Have you heard the PEPS talk?

Towards standardized public engagement practices for scientists (PEPS)

Nina M Martin[1,3*], Radames JB Cordero[2,3] and Gatien de Broucker[1,3]

[1] International Vaccine Access Center, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, 21231
[2] W. Harry Feinstone Department of Molecular Microbiology and Immunology, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, 21205
[3] Public Health United, Inc. Baltimore, MD, 21201, www.publichealthunited.org

*Correspondence to:
Dr. Nina M Martin
Email: nmarti38@jhu.edu

Abstract

Publicly-funded scientists have a responsibility to engage with the public on scientific information, but are lacking a standardized framework and assessment strategy to do it well. The *PEPS (Public Engagement Practices for Scientists) Method* is an outcomes-centered framework employing standardized pedagogical methods with quantifiable outcomes. This approach reveals that scientists often have unrealistic expectations for achieving affective learning outcomes (i.e. changing views from anti- to pro-vaccine) by solely cognitive learning strategies (i.e. supplying data). *The PEPS Method* can serve as a roadmap for standardized science communication assessments, complementing existing science communication training programs for the next generation of scientists.

Keywords: public engagement on science, science engagement, science communication, public understanding of science, deficit model, informal STEM learning, active learning

> *"Effective science communication happens when we listen and connect. It happens when we use empathy. Communication is headed for success when we pay more attention to what the other person is understanding rather than focusing solely on what we want to say."*
> *–Alan Alda*

1. Publicly-funded scientists have a responsibility to engage with the public on scientific ideas, processes, and findings, but lack a framework to do it well

Climate change, pandemics, poverty, genocide, and population growth are some of humanity's most pressing problems that can be approached through science—not addressing them could lead to our demise.[1,2,3] Billions of dollars in public and private funding have already generated many science-based solutions,[4–11] but they are at risk of being rejected by the public because of an omnipresent chasm between science and society, with frustrations felt from both the lay public[12,13] and scientists.[14–17] There is a general consensus that scientists' engagement with the public is paramount to building trust in the scientific process, data-based findings, and scientific solutions,[18–23] however, scientists have no standardized framework or assessment strategy for communicating science and research is disjointed.[22]

2. Best practices research for science communication is disconnected and standardized assessment strategies do not exist

The National Academies of Science (NAS), National Science Foundation (NSF), and American Association for the Advancement of Science (AAAS) concur that there are major gaps on what constitutes best communication practices and methods, as well as assessments that measure effectiveness of practices to reaching public engagement outcomes.[21,23,24] The NAS reports that "most research on science communication conducted to date is descriptive and correlational, and relatively little of the existing research can enable confident statements about causality."[22] Additionally, most research studies are disconnected from each other and are narrow in scope, so comparisons among them are difficult.[22] There is also a lack of explicit attention to the development of underrepresented populations in STEM (science, technology, engineering & math), both in the United States and in developing countries.[25–27]

There are respected efforts to train scientists to be better science communicators, but they are not coordinated or assessed properly.[28–31] These trainings for scientists teach common models and tactics. For example, the preferred model for communicating science, the *Public Engagement Model*, purports science communication to be an ongoing dialogue between all sectors of society (**FIG 1**).[19,32] It takes into account worldviews, beliefs, fears, uncertainties, and biases. The *Deficit Model*, although outdated, is still widely used by scientists in the United States. Incorrectly, it assumes that any skepticism towards scientific findings or processes would vanish if the public simply knew more.[24,33] These trainings also teach three common tactics for effective science communication: 'knowing your audience,' putting the 'so what' up front, and incorporation of 'hands-on' or active learning

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 October 2018 doi:10.20944/preprints201810.0050.v1

strategies.[34–42] Despite the anecdotal benefits, organizations are not performing standardized research, so it is difficult to compare, assess, and implement worldwide science communication training. To fill this research gap, *The PEPS (Public Engagement Practices for Scientists) Method* is a science communication framework for scientists that incorporates these tactics and can serve as a complementary backbone to organizations, like the Alda Center for Communicating Science, for assessment and improvement.

