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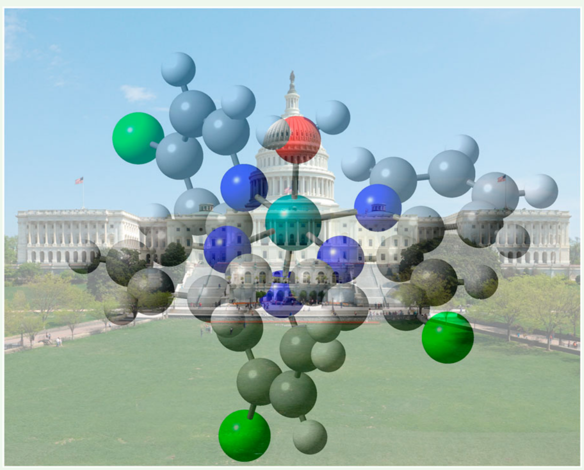
ABSTRACT

Although optimizing each of the Twelve Principles of Green Chemistry is necessary for achieving the greenest possible chemistry in the lab, there are additional creative ways to promote green chemistry not encompassed by these. Communicating to society the importance of green chemistry beyond the laboratory is essential. Of course, doing this effectively presents distinct challenges to those encountered when designing chemical syntheses. Here, I discuss several observations from my time working in federal science policy as an American Association for the Advancement of Science/American Chemical Society Congressional Science Fellow in the United States Senate. I suggest a practical science policy exercise that could be included as a companion to learning in the laboratory or classroom. This assignment provides an avenue to address broader applications of science to society while exposing students to meaningful ways to be involved in the democratic process beyond voting.



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Introduction

The Twelve Principles of Green Chemistry were articulated by Paul Anastas and John Warner in Green Chemistry: Theory and Practice (*1*). In the two decades since this publication, green chemistry not only has been transformative in the laboratory setting but has influenced education, industry, and public policy (*2*). The twelve principles are employed by those practicing chemistry in applications ranging from designing green syntheses to enhancing chemical safety. Effectively promoting green chemistry outside the lab requires communicating these improvements to an often non-technical audience. This presents a unique set of challenges but also opportunities to impact society on a much broader scale.

Although valuable resources have been developed to introduce green chemistry principles in labs and lectures, (see for example (*3–5*)) some challenges associated with integrating, focusing, and developing these concepts across the chemistry and biochemistry curriculum remain. In lower division college courses, there is constant tension between the variety of topics and applications that can be covered versus in-depth focus mastering the fundamentals. General and organic chemistry courses tend to be offered by a chemistry department, fairly narrowly defined in scope of creative content, and required to serve the needs of multiple majors and intended career paths. One could argue that green chemistry should be counted among the most fundamental of

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topics in chemistry. This may be true in terms of importance. However, in practice, understanding the meaning of all twelve principles requires knowledge of foundational chemistry concepts that are introduced in general and organic chemistry courses and further developed in upper division material. Although dedicated courses in mechanistic toxicology and green chemistry can be taught as upper division special topics, most curricula would classify those courses as electives designed for students majoring in chemistry or biochemistry. Hence, exposure to these advanced topics is typically limited to a small subset of the students who were enrolled in the general and organic sequences.

My experience with the chemical industry primarily derives from interaction with colleagues and my time working at the National Institute of Standards and Technology (NIST), which is a Department of Commerce laboratory and non-regulatory agency. In private sector research and development budgets, short-term goals often are prioritized over long-range innovation. Quarterly and annual profits are more readily quantified, while multi-year trends may be difficult to measure directly during performance reviews or for individual incentives. Green chemistry advances often result in tremendous cost savings but may require innovative business and market models to fully realize (*6*). Nevertheless, there can be challenges initiating the time and financial investment required for transformative innovations and communicating the intricacies of green chemistry to decisions makers in business and marketing to the public (*7*). Although it generally is popular to be "green," the quantifiable metrics by which this can be measured for green chemistry may be too technical to be described in a soundbite (*8*,*9*). These particular communication and prioritization challenges for business reflect those encountered in aspects of federal and global science policy as well (*10*).

