fig. 12.1.)

[1] The word "molecule" comes from the Latin words meaning "little lump." ("Mole" = mass or lump of matter and "cule" = tiny or little.)

Filling Educational Gaps

The atomic nature of matter is one of the major cross-cutting concepts listed in the Next Generation Science Standards (NGSS). Furthermore, the NGSS identifies working with models as one of the eight key science and engineering practices for students. Thus the curriculum avoids the pitfall of many well-designed stand-alone environmental health science programs that are provided to school districts by university staff that cannot be adapted because there isn't enough time in the public-school year to schedule these lessons.

Since an understanding of modern biology has become increasingly focused on molecular content, the Molecule Set helps to address student misconceptions about science and lack of basic chemistry training. The efficacy of this lesson series in helping students better understand abstract concepts has been carefully evaluated and subsequently promoted in the National Science Teachers Association publication, *Toward High School Biology* (Hermann-Abell et al. 2016). The teacher guide and the student workbook employ several modeling methods for atoms and the workbooks include lesson plans that utilize LEGO bricks as atoms, which focus on core chemistry concepts and National Science Standards.

These lessons assure School districts that classes will be well aligned in the context of modeling both disciplinary core ideas, and connecting crosscutting concepts about the atomic nature of matter. Specifically, the Molecule Set embodies how models, including physical representations of atoms, mathematical descriptions, and graphing techniques can be used to explain scientific phenomena across many scientific fields. The inclusion of environmental health content in the Molecule Set curriculum helps make abstract molecular concepts understandable by providing an example of real-world problems.

As previously stated, models make abstract concepts more concrete. This fact is well demonstrated when students learn about subscripts. Subscript numbers are often challenging for students since the subscript is placed *after* the symbol it describes, which is an unexpected location. Using the Molecule Set students can observe both the model and its chemical formula to learn how subscripts work. Teaching this notational method takes time and practice for young students. However, this tactile approach of building molecules makes this intellectual concept visually clear for students.

Word definitions in chemistry often have students falling back on memorization to pass a test, which can be challenging for many students. Tactile approaches can help students understand technical definitions and apply them through sorting exercises with the brick models. Bruner, Goodnow, and Austin first described a technique for concept attainment in 1956, which is often called, "Describe that rule!" This learning approach has students decipher the rules for a game by watching the game (Bruner et al. 1986). In the context of LEGO bricks, molecules are built and then sorted in two categories – an element group and a compound group. Looking at a brick model of N_2 (see Fig. 12.1) a student can see why N_2 is not a compound. While two atoms are joined together, the molecule is all the same color. Therefore, this molecule is all the same element. A representation of a compound, on the other hand, would need to clearly show the two or more different elements that comprise it. The models help make the concept easier to understand by engaging multiple senses and applying the definition, rather than just requiring memorization of a written definition that students may not understand.

The definition of what is a mixture and what is "not a mixture" can be demonstrated as well with the models. A mixture of water and carbon dioxide can be modeled by building two molecules of H_2O and two molecules of CO_2 and placing them nearby each other on the desktop. The molecules remain separate, and they could be easily separated by physical (versus chemical) means. This is the definition of a mixture. However, if a student mistakenly picks up and joins all bricks together into one molecule, she or he would no longer have an example of a molecular mixture. He or she has created a new compound. This becomes a very teachable moment where the student can be directed to write out the molecular formula for this new compound. It's no longer a mixture of separate CO_2 and H_2O molecules moving freely, but one compound with the formula of $H_4C_2O_6$.

Given the tactile and visual nature of these activities combined with the activity mats, the models have been shown to benefit English language learners. Students learn definitions by building concrete objects. Seeing the objects at the same time as hearing the name of the object helps cement the learning (Vandiver 2013).

Educational research studies found that many middle school students associate atoms and chemicals only with experiments in test tubes, because students' only educational experience with atoms involves experiments in laboratory settings (AAAS 2018). These lab-based educational experiences lead to major misconceptions about atoms and can leave students ill-prepared for understanding the role of atoms and molecules in their environment and in their bodies. Additionally, there is a common misconception that all "chemicals" are man-made and unhealthy products. Using the various guides, teachers can facilitate the understanding that atoms exist in all kinds of matter when they provide examples of chemical reactions with the same models in multiple fields of science.