3. Towards a standardized framework for communicating science: *The PEPS Method*

The PEPS Method[43] is a quantifiable framework for science engagement, grounded on evidence-based pedagogical processes and outcomes that defines scientists as educators and the public as learners. *The PEPS Method* systematically approaches four outcome pillars of science communication (critical thinking, human-dimension, science comprehension and engagement skills) that facilitates scientists to organize their engagement in an outcome-centered, audience-adaptable protocol (**FIG 2**). *The PEPS Method* also draws on evidence-informed pedagogical processes to design outcome-centered science communication plans. It is also designed to gain understanding of which outcomes and practices lead to learners caring about science and changing opinions based on scientific consensus. It is first of paramount importance that scientists understand that current best pedagogical practices presume that teachers are not merely one-way transmitters of knowledge, but facilitators of learning and engagement within a socio-cultural context.[44–49] Top educators set student learning outcomes first, select appropriate methods to reach outcomes, guide learners through both teacher-directed and self-regulated learning, and use assessments to measure effectiveness of methods to reach outcomes.[50,51] To successfully motivate students to learn and retain learning, educators select outcomes from multiple learning levels and domains, i.e. cognitive (thinking), affective (feeling), and psychomotor (physical) (**FIG 3**).[44,52] *The PEPS Method* helps scientists select appropriate outcome levels and types for a particular engagement. For example, a common desired outcome is changing an opinion from anti- to pro-vaccine. This is a high complexity level, affective domain learning outcome, and it will take affective approaches to achieve success. Scientists using cognitive approaches (i.e. sharing data) in a five-minute exchange have completely unrealistic outcome expectations and are using incorrect methods.

Because *The PEPS Method* is modeled after international standards of learning and teaching, we can incorporate indicators into other surveys, projects, or institutions. As such, this method provides a framework and assessment strategy that could be added to other science communication training programs, facilitating a standardized platform for comparisons.

3.1 The PEPS Method used by scientists to discuss controversial topics like vaccines. A universal tool for science communication should be able to be used in formal engagement contexts, like in a scientific conference, but also in informal contexts when addressing controversial topics with lay people. *The PEPS Method* has been tested extensively in informal discussion on the safety and efficacy of vaccines with both vaccine hesitant and confident peers (for definitions of hesitancy versus confidence refer to sources[17,53,54]). A representative outcome-centered framework is shown in **Table 1**.

This particular example is used by scientists to plan engagement with a lay person who had questions about graphs[55] that seem to show that vaccines are not effective.[56] When outcomes are organized into the four pillars of science communication (critical thinking, science comprehension, human-dimension, engagement skills), notice that three domains (cognitive, psychomotor, affective) and all levels of complexity are employed. For the lay person to achieve outcomes, the scientist serves as guide through three types and complexity levels of learning—a very challenging goal.

3.2 The PEPS Method implemented in underserved K-12 afterschool science programs. Broadening participation in STEM is a goal stated by many institutions worldwide, however, explicit attention and funding are lacking.[26,57,58] Towards filling this gap, evaluation of *The PEPS Method* is underway at *The Food Project*, a multi-sector and organizational K-12 afterschool program in Southwest Baltimore that teaches at-risk youths practical skills, like cooking and nutrition, to lead healthier, safer lives.[59] Specifically, scientists use *The PEPS Method* to teach and assess youths on the microbiology and immunology needed to understand the importance of hygiene (FIG 4). Each pillar of *The PEPS Method* is being tested and refined in this underrepresented context: engagement tactics to keep youths' attention in an informal learning setting; science comprehension processes on explaining concepts in terms that are relatable, understandable and correct; human-centered processes to be inclusive of cultural sensitivity and contextualization; and critical thinking processes to better formulate desired student learning outcomes and the methods used to achieve them. This contextual evaluation and refinement is of urgent importance, both in the United States and globally in developing countries where there is also a near complete lack of science communication training efforts in underserved STEM settings.[25,60,61] In the developing world, identifying contextual and sustainable ways to engage the public must be a priority for the research community, both on the part of foreign and in-country scientists.[62] As the number of global sites increase for *The PEPS Method* testing, it will be a tool that can be used to improve the unequal distribution of and access to quality STEM learning experiences.

4. Treating communication as an equally important step of the scientific method

There are two central challenges to improving science communication, not to mention a number of high priority actions that should be taken towards supporting scientists and unifying the field (**Table 2**). First, although communication is a step of the scientific method, it is not typically weighted with same importance as other steps—evidenced by the lack of top-down incentives or support for scientists to spend official time on engagement, beyond participation in scholarly communications. Towards addressing this imbalance, the National Institutes of Health should make a requirement to include, for example, a line item in all grant budgets dedicated to public engagement activities and training. Another recommendation is that publicly-funded scientists and trainees should also be required to take trainings in science engagement, supported by the both the funding mechanism and the scientist's institution.