Although promoting green chemistry in education and business is certainly important, here I want to focus on efforts in science policy for three reasons. The first is because I have some first-hand experience working in federal science policy as an American Association for the Advancement of Science/American Chemical Society (AAAS/ACS) Congressional Science Fellow in the U.S. Senate. The second is that this facet has the opportunity to enhance and shape programs for promoting green chemistry in education and business practices. Thirdly, the high degree of polarization that at times defines the political climate may discourage some readers from exploring this arena. Nevertheless, green chemistry actually provides great success stories garnering bipartisan support as well as cooperation between the public and private sector.

Promoting green chemistry beyond the laboratory setting

Federal science policy

In the last year of my doctoral studies, I decided that I wanted to spend a year working in federal science policy after graduation. At the time, I received many questions regarding why I did not want to pursue a more traditional year or two postdoctoral experience in collaboration on a research project I recently had joined and even more questions regarding what I possibly hoped to accomplish working in science policy. The standard message I heard from more senior scientists at that time was, "Well, I guess you can ask for more funding." Since the early 2000s, I believe the scientific community has made great strides in recognizing the importance of civic engagement including political involvement and communicating the importance of science to the public (*11*). Nevertheless, we can continue to improve as a community of scientists in finding ways to communicate the importance of scientific research and regulatory standards informed by science to the public and to those who politically represent us (*12*,*13*).

From grade school civics, many of us are familiar with the division of the United States Federal Government into executive, legislative, and judicial branches. Although scientists contribute in all three areas, science policy primarily is housed in the executive and legislative branches. In both of these, there is the possibility of promoting green chemistry using either the "carrot" or the "stick" model. The "stick" model includes regulatory policy that imposes fines or other consequences for offenders exceeding maximum allowed limits of pollutants or chemical waste. It may provide a needed and very powerful negative incentive but does little to encourage best behavior as the focus encourages avoiding consequences rather than fostering positive innovation (*14*). Thus, policy combining both carrot and stick models is most effective in fostering best practices while ensuring minimum standards.

The Green Chemistry Challenge (formerly called the Presidential Green Chemistry Challenge, (*15*)) is the most high-profile example of a "carrot" approach by the executive branch to promoting green chemistry. The awards for winning this voluntary challenge have been sponsored by the Environmental Protection Agency's Office of Chemical Safety and Pollution Prevention along with the American Chemical Society Green Chemistry Institute. The (Presidential) Green Chemistry Challenge has been awarding green chemistry innovation for over twenty years. The awards are currently split into three focus areas of 1) greener synthetic pathways, 2) greener reaction conditions, and 3) design of greener chemicals as well as categories in any of these three focus areas designated for small business and academic recipients and recently for environmental benefit related to climate change for technology reducing greenhouse gas emissions. Awardees include a "Who's Who" list of the major chemical companies as well as individual academic researchers and small businesses (*16*). On a related note, the P2 Recognition Project honors pollution prevention efforts with criteria for selection aligning with several of those for green chemistry as well (*17*).

Beginning in the early 2000s, "carrot" efforts to promote green chemistry using federal legislation on the Senate side were sponsored by Senator Olympia Snowe, with whom I had the honor of working during my Congressional Science Fellowship, and cosponsored by Senator John Rockefeller. In 2005 and again in 2007, the Green Chemistry Research and Development Act passed the House sponsored by Representatives Phil Gingrey and Jim Marshall. The companion legislation was sponsored in the Senate by Senators Olympia Snowe and John Rockefeller that first year it passed in the House and has been reintroduced in subsequent Congresses with various bipartisan cosponsors. In 2014, this transitioned to a bill (S. 2879) on sustainable chemistry sponsored by Sen. Coons and cosponsored by Senators Collins, Rockefeller, and Isakson. The vast majority of bills introduced in the House and Senate are referred to the committees with jurisdiction on that subject and never emerge from that committee for consideration by the full Congress much less a vote. This reality of bills languishing in committee to be reintroduced year after year in subsequent Congresses may seem frustrating or pointless to those who care deeply about a particular issue. However, a great value of such legislation is raising awareness of these issues and shaping policy accordingly regardless of the fate of the particular bill.