Connecting Chemistry to Real-World Issues

The lesson "Understanding Air" reinforces STEM learning goals about atoms and molecules in the context of climate change, air pollution, and energy. When energy was included in many new state science standards, it was noted that the lesson mats showing the combustion of fossil fuels illustrate a very important exothermic chemical reaction. Employing the instructional placemats and the LEGO bricks, students build molecules and compounds, then rearrange them after combustion. This tactile approach of actively binding atoms, breaking them apart, and reconnecting them as new molecules advances student understanding of chemical reactions and creation of final products, such as air pollution (Figs. 12.2 and 12.3).

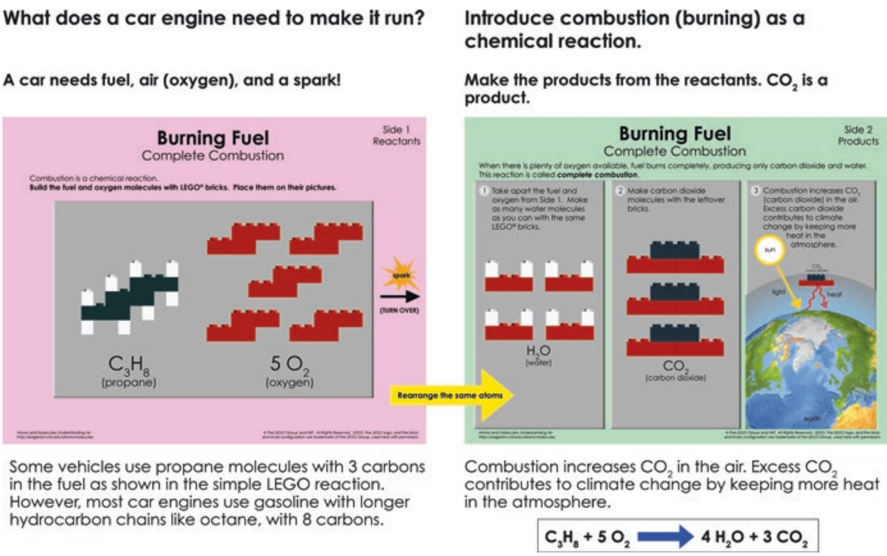


Fig. 12.2 Complete combustion reactants are placed on Side 1. Turn over mat. Create the products with the same atoms!

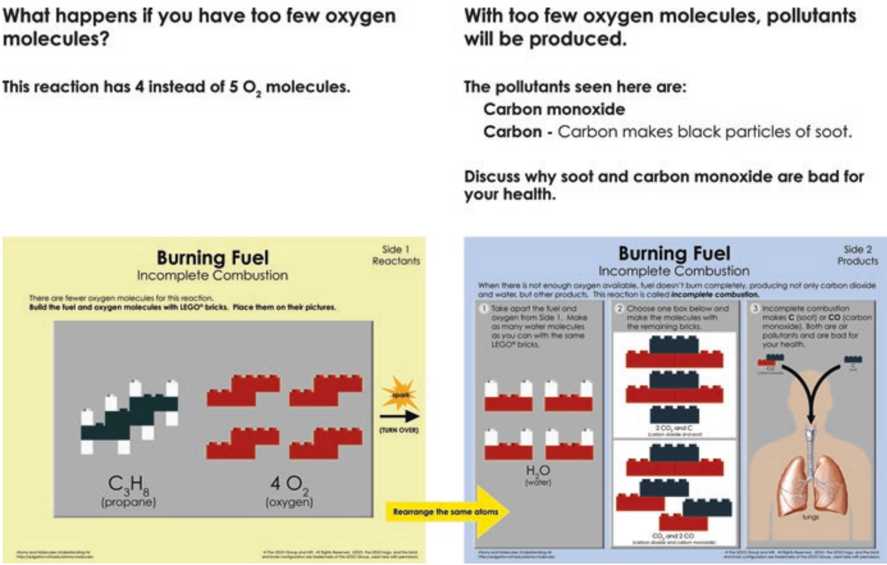


Fig. 12.3 INCOMPLETE combustion reactants are placed on Side 1. Turn over mat. Create the products with the same atoms!

