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Neuroscience and Sustainability: An Online Module on "Environmental Neuroscience"

Uta Wolfe and Hannah Lindeborg
Department of Psychology, Program for Neuroscience, University of St. Thomas, St. Paul, MN, 55105, USA.

Neuroscience has extensive and vital applications to environmental sustainability that have yet to be fully integrated into undergraduate education: The neurotoxicity of common chemicals and the health dangers of anthropogenic sensory noise are well known. Research on the neural bases for value-based decision making has implications for pro-environmental efforts. Neural and sensory responses to nature exposure show health benefits of such 'green' experiences. Despite these implications, the term "environmental neuroscience", in sharp contrast to "environmental psychology", is virtually unheard of in undergraduate education.

Here we present a model for explicitly integrating environmentally-relevant neuroscience content into an undergraduate class without sacrificing its standard range of materials. Students completed a stand-alone online "Environmental Neuroscience Module" by reading and reflectively writing about popular science articles on environmentally-applied neuroscience issues. Results show that students saw the module as enhancing their understanding of class material and their application of neuroscience to sustainability and their lives. Students showed better performance on a knowledge test of environmental neuroscience relative to a control group. They also showed higher self-ratings of connectedness to nature, a robust predictor of eco-friendly behaviors. The module might thus serve as an efficient model for enriching neuroscience education through environmental applications while also fostering its contribution to sustainability efforts. Our approach might also point to novel ways of integrating neuroscience with disciplines like environmental studies and of reaching a diverse student body by teaching neuroscience in the context of important societal issues.

Key words: neuroscience education, environmental education, interdisciplinary, online teaching, pedagogy

As neuroscience has intensely grown in its scope of societal applications it is now commonly applied to areas such as health, law, ethics, politics and business (Salomon et al., 2015; Been et al., 2016). Accordingly, the need to connect the discipline to other areas of study and to teach neuroscience through interdisciplinary and applied methods has been recognized by educators (Wiertelak and Ramirez, 2008; Wolfe and Moran, 2017).

One area in which neuroscience has extensive and vital applications that have yet to be more explicitly recognized in undergraduate neuroscience education is that of environmental issues. In contrast, the value of applying psychology to environmental problems is well-known; environmental psychology has been an established discipline for several decades and is taught in various forms at both the undergraduate and graduate level (Clayton and Saunders, 2012; Gibson, 2012; Manning et al., 2012; Spencer and Gee, 2009). While some of these courses include neuroscience material (e.g., Gibson, 2012) most are still framed in the context of eco- or environmental psychology, rather than of neuroscience. Similarly, a search for "environmental neuroscience" or "neuroscience AND sustainability" in a literature or standard search engine yields almost no results, including on sites for neuroscience programs. This seems to reflect the lack of a formal, coordinated area with this explicit focus, in general and in undergraduate neuroscience education in particular. It, however, belies the broad scope of neuroscience findings with significant applications to environmental topics and stewardship efforts. To name just a few:

The neurotoxicity of a wide range of compounds (including polychlorinated biphenyls (PBEs), polycyclic aromatic hydrocarbons (PAHs), lead, mercury and other heavy metals) is well-documented, and has been associated with disruptions in nervous system development, endocrine function and sexual behavior (Brockmeyer and D'Angiulli, 2016; Cecil et al., 2008; Gascon et al., 2012; Grandjean and Landrigan, 2014; Herbstman et al., 2010; Panzica et al., 2005; Ren et al., 2011).

Anthropogenic sensory pollution has been shown to impair animal sensory systems and behaviors, such as signaling and navigation, in various and complex ways (Halfwerk and Slabbekoorn, 2015). One famous example is navy sonar interfering with whale navigation and even causing mass whale strandings (Goldbogen et al., 2013; Jepson et al., 2013; Tyack and Zimmer, 2011), a finding that has informed recent legal decisions placing limits on navy sonar use (Morell, 2015). In humans, auditory noise leads to both auditory and non-auditory public health risks including hearing loss, tinnitus, cardiovascular disease, sleep disturbance, and cognitive deficits (Basner et al., 2014). The dangers of light pollution are illustrated by findings that light (especially at night and/or in the blue range) disrupts circadian rhythm and pineal melatonin production and has been associated with cancer (Reiter et al., 2007; Holzman, 2010).