Federal green chemistry efforts have been mirrored at the state level. Michigan's Executive Directive No. 2006–6 was signed for the promotion of green chemistry for economic development and public health protection in 2006. Early innovators included the Green Chemistry Initiative started by the California Environmental Protection Agency in 2007. The next year, this was followed by California state legislation (*18*) as well as Michigan's Department of Environmental Quality initiating the early stages of their "Advancing Green Chemistry" process (*19*). In the ensuing decade, a number of countries, states, and local authorities have hosted green chemistry conferences and developed green chemistry policy related to the resulting ideas and recommendations.

Policy and politics

Although I was aware of the distinction in the English language between policy and politics, it was not until my time working in science policy in Washington, D. C., that I truly appreciated the difference. In many respects, developing policy is similar to the academic experience with overarching ideas driving development of principles and plans of action. Distinctly from many instances in academic research projects, bringing the various stakeholders together to shape legislation may be essential if one hopes to accomplish something more formal than simply drawing attention to an issue. Legislation introduced by a single congressional office without bipartisan sponsors is often more political in motivation and impact. It may make a statement but is unlikely to do more. Like changing the course of a large cruise ship or barge, modifying policy is an arduous process that takes time and significant cooperation across partisan and other divides. This may be a form of protection ensuring that new members of Congress do not overthrow years of progress and traditions overnight. Nevertheless, it can make quick responses to new challenges or innovation unlikely.

Working with the Congressional Research Service (CRS) to develop detailed language for legislation was an amazing learning experience during my time working with the Senate. CRS is a legislative branch agency within the Library of Congress that assists individual members as well as congressional committees in preparing legislation by providing nonpartisan policy and legal analysis. In working with CRS in the early 2000s, I learned that U.S. legislation was not supposed to be developed according to the precautionary principle. Instead, the goal was to create legislation and policy based on accepted science to limit the influence of politics anticipating issues that were not well studied and rather focus policy on responding to issues where the science was understood. The debate over the degree of influence and importance of the precautionary principle in science policy has increased over the past few decades (*20*). In abstraction, there is value in basing policy decisions on "settled" science – where the action items are not subject to uncertainty and as-yet-incomplete understanding of a topic. In practice, and perhaps increasingly as the pace of innovation advances and comprehensive implications of the environmental and health impacts necessarily lag behind the introduction of new technologies, policy developed with exclusive reliance on well-established science may be too late to be of any use. Naturally, who represents the authority to define settled science can be debated, and certainly this increases the need for active communication and involvement in a representative government. Climate change may present the most obvious grand challenge for such a timing disconnect. Many areas including nanotechnology, artificial intelligence, and genetic engineering to improve crop yield as well as human health provide additional examples where science policy is essential but the fields are new enough and innovating at such a rapid rate that any regulation or promotion at the legislative level risks being obsolete before it is even enacted. Advancing innovation by legislating directed funding may be beneficial, but ideally executive agencies responsible for distributing federal research funds would be more nimble and responsive to current trends and advances through the checks and balances inherent in the peer review process of the scientific grant system.

Even though legislation may prove cumbersome and unwieldy in driving most scientific innovation, Members of Congress as elected representatives can provide several different levels of direction and support in this way. Perhaps the most familiar is through introduction of legislation in the form of bills, also knowns as Acts of Congress or Statutes, which need to be passed by both houses of Congress and subsequently signed by the President of the United States before becoming law. As mentioned, although introduction of such legislation may draw attention to an issue and be useful for educating the public and to lay foundations for future policy, very few bills ever progress to this stage. Most simply are introduced and referred to the congressional committee with jurisdiction related to that issue. Beyond bills, Congress can introduce "resolutions" of three distinct varieties: joint, concurrent and simple. Resolutions can provide a way to communicate goals or intentions with executive agencies without requiring the time and effort to pass bills and formally create law.