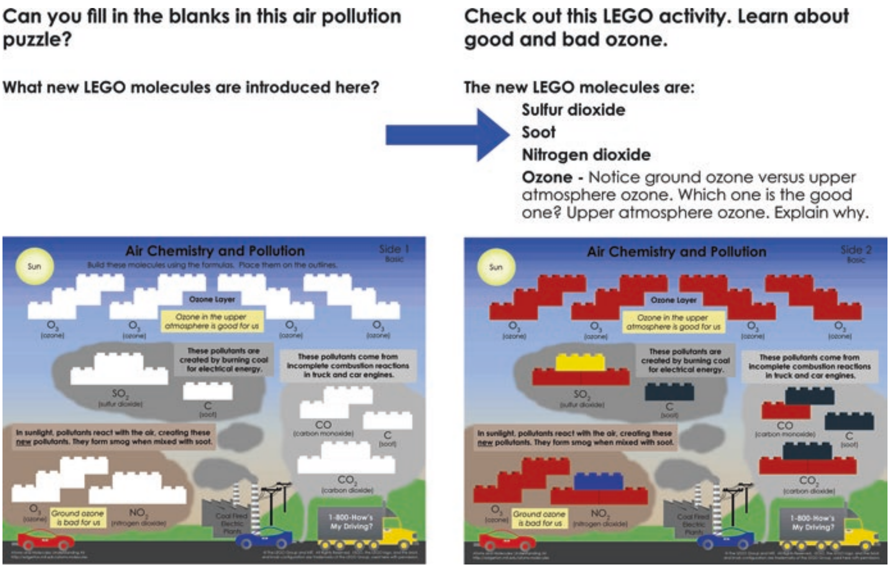


Fig. 12.4 Air chemistry and pollution. This mat has the five EPA criteria air pollutants depicted with the LEGO brick models

Tactile models combined with evidenced-based teacher materials additionally enable students to reflect on policy issues and how they relate to human health, such as the five Environmental Protection Agency's (EPA's) criteria air pollutants. (Fig. 12.4). The EPA calculates an "Air Quality Index" based on five major air pollutants regulated by the Clean Air Act, i.e., ground ozone (O_3), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) carbon monoxide (CO) and particulates (also known as particulate matter) (EPA 2016). As students build these air molecules and compounds, they learn about and explore their importance to human health and the environment, and consider the rationale behind certain policies.

The manipulative models, when combined strategically with lesson mats, can be applied to systems thinking such as the inter-relationship of air, water, and the food web. The "Understanding Oceans" lesson shows students how ocean acidification is caused by increased carbon dioxide in the atmosphere. Students assemble and rearrange bricks to observe how excess CO_2 from the atmosphere gets absorbed into ocean waters. (See Figs. 12.5 and 12.6).

The bricks demonstrate how the pH scale is used to record the concentration of free hydrogen atoms in the water and how the ocean food webs are interdependent. The Ocean Acidification Mat builds upon the knowledge gained about pH, and prompts students to consider how these changes may affect the food web. Students use the bricks to explore how acidification can have an impact on sea creatures like corals and crabs. By manipulating the molecules, students observe how these sea creatures will no longer be able to build their shells due to the chemical changes in the water. The consequences become obvious as the students are prompted to

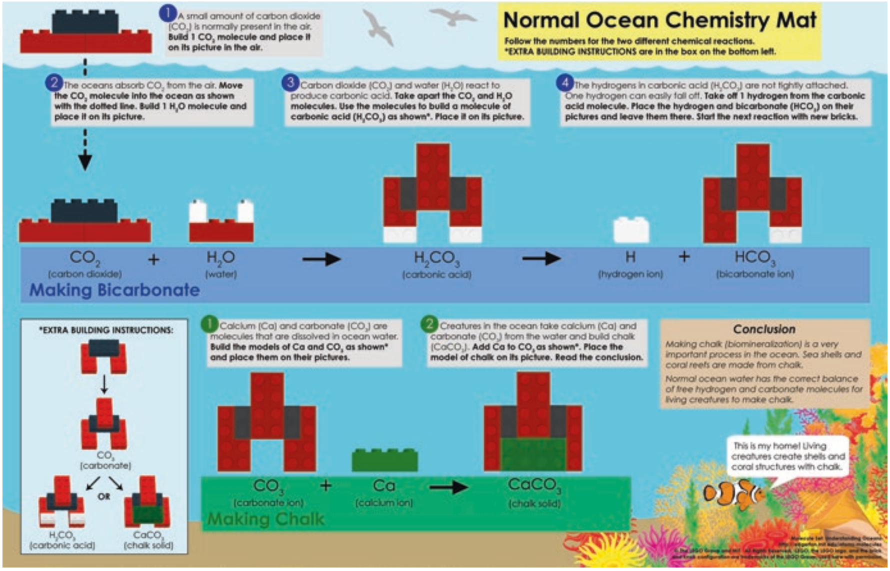


Fig. 12.5 Normal ocean chemistry mat. This mat demonstrates how small amounts of carbon dioxide entering into the water do not interfere with the pH balance of the ocean water. Sea creatures can make chalk for their shells