Conversely, consistent with the theory of "biophilia" (Wilson, 1984) which postulates humans' affinity for the natural environment, visual neuroscientists have shown that natural scenes are processed more efficiently and with greater neural impact than non-natural scenes (Li et al., 2005). Similarly, exposure to nature has been linked to health-positive outcomes in recent neuroscientific studies: Walking in nature reduced self-reported rumination as well as activity in the subgenual prefrontal cortex, an area associated with rumination and other types of behavioral withdrawal (Bratman et al., 2015). Viewing images of green spaces aided physiological recovery from cardiovascular stress through increased parasympathetic nervous system activity (van den Berg et al., 2015).

Furthermore, studies on the neural bases of social and value-based decision making can inform efforts to promote pro-environmental attitudes and behaviors. For example, heightened oxytocin has recently been shown to induce a bias towards social, at the cost of ecological, responsibility, pointing to the importance of properly framing pro-environmental messages (Marsh et al., 2015). Enax and colleagues (2015) identified a possible mechanism for valuation of socially-sustainable food products. Their research showed that foods labeled as sustainable induced greater valuation, higher taste ratings and increased neural activity and connectivity in cortical areas related to reward and attention.

These select examples show that neuroscience can significantly contribute to both sustainability efforts and to disciplines related to environmental issues, such as environmental science or environmental psychology. Conversely, couching neuroscience material in applied content can be beneficial for learning, as has recently been shown for content applied to health-related issues (Been et al., 2016; Wolfe and Moran, 2017).

Here we present a way to integrate environmentally applied neuroscience content into a mid-level undergraduate biopsychology class without reducing the range of standard neuroscience materials normally covered in the course. Environmental material was contained in a stand-alone online "Environmental Neuroscience Module" that students completed outside of class by reading and reflectively writing about popular science articles related to environmentally relevant neuroscience topics. Results show that students saw the module as helping their understanding of class material and their application of neuroscience to sustainability and to their lives. They also outperformed a control group on a knowledge tests of environmentally-relevant neuroscience content. Finally, compared to the control group, they showed higher self-ratings of their connectedness to nature, a robust predictor of pro-environmental behaviors (Gosling and Williams, 2010; Liefländer et al., 2013). Together these findings suggest that the module is an efficient means both for enhancing neuroscience education through environmental applications and for connecting the fields' important contributions to societal sustainability efforts.

MATERIALS AND METHODS

All research followed ethical guidelines, was approved by the IRB of the university, and was conducted in a mid-level "Brain and Behavior" course (Psyc 206) in Fall Semester 2011. The class at the time counted as an elective for neuroscience majors and as fulfilling the biological/cognitive requirement for psychology majors. Enrollment was split about evenly between neuroscience majors, psychology majors (each about 1/3), and other (mainly Premed and Biology) or undeclared majors. Students in one section of the course (n=26) completed an online "Environmental Neuroscience Module" (see Supplementary Material) to learn how neuroscience topics can be applied to issues of environmental sustainability. The module was posted on the class Blackboard site and contained five thematic sets of popular science articles linking environmental issues to themes in neuroscience. It also contained the instructions for creating an "Environmental Stewardship Portfolio" due at the end of the term. Over the course of the semester, students read and wrote reflectively about five articles of their choosing, one from each thematic set. For each article, they wrote a 700-800 word "S.P.I.T." paper: They ***s****ummarized* the main concepts, ***p****ersonalized* and ***i****ntegrated* them by making a clear connection both to information from class and to experiences or materials outside of class (such as personal experiences, newspaper articles, websites, documentary films, content from other classes, etc.), and ***t****hought creatively* about the material (by offering criticism, original ideas for applications or for future research directions, etc.). They were encouraged to be as creative and integrative as possible by drawing on a variety of sources and styles of presentation (including flowcharts, drawings, relevant journal clippings, etc.). Themes and due dates were aligned with current class topics so that one paper was due every 2-3 weeks. Themes and article topics included:

1. Neuroanatomy (including blood-brain barrier and endocrine system), neurons and hormones. Example article topics: mercury's ability to cross the blood-brain barrier and disrupt neural functioning (American Chemical Society, 1999), endocrine disruptors and their effect on hormonal balance, puberty and reproductive function (EarthTalk, 2008, 2013; Coghlan, 2004; Agin, 2008).
2. Neural development and plasticity. Example article topics: Pollution and neural tube defects (Sanderson, 2011), lead's effects on neural development (Lidsky, 2003), effects of prenatal exposure to air pollutants on cognitive development (Cone and Elert, 2010).
3. Neural bases of sensation and perception. Example article topics: superior visual processing of natural scenes (Jochen, 2003), application of biophilia to architecture and design (Davis, 2007), effect of navy sonar on whale strandings (George Mason University, 2008).
4. Sleep and circadian rhythm. Example article topics: Sleep disordered breathing and air pollution (American Thoracic Society, 2010), light pollution and blue light and circadian rhythm (Evans, 2011; Holzman, 2010).
5. Neural bases of motivation, emotion and homeostasis. Example article topics: Pollution's effect on

obesity and diabetes (Westervelt, 2011), lead exposure and aggression (Stretesky and Lynch, 2001).

Students received feedback on their first three papers and had a chance to revise them before including them in their final portfolio of five papers (worth 10% or their final grade, with the lowest paper dropped) at the end of the term. In their final portfolio, they were asked to mark what they considered their two 'best' entries and their weakest entry, and to explain the reasons for their ratings, as well as how they could improve their weak entry.

While connections of course material to the articles in the module were pointed out briefly during class meetings where appropriate, the module was overall independent of class in that students completed all work online and outside of class, none of the articles were discussed in class in depth, and the textbook (Kalat, 2009) did not specifically cover environmental topics. The module thus did not take up class time or supplant other content normally covered in the course.

At the end of the semester, students completed an anonymous evaluation in which they rated how much the module improved their understanding of course material, their understanding of the relationship between neuroscience and environmental issues, and their awareness of nature. The six items are shown in Figure 1 and were rated on a seven-point scale (0-Definitely False, 6-Definitely True).

Students also completed a knowledge test (15 items) on basic facts they were expected to learn from the module, such as PAHs' (polycyclic aromatic hydrocarbons') effects on neural tube development, the relation between fine particulate air pollution and sleep apnea, or the effect of lead on cognitive function. Finally, as an assessment of their connectedness with nature, they completed the "Inclusion of Nature in Self" (INS) scale (Schultz, 2001), a graphical, one-item scale. They chose from seven pairs of circles, one circle representing 'nature', the other 'self', with different degrees of overlap to indicate how connected they felt with nature (1-no overlap/inclusion to 7-complete overlap/inclusion). The scale is commonly used as a measure of the cognitive aspect of nature connectedness, and it correlates strongly with other measures of pro-nature attitudes and with pro-environmental behaviors (Liefländer et al., 2013; Gosling and Williams, 2010).

For comparison, a control group (n=27) who had taken the same course in the same semester (Brain and Behavior, Psyc 206, Fall 2011), but in a section without the environmental neuroscience module, anonymously completed the same knowledge test and INS scale. There was no difference in how the two sections of the class were designated for registration so that there is no reason to believe that students self-selected into sections based on their environmental interest, knowledge or attitudes.

Group means on the knowledge test and INS scale were compared using independent t-tests. The size of the difference between group means was assessed using Cohen's d, a measure of effect size that states the difference between group means in units of the pooled standard deviation.