A second challenge is that the field of science communication is disorganized and cannot properly inform scientists to be better communicators. Integration of a common outcome and assessment framework like *The PEPS Method* into research and science communication studies is a high priority. The use of a common framework for outcome tracking will help unify the field of science communication and better support scientists to carry out their work. *The PEPS Method* should also be globally expanded to verify applicability to a variety of contextual situations, e.g. for scientists engaging with policymakers or other scientists. Scientists can improve the field by using an outcomes-centered framework; use of *The PEPS Method* has shown that scientists often have unrealistic expectations: by supplying people with data (low level, cognitive domain), scientists unrealistically expect highly complex outcomes (i.e. changing views from anti- to pro-vaccine). In order to achieve these high-level outcomes, scientists must master and implement use of multiple domain learning approaches as well as evaluate if methods are appropriate for the desired outcomes, audience, and length of engagement.

We live in a time of rapid scientific progress; continuation of progress can only happen when we have public buy in, which is best achieved by supporting and incentivizing scientists to be excellent science communicators. Adopting a standard framework that can be refined to different contexts is a positive step towards filling these gaps and unifying the field.

Acknowledgements

We thank Dr. Patrice de Broucker, Dr. Julie Nadel, Dr. Naor Bar-Zeev, Dr. Alan Scott, Dr. Arturo Casadevall, Dr. William Moss, Dr. Gundula Bosch, and Swati Sudarsan for support and feedback.

References

1. Fang FC, Casadevall A. Reforming science: structural reforms. *Infect Immun*. 2012;80(3):897-901. doi:10.1128/IAI.06184-11.
2. Casadevall A, Fang FC. Reforming science: methodological and cultural reforms. *Infect Immun*. 2012;80(3):891-896. doi:10.1128/IAI.06183-11.
3. Casadevall A. *Crisis in Biomedical Sciences: Time for Reform?* United States: Deans Lecture Johns Hopkins School of Public Health; 2017.
4. Desmond-Hellmann S, Hurd N. To end poverty, put science at the heart of development | Sue Desmond-Hellmann and Nick Hurd | Global development | The Guardian. The Guadian. https://www.theguardian.com/global-development/2016/mar/16/to-end-poverty-put-science-at-the-heart-of-development. Published 2016. Accessed August 6, 2018.
5. Abraham C. Keep science at the heart of new push to end poverty | New Scientist. New Scientist. https://www.newscientist.com/article/mg22530020-200-keep-science-at-the-heart-of-new-push-to-end-poverty/. Published 2014. Accessed August 6, 2018.
6. Pingali PL. Green revolution: impacts, limits, and the path ahead. *Proc Natl Acad Sci U S A*. 2012;109(31):12302-12308. doi:10.1073/pnas.0912953109.
7. Stevenson JR, Villoria N, Byerlee D, Kelley T, Maredia M. Green Revolution research saved an estimated 18 to 27 million hectares from being brought into agricultural production. *Proc Natl Acad Sci U S A*. 2013;110(21):8363-8368. doi:10.1073/pnas.1208065110.
8. Weatherall D, Greenwood B, Chee HL, Wasi. P. *Science and Technology for Disease Control: Past, Present, and Future in Disease Control Priorities in Developing Countries*. 2nd ed. (Jamison D, Breman J, Measham A, eds.). Washington, D.C.; New York: The International Bank for Reconstruction and Development / The World Bank and Oxford University Press;