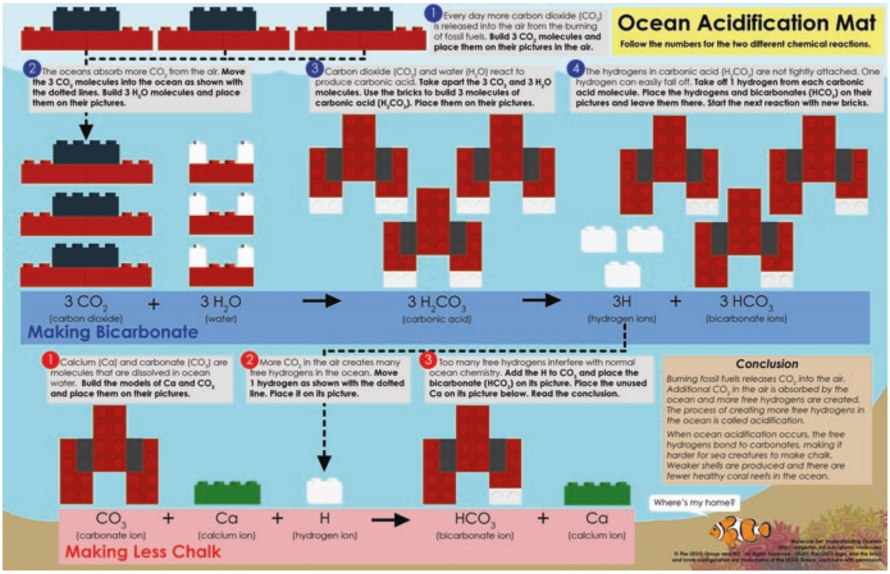


Fig. 12.6 Ocean acidification mat. A lot of carbon dioxide entering the water causes an increase in number of free hydrogens. Too many hydrogens can interfere with a sea creatures' ability to make a chalk molecule to create their shells. The free hydrogens interfere and prevent the calcium from binding and making chalk. This reaction shown in red: Calcium can't bind. The calcium remains in the water and doesn't form chalk

consider how pH changes will affect numerous interdependent ocean species. Creatures in the ocean are dependent on each other for food, and the loss of one species often affects other species. One example are krill in the Arctic Ocean – the chemical changes that lead to their loss or reduction would affect animals that depend on them for food, including whale species.

Further extension of the mats connects pH changes in the oceans to human health. **Oceans and the pH Scale** mat builds upon the knowledge gained from the previous two lessons and prompts students to think about future implications of small changes over time for human health and strategies for taking corrective action. The mat illustrates the pH predicted for the ocean in the future (e.g., year 2100). Once again, a very abstract concept becomes obvious to the learner. Small changes in the pH number look harmless, a change of just 0.3 pH points; however, as the students work with the bricks, they observe the concentration of hydrogen in the ocean water will more than double.

Teacher materials are essential to making the connections in these activities. While the students are doing the work, and exploring the concepts with the bricks, teachers guide the inquiry process. In this lesson, for example, prompts on the mat, and in the teacher materials, help educators connect the concept of healthier air with healthier oceans, as well as get the students to think about what they can do as individuals and what we can do as a society to reduce harmful exposures. This combination of hands on activities and guided inquiry can be a powerful method for building environmental health literacy.

The "Toxic Mercury in our Environment" lesson further emphasizes the interrelationship of different components of an ecosystem and can serve as a way to challenge students to think about individual and societal solutions. Using the bricks, students learn the physical and chemical process by which mercury in the water from mining and manufacturing, and mercury in the air develop from coal-fired electric plants and volcanic sources. The combination of bricks and mats helps students see and understand that mercury in the atmosphere is the product of these specific industrial and natural sources and has become a global pollutant, since it can be deposited in lakes and streams thousands of miles away from its source.

The interactive lessons help students understand why there are advisories about eating fish. The bricks and mats walk the students through the bioaccumulation process of toxic mercury in larger predator fish, like the tuna. Students use the bricks to learn how soil bacteria take up mercury from contaminated lakes and water bodies and how the chemical nature of the mercury is altered by the addition of a methyl group (CH_3) to the metal. Students observe how the addition of the methyl group alters the fate of the mercury, creating a carbon compound that can enter the food chain.