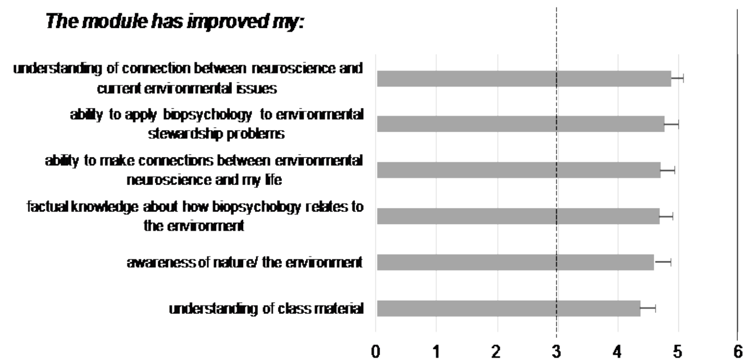

Figure 1. Module Evaluation: Mean ratings for six evaluation items (see text for details). Error bars denote standard errors. Black dashed line marks most positive rating possible (6), grey dashed line marks neutral rating (3).

RESULTS

Module Evaluation: In their anonymous ratings of the module, students indicated appreciation of the module by giving positive ratings for the items shown in Figure 1 (M=4.67, SD=1.15; individual item means ranged from 4.37 to 4.89). A one-sample t-test showed that ratings were significantly larger than 3, the neutral rating (t=7.40, df=25, $p<0.0001$). Students agreed that the module improved their understanding of class material, of how neuroscience relates to sustainability and of how environmental biopsychology applies to their own life. They also agreed that the module helped their awareness of nature and the environment, a point further strengthened by the finding below that the module seems to have also increased their ratings of connectedness-to-nature.

Knowledge Test: As illustrated in Figure 2a, students in the class section with the online environmental module scored significantly higher (M=67.8, SD=16.9) on the knowledge test than students in the control section (M=42.3, SD=18.2; t=3.90, df=53, $p<0.0005$). Cohen's d (0.94) indicates a large effect size.

Connectedness to Nature: As shown in Figure 2b, students in the section with the online module scored significantly higher (M=4.3, SD= 0.68) on the Inclusion-of-Nature-in-Self (INS) scale than students in the control section (M=3.07, SD=1.07; t=4.8, df=52, $p<0.0001$). Cohen's d (1.2) indicates a large effect size.

DISCUSSION AND CONCLUSIONS

Whereas the study of neuroscience can both greatly advance environmental efforts and, conversely, be enriched by such an application, topics of environmental sustainability are usually not found in undergraduate neuroscience classes. Especially in mid-level survey courses, this is partly due to the limited time available to cover the wide range of basic topics normally expected from such courses. For example, the class described here generally covers 13 textbook chapters in 14 weeks, not leaving much time for additional materials.