2006. https://www.ncbi.nlm.nih.gov/books/NBK11740/.
9. Colf LA, Brothers R, Murata CE. A Role for Science in Responding to Health Crises. *Heal Secur*. 2016;14(4):272-279. doi:10.1089/hs.2016.0001.
10. Burch JB, Augustine AD, Frieden LA, et al. Advances in geroscience: impact on healthspan and chronic disease. *J Gerontol A Biol Sci Med Sci*. 2014;69 Suppl 1:S1-3. doi:10.1093/gerona/glu041.
11. Carlson R. Estimating the biotech sector's contribution to the US economy. *Nat Biotechnol*. 2016;34(3):247-255. doi:10.1038/nbt.3491.
12. Durant J, Ibrahim A. Celebrating the culture of science. *Science*. 2011;331(6022):1242. doi:10.1126/science.1204773.
13. Pew Research Center. *Public and Scientists' Views on Science and Society*.; 2015. www.pewresearch.orghttp://www.pewresearch.org/science2015. Accessed August 6, 2018.
14. Lewandowsky S, Oberauer K, Gignac GE. NASA faked the moon landing--therefore, (climate) science is a hoax: an anatomy of the motivated rejection of science. *Psychol Sci*. 2013;24(5):622-633. doi:10.1177/0956797612457686.
15. Cook J, Nuccitelli D, Green SA, et al. Quantifying the consensus on anthropogenic global warming in the scientific literature. *Environ Res Lett*. 2013;8(2):024024. doi:10.1088/1748-9326/8/2/024024.
16. Rosenau J. Science denial: a guide for scientists. *Trends Microbiol*. 2012;20(12):567-569. doi:10.1016/j.tim.2012.10.002.
17. Larson HJ, Jarrett C, Eckersberger E, Smith DMD, Paterson P. Understanding vaccine hesitancy around vaccines and vaccination from a global perspective: a systematic review of published literature, 2007-2012. *Vaccine*. 2014;32(19):2150-2159. doi:10.1016/j.vaccine.2014.01.081.
18. Bauer MW, Jensen P. The mobilization of scientists for public engagement. Bauer MW, Jensen P, eds. *Public Underst Sci*. 2011;20(1):3-11. doi:10.1177/0963662510394457.
19. Markowitz E, Professor A. Public Engagement Research and Major Approaches. *AAAS*. 2015. https://www.aaas.org/sites/default/files/content_files/Biblio_PublicEngagement_FINAL11.25.15.pdf. Accessed October 20, 2017.
20. National Science Foundation. *NSF, Science Communication, and You: Resources for Communicating through NSF*. https://www.nsf.gov/about/congress/reports/NSFScienceCommunicationAndYou.pdf. Accessed October 20, 2017.
21. National Science Foundation. *Communicating Science and Technology in the Public Interest*.; 2010.
22. Committee on the Science of Science Communication. *Communicating Science Effectively*. Washington, D.C.: National Academies Press; 2017. doi:10.17226/23674.
23. Olson S, ed. *The Science of Science Communication III*. Washington, D.C.: National Academies Press; 2018. doi:10.17226/24958.
24. Nisbet M, Markowitz E. *SCIENCE COMMUNICATION RESEARCH: BRIDGING THEORY AND PRACTICE*.; 2016. https://www.aaas.org/sites/default/files/content_files/NisbetMarkowitz_SciCommAnnotatedBibliography_Final.pdf. Accessed October 20, 2017.
25. Karikari TK, Yawson NA, Quansah E. Build the Future of Science Communication in Developing Countries through Systematic Training of Young Scientists. *J Microbiol Biol Educ*. 2016;17(3):327-328. doi:10.1128/jmbe.v17i3.1150.
26. Committee on Underrepresented Groups and the Expansion of the Science and Engineering Workforce Pipeline, ed. *Expanding Underrepresented Minority Participation*. Washington, D.C.: National Academies Press; 2011. doi:10.17226/12984.
27. Dawson E. "Not Designed for Us": How Science Museums and Science Centers Socially Exclude Low-Income, Minority Ethnic Groups. *Sci Educ*. 2014;98(6):981-1008. doi:10.1002/sce.21133.
28. Alda Center for Communicating Science. The Alda Method®. https://www.aldacenter.org/alda-method®. Accessed August 8, 2018.
29. *COMPASS - Mission and Values*. https://docs.wixstatic.com/ugd/e58a91_d9bbf51c151c4c8c9ac19db86eb2299d.pdf. Accessed August 6, 2018.
30. Neely L, Goldman E, Smith B, Baron N, Sunu S. *GRADSCICOMM REPORT AND RECOMMENDATIONS Mapping the Pathways to Integrate Science Communication Training into STEM Graduate Education*.; 2014. https://docs.wixstatic.com/ugd/e58a91_25e6c51946db4205ae272a2a62413e96.pdf.