Through the guided inquiry approach, students learn how fish can accumulate high levels of this mercury if they are predator fish, by eating smaller fish that earlier picked up methylmercury from eating plants that were contaminated from the soil. Teachers guide classroom discussions about solutions to these challenges based on the underlying chemical processes they have just learned about. These problem-based approaches advance the EHL of students by increasing their understanding of

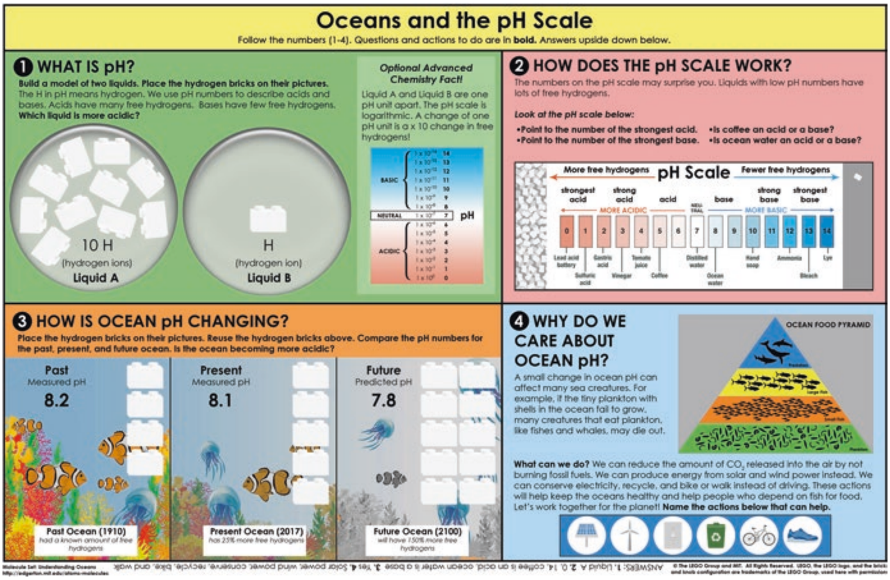


Fig. 12.7 Oceans and the pH Scale. This mat focuses on the relationship between hydrogen concentration and the pH number scale. Some middle school students may be too young to understand the exponents needed to explain the pH scale. Therefore this mat explains the pH scale in simpler terms

the connection between environmental exposures and health, as well as building their awareness of the actions they can take to reduce those exposures (Fig. 12.7).

The Molecule Set demonstrates the potential of tactile learning to build the environmental health literacy of both students and teachers. It is one example of the value of providing engaging classroom-ready materials for teachers that enable them to integrate lessons from biology and chemistry. Such standards-based kits could lead to the inclusion of more environmental health education into mainstream science classes. Science programs in grades six through eight offer the best opportunity because curricula for these grades overlap with environmental health literacy topics almost completely. Science subjects in middle schools are also taught with greater sequencing flexibility than at the high school level. Middle schools often have a spiraling or integrated approach that touches upon several different branches of science in one year, unlike the high school "layer-cake" sequence for the sciences with a separate year for each of subject such as biology, chemistry, and physics (Education 2016; Osland 2005). Given this educational context, well-designed lessons that combine the use of models, activity placemats, and teacher guides can increase the EHL of students and teachers (Fig. 12.8).

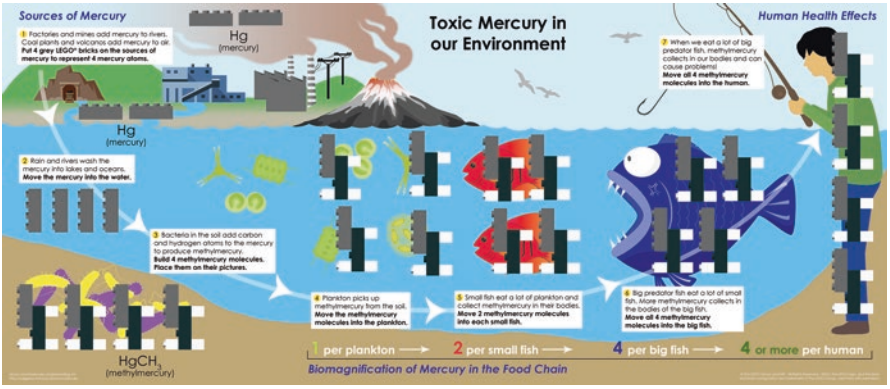


Fig. 12.8 Toxic mercury in our environment. Four sources of mercury and the important role of microorganisms are depicted. Learners act out the steps with the bricks. The bio-magnification of mercury in the food chain helps to explain the fish consumption limits. The public environmental health messaging with this activity at informal science events with the public can be enhanced by providing information about local fish consumption advisories. Information about the dietary benefits of fish consumption to help the public find a health balance for fish as a nutritious food source can also be provided