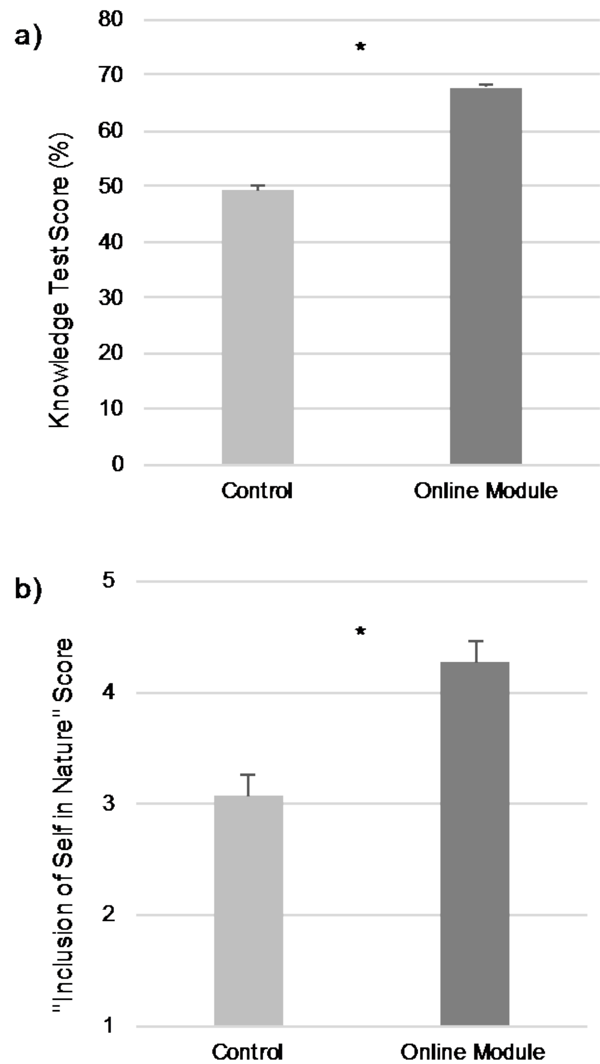

Figure 2. Knowledge test and INS: *a)* Scores on environmental neuroscience knowledge test for the control group and the group completing the online environmental module. Bars show standard errors; * indicates significant difference ($p<0.0005$). *b)* Scores on the "Inclusion of Self in Nature" scale for control group and group completing the module. Bars show standard errors; * indicates significant difference ($p<0.0001$).

Here we present a stand-alone online module as an efficient and feasible means of introducing undergraduate students to important applications of neuroscience to environmental issues. The tool is easily added to a midlevel survey class without displacing any of its standard materials or requiring class time or other resources. Results show that students perceived the module as improving their understanding of course material in general and their awareness of neuroscience-related environmental issues in particular. The module was also effective in teaching environmental material because in comparison to a control section of the course, taking the module increased knowledge of this material. As noted earlier, student self-selection into sections based on previous environmental knowledge, interest or attitudes is unlikely and neither the class meetings nor textbook in the section with the module covered environmental materials. While there is the slight possibility that some students from the different sections might talk to each other about the class, thus generating demand characteristics for a few students completing the module, we believe this to be at most a small factor. It is thus reasonable to attribute much of the difference between sections to the module.

What might be an even more important outcome, from a sustainability perspective, is that the module also seems to increase self-ratings of nature connectedness as the group completing it scored significantly higher on the INS scale than the control group. Such nature connectedness has been shown to predict environmental stewardship behaviors (such as recycling, treatment of animals, etc.; Gosling and Williams, 2010). In fact, as reviewed by Liefländer and colleagues (2013), it is this connectedness to nature, more so than environmental knowledge, that provides the motivation for pro-environmental behavior, and should thus be a focus of environmental education. The module might thus serve as a tool to enhance both neuroscience education and environmental efforts.

One limitation of the study is that we currently do not have comparative objective measures of learning outcomes, such as exam scores, that would validate students' subjective self-report that the module helped their understanding of general class material. Although students completing the module outperformed controls on the knowledge test of specific environmental neuroscience content, we thus do not know if this advantage extends to their understanding of class material in general.

Despite this caveat, the results seem to indicate that the module, which is easily integrated into a standard undergraduate course, can improve self-reported student understanding and application of neuroscience material, knowledge of environmentally-related content, and an important indicator of pro-environmental attitudes. It might thus serve as an efficient model for enriching neuroscience education through environmentally-applied instruction while at the same time advancing our field's contribution to sustainability efforts. It might also point to new modes of integrating neuroscience with other disciplines, like environmental studies, environmental science, and environmental psychology. This integration could lead a wider range of students to appreciate the field's application to pressing real-world problems.

REFERENCES

Agin D (2008) Plastic bottles, poison, and endocrine disruptors. Huffington Post, April 18.

American Chemical Society (1999) Mercury can jump barrier that keeps toxins out of brain. ScienceDaily, September 9. Available at www.sciencedaily.com/releases/1999/09/990909080318.htm.

American Thoracic Society (2010) New link between pollution, temperature and sleep-disordered breathing. ScienceDaily, June 21. Available at https://www.sciencedaily.com/releases/2010/06/100614141346.htm.

Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S, Stansfeld S (2014) Auditory and non-auditory effects of noise on health. Lancet 383(9925):1325-32.