Accessed August 6, 2018.
31. AAAS. Communicating Science Workshops. American Association for the Advancement of Science. https://www.aaas.org/Communicating-Science-Workshops. Accessed August 8, 2018.
32. Dudo A, Besley JC. Scientists' Prioritization of Communication Objectives for Public Engagement. d'Acquisto F, ed. *PLoS One*. 2016;11(2):e0148867. doi:10.1371/journal.pone.0148867.
33. Martin N, Durant J. Episode 61: John Durant On Public Understanding of Science. Public Health United, Inc. Podcast. http://www.publichealthunited.org/episode-61-john-durant-public-understanding-science/. Published 2018. Accessed August 6, 2018.
34. American Association for the Advancement of Science. Communication Fundamentals. AAAS. https://www.aaas.org/page/communication-fundamentals-0. Accessed August 21, 2018.
35. Illingworth S. Delivering effective science communication: advice from a professional science communicator. *Semin Cell Dev Biol*. 2017;70:10-16. doi:10.1016/j.semcdb.2017.04.002.
36. THE NATIONAL ACADEMIES PRESS Effective Chemistry Communication in Informal Environments. 2016. doi:10.17226/21790.
37. Scheufele DA. Communicating science in social settings. *Proc Natl Acad Sci U S A*. 2013;110 Suppl 3(Supplement 3):14040-14047. doi:10.1073/pnas.1213275110.
38. Dietz T. Bringing values and deliberation to science communication. *Proc Natl Acad Sci*. 2013;110(Supplement_3):14081-14087. doi:10.1073/pnas.1212740110.
39. Medin DL, Bang M. The cultural side of science communication. *Proc Natl Acad Sci*. 2014;111(Supplement_4):13621-13626. doi:10.1073/pnas.1317510111.
40. Cohen J. Great Presenters. *Science (80-)*. 2013;342(6154):78-78. doi:10.1126/science.342.6154.78.
41. Shepard M. 9 Tips For Communicating Science To People Who Are Not Scientists. Forbes. https://www.forbes.com/sites/marshallshepherd/2016/11/22/9-tips-for-communicating-science-to-people-who-are-not-scientists/#6197795f66ae. Published 2016. Accessed August 21, 2018.
42. Greer S, Alexander H, Baldwin TO, et al. The Art of Science Communication—A Novel Approach to Science Communication Training †. *J Microbiol Biol Educ*. 2018;19(1). doi:10.1128/jmbe.v19i1.1547.
43. Martin NM. The PEPS Program. Public Health United, Inc.
44. Nilson LB. *Teaching at Its Best : A Research-Based Resource for College Instructors*. Jossey-Bass; 2010. https://www.wiley.com/en-us/Teaching+at+Its+Best%3A+A+Research+Based+Resource+for+College+Instructors%2C+3rd+Edition-p-9780470401040. Accessed August 13, 2018.
45. Fink LD. *CREATING SIGNIFICANT LEARNING EXPERIENCES An Integrated Approach to Designing College Courses*. https://www.unl.edu/philosophy/%5BL._Dee_Fink%5D_Creating_Significant_Learning_Experi(BookZZ.org).pdf. Accessed August 13, 2018.
46. Freeman S, Eddy SL, McDonough M, et al. Active learning increases student performance in science, engineering, and mathematics. *Proc Natl Acad Sci*. 2014;111(23):8410-8415. doi:10.1073/pnas.1319030111.
47. Storksdieck M. Center for Research on Lifelong STEM Learning. https://www.aaas.org/sites/default/files/content_files/AAAS_Typology.pdf. Accessed October 19, 2017.
48. Yale Center for Teaching and Learning. Active Learning. Yale University. https://ctl.yale.edu/ActiveLearning. Published 2018. Accessed August 7, 2018.
49. Fischer CN. Changing the science education paradigm: from teaching facts to engaging the intellect: Science Education Colloquia Series, Spring 2011. *Yale J Biol Med*. 2011;84(3):247-251. http://www.ncbi.nlm.nih.gov/pubmed/21966043. Accessed August 6, 2018.
50. Vieluf S, Kaplan D, Klieme E, Bayer S. Teaching Practices and Pedagogical Innovation Evidence from TALiS. *OECD Publ*. 2012. doi:10.1787/9789264123540-en.
51. OECD. *TALIS 2013 Results*. OECD Publishing; 2014. doi:10.1787/9789264196261-en.
52. Bloom BS, Engelhart MD, Furst EJ, Krathwohl DR. *TAXONOMY OF EDUCATIONAL OBJECTIVES The Classification of Educational Goals HANDBOOK1 COGNITIVE DOMAIN LONGMANS*.; 1956. http://www.univpgri-palembang.ac.id/perpus-fkip/Perpustakaan/Pendidikan & Pengajaran/Taxonomy_of_Educational_Objectives__Handbook_1__Cognitive_Domain.pdf. Accessed August 13, 2018.