Manipulatives Outside the Classroom

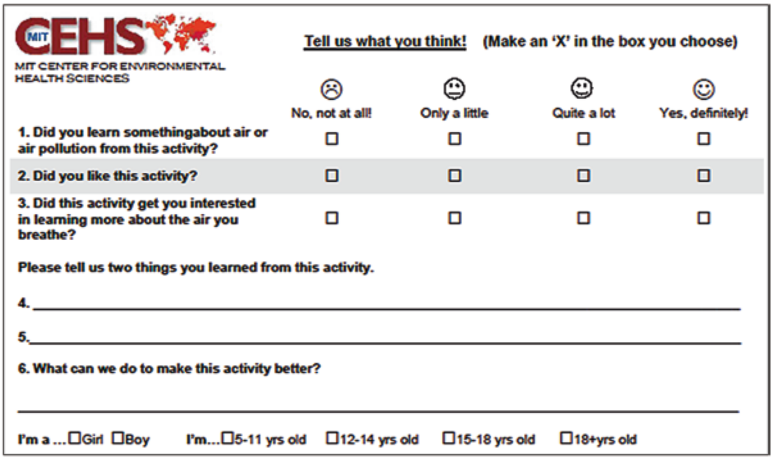
Tactile learning can be used just as effectively outside the classroom in more informal settings. Observational research of volunteers using the "Understanding Air" lessons at informal science education events indicate that this activity can be used to build the EHL of the general public. The results suggest that "Understanding Air," which is designed for middle school audiences, is at an appropriate informational level to provide an effective tool for communicating health science information to the general public.

It is important for educators to track the efficacy of such teaching aids. However, finding a well-accepted evaluation instrument for analyzing responses independent of participant age and topic can be challenging. The "System for Assessing Mission Impact (SAMI)," which science museum professionals developed, has been validated and shared by the St. Louis Science Center. This evaluation instrument was originally designed to collect and summarize key performance indicators for educational programs at the St. Louis Science Center (Center 2014). The **SAMI Card** that they developed is a deceptively simple survey instrument, yet effective. Three simple questions assess and measure the following information: (1) a measure of self-reported learning about the topic; (2) a rating of how enjoyable the activity was; and (3) whether the activity raised their interest in learning more about the subject. Question 3 is a key question as it measures whether the educational activity has increased the person's interest in the subject area not just whether the information was understandable.

Fig. 12.9 The American Association for the Advancement of Science (AAAS) "Family science days" event. This was our first informal tabling event. The tables had 4 different activity stations, each with a different activity mat from the "Understanding Air" curriculum. The event took place in Boston MA. The LEGO bricks attracted many people. All ages were eager to try the activities

A small study compared an 8th grade classroom presentation at an urban middle school with an informal event using the same "Understanding Air" materials. The informal education event took place at booths at "Science Family Days," sponsored by the American Association for the Advancement of Science (AAAS) in downtown Boston, MA in February 2013. Over two weekend days, about 250 people learned about climate change and air pollution at the "Understanding Air" booth, which was arranged with four stations at the tables, each with a different LEGO activity mat. These four mats were: What is Air Made Of? Guess!; Complete Combustion; Incomplete Combustion; and Air Chemistry and Pollution. The students were also shown a PM 2.5 counter demonstration. An MIT undergraduate or graduate student stood at each station to explain the concepts. He or she facilitated the activity and answered the participant's questions. The children, many who were attracted to the tables by the sight of the LEGO bricks, were accompanied by their parents, who also showed an interest in playing with the LEGO bricks. Consequently, both the parents and the youth learned about air pollution and the potential human health effects (Fig. 12.9).

The collected SAMI card results from the youth participants were compared to the classroom-led activity with the same hands-on materials at a nearby urban middle school, in Revere Massachusetts. Unfortunately, the adult responses with SAMI cards at the AAAS booth were not analyzed because the focus was on the youth data for comparison (See Fig. 12.10).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Tell us what you think! (Make an 'X' in the box you choose)

	No, not at all!	Only a little	Quite a lot	Yes, definitely!
1. Did you learn somethingabout air or air pollution from this activity?	☐	☐	☐	☐
2. Did you like this activity?	☐	☐	☐	☐
3. Did this activity get you interested in learning more about the air you breathe?	☐	☐	☐	☐

Please tell us two things you learned from this activity.