Been LE, Mermelstein PG, Meisel RL (2016) Using a pop-science book to teach introductory neuroscience: Advantages for

science majors and non-science majors alike. J Undergrad Neurosci Educ 15:A67–A71.
Bratman G, Hamilton JP, Hahn K, Daily G, Gross J (2015) Nature experience reduces rumination and subgenual prefrontal cortex activation. PNAS 112: 8567–8572.
Brockmeyer S, D'Angiulli A (2016) How air pollution alters brain development: the role of neuroinflammation. Transl Neurosci 7(1):24-30.
Cecil KM, Brubaker CJ, Adler CM, Dietrich KN, Altaye M, Egelhoff JC, Wessel S, Elangovan I, Hornung R, Jarvis K, Lanphear BP (2008) Decreased brain volume in adults with childhood lead exposure. PLoS Med 5:e112.
Clayton SD, Saunders CD (2012) Introduction: Enviromental and conservation psychology. In SD Clayton (ed), The Oxford handbook of environmental and conservation psychology. New York: Oxford University Press.
Coghlan A (2004) Pollution triggers bizarre behaviour in animals. New Sci, September 3.
Cone M, Elert E (2010) Urban air pollutants can damage IQs before baby's first breath. Sci Am, July 26. Available at https://www.scientificamerican.com/article/urban-air-pollutants-can-damage-iqs-before-babys-first-breath/.
Davis K (2007) Learning from nature takes on new import as we pursue mitigation. Vancouver Sun, November 24.
EarthTalk (2008) The environmental effect on puberty. Sci Am, July 17. Available at https://www.scientificamerican.com/article/the-environmental-effect-on-puberty/.
EarthTalk (2013) Rises in early puberty may have environmental roots. Sci Am, October 19.
Enax L, Krapp V, Piehl A, Weber B (2015) Effects of social sustainability signaling on neural valuation signals and taste-experience of food. Front Behav Neurosci 9:247.
Evans M (2011) Light pollution disrupting sleep and wildlife, says rural body. The Telegraph, January 31.
Fahrenthold DA (2004) Male bass in Potomac producing eggs. The Washington Post, October 15.
Gascon M, Fort M, Martinez D, Carsin AE, Forns J, Grimalt JO, Santa Marina L, Lertxundi N, Sunyer J, Vrijheid M (2012). Polybrominated diphenyl ethers (PBDEs) in breast milk and neuropsychological development in infants. Environ Health Perspect 120:1760–1765.
George Mason University (2008) U.S. navy sonar linked to whale strandings, environmental scientists argue. ScienceDaily, October 6.
Gibson, PR (2012) Integrating ecological issues into psychology: A senior seminar in environment, health, and behavior. Ecopsychology 4:137-147.
Goldbogen JA, Southall BL, De Ruiter SL, Calambokidis J, Friedlaender AS, Hazen EL, Goldbogen JA, Southall BL, De Ruiter SL, Calambokidis J, Friedlaender AS, Hazen EL (2013) Blue whales respond to simulated mid-frequency military sonar. Proc Roy Soc B-Biol Sci 280(1765):1-8.
Gosling E, Williams KJH (2010) Connectedness to nature, place attachment and conservation behaviour: Testing connectedness theory among farmers. J Environ Psychol 30:298-304.
Grandjean P, Landrigan, PJ (2014) Neurobehavioural effects of developmental toxicity. Lancet Neurol 13:330-338.
Halfwerk W, Slabbekoorn H (2015) Pollution going multimodal: the complex impact of the human-altered sensory environment on animal perception and performance. Biol Lett 11:2014105. Available at http://rsbl.royalsocietypublishing.org/content/11/4/20141051?ijkey=dd428dd95cb1b26a70e731b029779234a12aefd1&keytype2=tf_ipsecsha.
Herbstman JB, Sjodin A, Kurzon M, Lederman SA, Jones RS, Rauh V (2010) Prenatal exposure to PBDEs and neurodevelopment. Environ Health Perspect 118:712–719.
Holzman DC (2010) What's in a color? The unique human health effect of blue light. Environ Health Perspect 118:A22–A27.