53. Danchin M, Nolan T. A positive approach to parents with concerns about vaccination for the family physician. *Aust Fam Physician*. 2014;43(10):690-694. http://www.ncbi.nlm.nih.gov/pubmed/25286425. Accessed August 24, 2018.
54. Salmon DA, Dudley MZ, Glanz JM, Omer SB. Vaccine Hesitancy: Causes, Consequences, and a Call to Action. *Am J Prev Med*. 2015;49(6 Suppl 4):S391-8. doi:10.1016/j.amepre.2015.06.009.
55. ChildHealthSafety. Vaccines Did Not Save Us -- 2 Centuries of Official Statistics. https://childhealthsafety.wordpress.com/graphs/. Published 2009. Accessed August 6, 2018.
56. Armstrong GL, Conn LA, Pinner RW. Trends in infectious disease mortality in the United States during the 20th century. *JAMA*. 1999;281(1):61-66.
57. Riley WJ, Ruffin J, Silverstein SC, et al. *Draft Report of the Advisory Committee to the Director Working Group on Diversity in the Biomedical Research Workforce*. Bethesda; 2012. https://acd.od.nih.gov/documents/reports/DiversityBiomedicalResearchWorkforceReport.pdf. Accessed August 24, 2018.
58. *NSF INCLUDES Report to the Nation*. Washington, D.C.; 2018. https://www.nsf.gov/od/broadeningparticipation/INCLUDES_report_v16_WEB.pdf. Accessed August 24, 2018.
59. Martin NM, Raisanen J, Suazo M. The Food Project. Public Health United, Inc. www.publichealthunited.org/thefoodproject. Published 2018. Accessed August 5, 2018.
60. Karikari TK, Yawson NA. A Model Approach to Public Engagement Training for Students in Developing Countries †. *J Microbiol Biol Educ*. 2017;18(1). doi:10.1128/jmbe.v18i1.1244.
61. Karikari TK, Yawson NA, Quansah E. Developing Science Communication in Africa: Undergraduate and Graduate Students should be Trained and Actively Involved in Outreach Activity Development and Implementation. *J Undergrad Neurosci Educ*. 2016;14(2):E5-8. http://www.ncbi.nlm.nih.gov/pubmed/27385932. Accessed August 6, 2018.
62. Markowitz E, Professor A. *Public Engagement Research and Major Approaches*. Washington, D.C.; 2015. https://www.aaas.org/sites/default/files/content_files/Biblio_PublicEngagement_FINAL11.25.15.pdf. Accessed August 6, 2018.

Figures

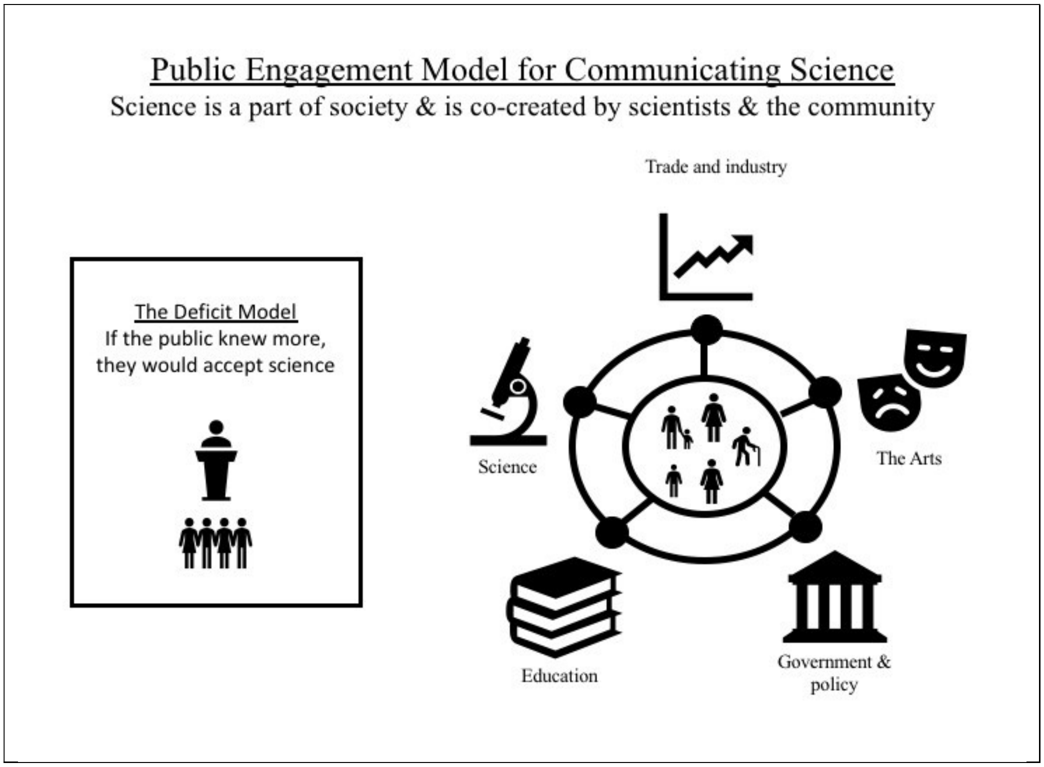

FIG 1: *The Public Engagement Model of Communicating Science*: science is an integral part of society and should be co-created by scientists and the community. Key characteristics: scientific ideas, processes and results are part of an ongoing public dialogue within a social context that also addresses benefits, risks, uncertainties, and fears, technology is owned by the community.[34,35] *The Deficit Model* incorrectly assumes that if the public knew more, they would accept science. Figure adapted from sources.[34,35]