4. ______

5. ______

6. What can we do to make this activity better?

______

I'm a …☐Girl ☐Boy I'm…☐5-11 yrs old ☐12-14 yrs old ☐15-18 yrs old ☐18+yrs old

Fig. 12.10 System for assessing mission impact (SAMI) card. This half-sheet of paper was used to obtain responses to the activity "Understanding Air" at both informal and formal settings. The Likert scale questions used pictures (instead of numbers like 1–4) to improve accuracy. The answers to the two open ended questions were later catalogued by subject. Lastly, the age and gender of the participant is recorded

Informal Setting for families:	Eighth Grade Students in Classroom:
AAAS Family Science Days, Boston, MA Feb 2013	Susan B. Anthony M.S., Revere, MA Nov 2012
(n=88) (ages: 73%= 5-11 yr; 15 %= 12-14; 2%=18+)	(n=137) (ages: 89%=12-14 yr; 11% =15-18)
(gender 61%=M; 39%=F)	(gender: 46%=M; 54%=F)
1 Did you like this activity?	1 Did you like this activity?
Average = **3.8 ± 0.4**	Average = **3.4 ± 0.6**
2 Did you learn from this activity?	2 Did you learn from this activity?
Average = **3.3 ± 0.6**	Average = **3.3 ± 0.6**
3 Would you like to learn more?	3 Would you like to learn more?
Average = **3.5 ± 0.8**	Average = **3.2 ± 0.6**

Fig. 12.11 Data from informal and formal learning settings for the "understanding air" curriculum is shown

Response to the "Understanding Air" activities was highly positive in settings with the general public as well as with the 8th grade students (Fig. 12.11**).** These surveys used Likert Scales; the scores to the questions for both settings averaged between 3.2 and 3.8 (out of 4.0). The results show that the informal group was a little younger and scored themselves higher on: (1) learning, (2) enjoyment and (3) interest. In the open-ended questions, the informal group subjects' top responses were that they learned about: the composition of air, how to write formulas, and the existence of particles in the air). Overall, the 8th graders' top responses were that they learned about: the composition of air and the chemical reaction of combustion. In addition, health was mentioned as a topic learned in 11% of the responses in both audiences. Taken together, these results are strong indicators that the key concepts for climate change and air pollution were acquired through this activity. These responses indicate that the "Understanding Air" curriculum material can deliver an effective environmental health outreach program to students in classrooms as well as to general audiences at public events (Fig. 12.11).

In addition to educating English speaking students, the Molecule Sets have been an effective tool for English as a Second Language students. The Molecule Sets and the "Understanding Air" curriculum can also be adapted for other languages and cultures based on their use of visual and tactile methods of communication rather than the written word. Given this emphasis on visual information, the set and curriculum were relatively easy to translate and implement at large urban Science Festivals in Asia and in Mexico. For example, preparations for the Cambodia (March 2015) event revealed that the activity mats for "Understanding Air" have minimal English text, which made it possible to easily translate the activities into Cambodian (Khmer). Using a train-the-trainer approach, local volunteers received training to host the table activities at these events and to educate the public. Bilingual university volunteers were selected for their strong background in chemistry and received thorough training before teaching the lessons at the festival booths. This approach enabled culturally and linguistically appropriate communication by engaging with participants in their own language and presenting materials that had been translated into their local language(s). The Cambodian Science and Engineering Festival was the first one ever held – it brought in a crowd of over 10,000 participants in 3 days! The organizers expected only 3000. (See Fig.12.12).

The Cambodian Science and Engineering Festival was specifically designed to encourage more Cambodian youth to enter science and engineering fields. The Molecule Set was well-received by all ages with continued popularity and attendance for the two successive years it was used at the environmental health booth. The government wanted more young people to become engineers and scientists to sustainably grow the country's infrastructure and to manage the growing population's environmental health issues. These issues include serious urban air pollution problems, created by the huge numbers of unregulated motorbikes and the high number of unpaved roads. In this context, the "Understanding Air" activities helped to fill an identified need and address a lived experience for Cambodian residents.

The training approach for the Beijing Science Festival was slightly modified from that used in Cambodia. In Beijing, approximately 30 bilingual middle school volunteers, selected from top middle schools in the region, received daily training for 4 days. These students worked at the eight activity tables and demonstrated the molecule sets. These students felt honored to be able to participate along with the university partners from MIT at the Beijing Science Festival. Similar to the experience in Cambodia, the Beijing residents found the "Understanding Air" lessons particularly relevant in the context of the poor air quality in their city. Results show that participants liked the activity and came away from the experience more knowledgeable about air pollution and its effect on their health.