Jepson PD et al. (2013) What caused the UK's largest common dolphin (*Delphinus delphis*) mass stranding event? PLoS ONE 8(4):e60953.
Jochen B (2003) Natural scenes upset the visual applecart. Trends Cogn Sci 7:7-9.
Kalat JW (2009) Biological psychology. 10th edition Belmont CA: Wadsworth.
Li F, VanRullen R, Koch C, Perona P (2005) Why does natural scene categorization require little attention? Exploring attentional requirements for natural and synthetic stimuli. Vis Cogn 12:893-924.
Lidsky TI, Schneider JS (2003) Lead neurotoxicity in children: basic mechanisms and clinical correlates. Brain 126:5–19.
Liefländer AK, Fröhlich G, Bogner FX, Schultz PW (2013) Promoting connectedness with nature through environmental education. Environ Edu Res 19:370–384.
Manning C, Amel E, Bock T (2012) Environmental conservation and introductory psychology: A natural partnership. Ecopsychology 4:122–126.
Marsh N, Scheele D, Gerhardt H, Strang S, Enax L, Weber B, Maier W, Hurlemann R (2015) The neuropeptide oxytocin induces a social altruism bias. J Neurosci 35(47):15696-701.
Morell V (2015) U.S. Navy to limit sonar testing to protect whales. Science, September 16. Available at http://www.sciencemag.org/news/2015/09/us-navy-limit-sonar-testing-protect-whales.
Panzica GC, Viglietti-Panzica C, Ottinger MA (2005) Introduction: Neurobiological impact of environmental estrogens. Brain Res Bull 65:187-191.
Reiter RJ, Tan DX, Korkmaz A, Erren TC, Piekarski C, Tamura H, Manchester LC (2007) Light at night, chronodisruption, melatonin suppression, and cancer risk: a review. Crit Rev Oncog 13(4):303-28.
Ren A, Qiu X, Jin L, Ma J, Li Z, Zhang L, Zhu H, Finnell RH, Zhu T (2011) Association of selected persistent organic pollutants in the placenta with the risk of neural tube defects. Proc Natl Acad Sci USA 108:12770–12775.
Sanderson K (2011) Neural-Tube Birth Defects Tied to Organic Pollutants Levels of polycyclic aromatic hydrocarbons linked to neural tube defects. Sci Am, July 18.
Schultz PW (2001) The structure of environmental concern: Concern for self, other people, and the biosphere. J Environ Psychol 21:1–13.
Salomon D, Martin-Harris L, Mullen B, Odegaard B, Zvinyatskovskiy A, Chandler SH (2015) Brain literate: Making neuroscience accessible to a wider audience of undergraduates. J Undergrad Neurosci Educ 13:A64–A73.
Spencer C, Gee K (2009) The roots and branches of environmental psychology. The Psychologist 22(2):180-182.
Stretesky PB, Lynch MJ (2001) The relationship between lead exposure and homicide. Arch Pediat Adol Med 155:579–582.
Tyack PL, Zimmer WM (2011) Beaked whales respond to simulated and actual navy sonar. PLoS One 6:e17009.
van den Berg MM, Maas J, Muller R, Braun A, Kaandorp W, van Lien R, van Poppel MN, van Mechelen W, van den Berg AE (2015) Autonomic nervous system responses to viewing green and built settings: differentiating between sympathetic and parasympathetic activity. Int J Environ Res Public Health 12:15860–15874.
Westervelt A (2011) Two new reasons to worry about air pollution: Obesity and diabetes. Forbes, October 10.

Wiertelak EP, Ramirez JJ (2008) Undergraduate neuroscience education: Blueprints for the 21(st) century. J Undergrad Neurosci Educ 6:A34-39.

Wilson E O (1984) Biophilia. Cambridge, MA: Harvard University Press.

Wolfe U, Moran A (2017). Integrating brain science into health studies: An interdisciplinary course in contemplative neuroscience and yoga. J Undergrad Neurosci Educ 16:A77–A82.

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Address correspondence to: Dr. Uta Wolfe, Psychology Department/ Program for Neuroscience, University of St. Thomas, JRC LL56, 2115 Summit Avenue, St. Paul, MN 55105. Email: uta.wolfe@stthomas.edu

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