 doi:10.20944/preprints201810.0050.v1

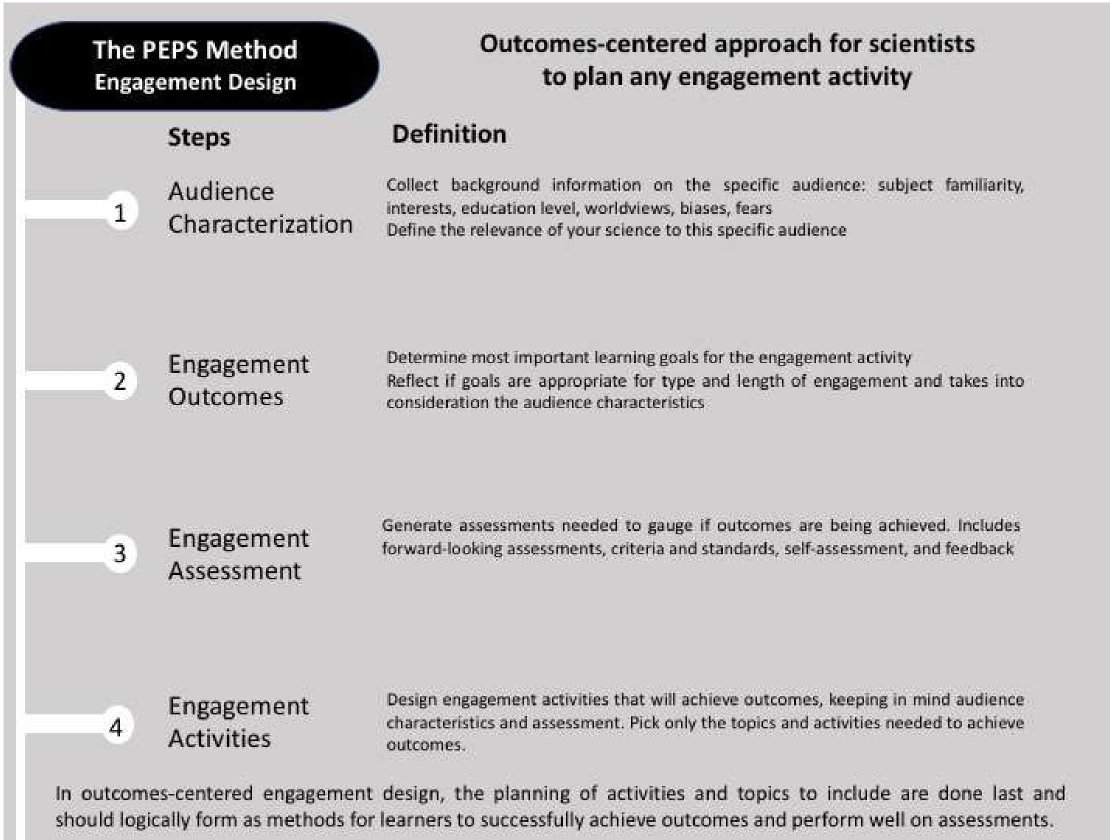

FIG 2: *The PEPS Method*: Engagement Design. *The PEPS Method* is an evidence-based, outcomes-centered pedagogical framework for improving and measuring public engagement practices for scientists in both formal and informal STEM learning environments. In outcomes-centered engagement design, scientists determine appropriate outcomes for the type and length of engagement as well as in relation to the audience characteristics. Assessments are then planned to best determine if outcomes are achieved. Last, engagement activities are designed in order to promote student success in achieving outcomes as evaluated in the planned assessments.