In November 2016, the MIT team partnered with an outreach program at the Ecological Institute of Mexico, INECOL, in Veracruz, Mexico. The teams worked together to translate the entire Molecule Set curriculum and teacher materials into

Fig. 12.12 The First National Cambodian Science and Engineering Festival took place in Phenom Penh, March 2015. The college volunteers who are the explainers are wearing yellow T-shirts. Kathleen Vandiver is in the middle of the line-up with the yellow shirts. All the materials were translated into Khmer

Spanish. Unlike the other two examples, this collaboration sought a more sustainable outcome; INECOL wanted to continue using the curriculum after the science days. The team trained local teachers as well as staff members at the INECOL Ecological Institute. The training was a success, as the INECOL Institute now hosts events with these materials for students on school trips during the academic year.

The Molecule Set is gaining international exposure from the MIT Blossoms website, an online repository of instructional videos with voice-overs versions in different languages. Through this portal, educators from around the world can access classroom activities and teacher guides such as the Photosynthesis and Chemical Reactions lessons, which have voice-over sound tracks in Arabic and Japanese, among other languages (Vandiver 2018a, b). These videos are specially designed to be paused from time to time to have the classroom teacher work with the students in his or her class according to the video teacher's instructions. This approach provides a scaffold for teachers using the video to help them learn new subjects and new teaching techniques.

Conclusions and Future Directions

Much like the Montessori approach of using manipulatives to teach math concepts, the Molecular Set demonstrates the many benefits of tactile approaches to teach and communicate abstract environmental health concepts in concrete ways. The set provides educators in the United Stated with easy to use, standards-based, classroom-ready lessons. As such, teachers and school systems feel comfortable employing them in the classroom because they fill important educational gaps without requiring much additional work. From a learners' perspective, the set allows students to explore integrated concepts of biology and chemistry in a hands-on fashion and receive immediate feedback on their understanding. As described in this chapter, the sets are just as effective outside the classroom. More importantly, this tactile approach has shown that it can transcend language and culture. These successes have been documented with the SAMI feedback forms, as well as by observing the interest and enthusiasm of both the volunteers and participating members of the public.

The teachers in classrooms and the volunteers at informal events found that the visual, tangible, and kinesthetic methodologies all work to reinforce the environmental health learning. This approach can improve environmental health literacy because the methodology is learner-centered. Overall, hands-on activities with LEGO models help to express the abstract ideas about atoms in a concrete way. People can experience the concepts with their hands as well as visualize them with their eyes.

As noted in the STEM education chapter, the success of teacher training relies on quality materials (Chap. 7). The LEGO bricks represent just one part of the set. The well-designed activity mats and the teacher training guides are the two other essential parts. Material development, especially in the context of environmental health, requires transdisciplinary partnerships. The Molecule Set was developed in partnership among education experts, science communicators, and environmental health researchers. It was the combination of the skill sets of these disciplines that has contributed to the positive environmental health literacy outcomes.

The Molecule Set is just one example of how manipulatives can be used effectively in classrooms. More research is needed to better understand how similar standards-based kits could lead to the inclusion of more environmental health messages into mainstream science classes. While the MIT Blossoms webpage shows some potential for scale up of the Molecule Set lessons domestically and internationally, more work will be required to understand other sustainable approaches.

Manipulatives have demonstrated efficacy for increasing a learner's understanding and awareness of topics. In this case the connection between environment and health. However, the question remains can these hands-on approaches be used to advance EHL to higher stages? This question requires further consideration.

Tactile approaches to learning have shown the ability to transcend language and cultural barriers. Model representations of abstract concepts such as numbers, atoms, molecules, or DNA enable broader utilization because they emphasize imagery over text. As noted in the Molecule Set, it was easy to convert the activity mats because there was minimal text. Further examination into this approach in the context of EHL would be helpful to see how it relates to other communities and cultural contexts.

The Montessori approach to math using manipulatives has been successful in large part to its simplicity, its sustained application over time, and its connection to numbers. Because, EHL relies heavily on several different scientific disciplines such as chemistry, biology, as well as math, it is vital to make a connection to real-world issues to overcome this greater complexity. For example, the "Understanding Air" lessons worked well in Cambodia and Beijing in part because of the concerns related to air pollution. Boston, MA also has a strong connection to air pollution and the ocean which made those lessons particularly relevant to the local students and teachers. It would be appropriate to test these lessons in other parts of the country with different environmental health issues to validate the efficacy of these tactile approaches.

Finally, as educators embrace more digital approaches for education, there are opportunities to consider the efficacy of manipulatives in the virtual space for advancing EHL.

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Notes All MIT Molecule Set lesson plans and supporting materials are available for free download from http://edgerton.mit.edu/molecule-set.

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