 doi:10.20944/preprints201810.0050.v1

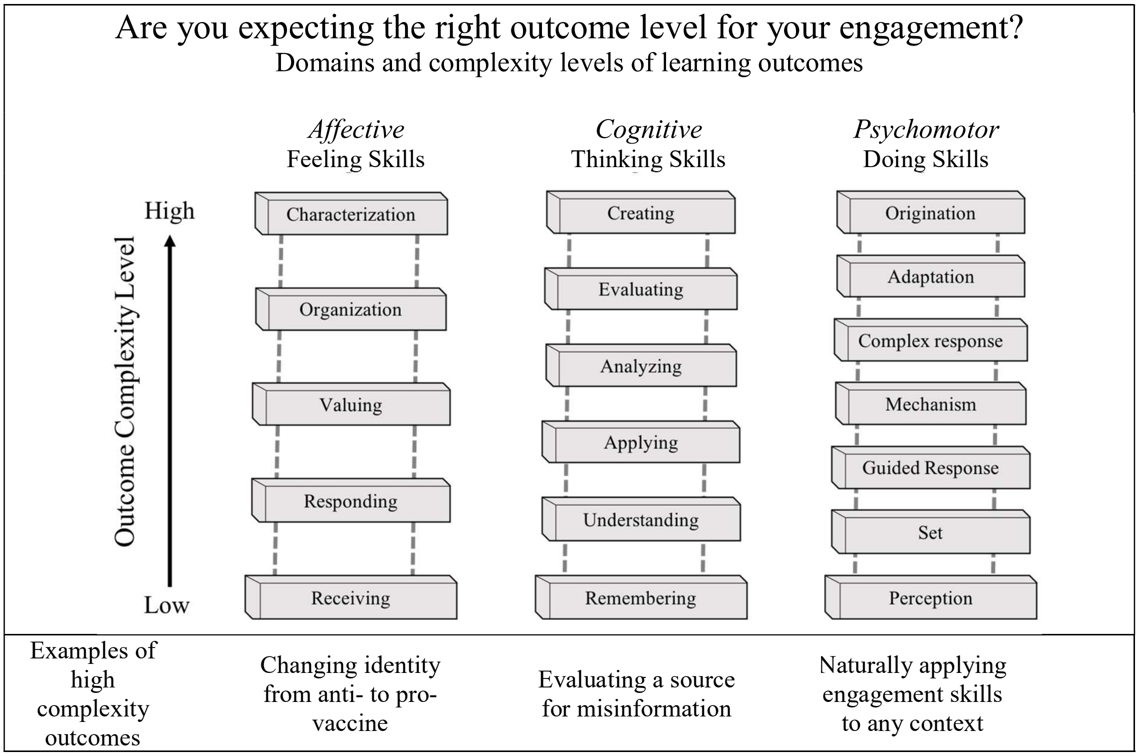

FIG 3: Three domains of learning, from low (bottom) to high (top) complexity educational learning outcomes. The affective domain, left, includes factors like motivation, attitudes, perceptions and values.[55] The cognitive domain, center, includes learning related to knowledge.[56] The psychomotor domain, right, includes learning related to actions and motor skills.[56] Ladders adapted from Bloom's Taxonomy of student learning outcomes.[55, 56]

Pillar	Engagement Outcome A successful learner will be able to:	Outcome Type & Complexity Level	Outcome Assessment	Engagement Activities
Critical Thinking	Analyze graph for legitimacy, uncertainties, biases. Ask appropriate questions	High, Cognitive	Performance checklist: Did learners complete all steps to check legitimacy of data?	10 minutes for learners to analyze graph (will be very challenging for students with low critical thinking skills) 10 minute guided graph analysis
Science Comprehension	Describe science concepts needed to understand graph	Middle, Cognitive	Knowledge Survey: Learners explain main concepts to peers and to larger group	Learners list science concepts found in the graph, noting unfamiliar ones. 5 minutes for peer instruction followed by teacher guidance and emphasis on most important concepts
Human-Dimension	Value the impact vaccines have had on infectious disease Form beliefs that vaccines have an impact on diseases	High, Affective	Reflect & Write: Learners share stories of value of vaccines and put data in storytelling context	Personal stories of impact and value of vaccines. Show data only to show that graphs are misleading and the human-dimension
Engagement Skills	Use respectful behaviors Feel comfortable asking questions and sharing uncertainties or fears Display open attitude	High, Affective & Psychomotor	Behavior Checklist Self-reflective journal entry	Learners self-generate rules and guidelines at beginning of session

Table 1: *The PEPS Method*: Outcome-Centered Planning. Using *The PEPS Method* to plan engagement on vaccine efficacy uses highly complex and varied types of learning outcomes. These outcome types already have validated assessments that have been in formal STEM learning environments; we've adapted them for use in informal STEM learning environments.

 doi:10.20944/preprints201810.0050.v1

FIG 4: The Food Project. Scientists using *The PEPS Method* to teach microbiology & immunology in underserved STEM communities

 doi:10.20944/preprints201810.0050.v1

Recommendations for…
The PEPS Method
1) Wider testing and validation of *The PEPS Method*, e.g. expansion of program from original U.S. site to multiple, global sites 2) Continued and expanded refinement of *The PEPS Method* in underserved STEM communities 3) Assessment of *The PEPS Method* for engagement with policymakers
Scientists
1) Requirement for continued trainings in science communication for publicly funded scientists and trainees. 2) Wider subscription by scientists to the Public Engagement Model, supporting that science communication should be an ongoing dialogue with all levels of society 3) Personal reflection on matching appropriate engagement goals for the timeframe and type of activity 4) Demand that time spent on science communication is considered a legitimate part of work week 5) Inclusion of oral science communication practicums as part of core curriculum in graduate and undergraduate STEM programs.
The field of Science Communication
1) Creation of common assessment tools to measure impact of engagement efforts 2) Defined list of standardized engagement outcomes 3) More collaboration between researchers and practitioners

Table 2: Recommendations for *The PEPS Method*, scientists, & the science communication field