In many instances, holding Congressional hearings in committees may be the most timely and influential form of representation that Congress can provide related to emerging issues in science research and regulation. On the Senate side, many of these naturally would go through the Commerce, Science and Transportation Committee although there can be overlap or topics that reside within other committees such as the Energy and Natural Resources, Environmental and Public Works, or Health, Education, Labor, and Pensions Committees. On the House side, the Committee on Science, Space, and Technology often would be the most relevant. Similar to the Senate however, Energy and Commerce, Education and the Workforce, and other committees might hold jurisdiction on a particular topic very significant to shaping comprehensive science policy. The status of all types of legislation including the full text and description of how it was introduced as well as the calendar of committee hearings and other Congressional activities can be explored in detail at the Congressional government website and is a valuable resource for exploring the current and past status of legislative issues, hearings and other activities of Congress (*21*).

Influencing policy via active representation

One of my most significant surprises during my time working in the U.S. Senate was seeing first-hand how seriously the Congressional offices approached the task of reading and responding to constituent mail. No doubt this partly results from the democratic structure that ensures Members of Congress must continue to "earn" their job through the ballot box. Although Members of Congress represent a large number of constituents with often opposing viewpoints, those who take the time and effort to contact their House and Senate Representatives with a personal letter are few and far between. Nevertheless, such constituents are extremely important since they clearly are highly motivated and involved, meaning they are very likely to vote and possibly to organize those around them. Furthermore, that single letter is considered to represent the views of numerous likeminded voters who never took the time to write. Although it is generally most effective to contact one's own representative to express concerns on a given issue, it can be valuable to include the committee members and particularly the chairs and ranking members (the highest member from the minority party) on the appropriate committees as well. Those members will be more influential in scheduling hearings and addressing legislation that comes through the committee responsible for handling a particular issue. Thus, these members may be the most necessary contacts to ensure informed representation on technical topics where specialized scientific knowledge may be needed to understand the many facets of an issue.

The response to constituent mail was most interesting on new issues and those that were "below the radar" in the media. In these cases, it was often the case that a member had not yet formed and formally stated a policy position. Despite what cynics might lead you to believe, Members of Congress take great pains to avoid flip-flopping, i.e. changing positions on an issue. Doing so, especially on something that later becomes a high-profile media issue, can create public relations disasters and result in a lot of negative press that could have been avoided with careful consideration of the issue and a well-formulated response consistent with the member's overall themes and positions.

The cynic in each of us might have an unfavorable association with lobbyists. There may be concern that these individuals wield outsized influence on shaping public policy since they have the luxury of being paid to represent a given position full-time while most of us need to pursue such efforts in our free time. While professional lobbyists typically do have resources beyond what most of us have as private individuals, they are constrained to represent the positions and interests in the capacity for which they are hired and may not be permitted to support personal causes even in their free time. Although lobbyists do lobby for a given position as their title not-so-subtly implies, the best lobbyist thoroughly present all sides of an issue while advocating for their own. They realize this background work needs to be done before a Congressional member will be ready to formulate a policy of his/her own. It is inefficient to expect the member's staff to provide all of the opposing information and analysis and probably will result in that issue being neglected and delayed. Likewise, presenting incomplete or misleading facts regarding how that issue impacts the various stakeholders is a guaranteed way to lose access as a lobbyist.

Science policy green chemistry lab or lecture project

I provided this context on the actions Members of Congress can take – be it via crafting legislation, holding hearings, or interacting with Executive Agencies – and the role that lobbyists can serve to set the stage for suggesting a green chemistry student project in a lecture or lab course. As scientists, we tend to practice technical writing in labs but rarely expository or persuasive writing. It can be a valuable learning experience to write persuasively as well as very meaningful when applied to real and important issues. An exercise to expand a green or sustainable chemistry study would be to ask the students to contact their representative(s) regarding a related issue. Effectively, the students would be "lobbying" for science by informing and requesting action by Member(s) of Congress on a given subject. Ideally, the letter should be tailored to a non-technical audience, begin by clearly describing the scientific importance of an issue, describe the various sides and potentially competing interests involved, and ask the member to support a position or action. It should conclude by asking for a response including in what way(s) the member has been involved previously with such issues and what future actions or policy is planned. It is important that this last paragraph be worded specifically as a request for a response. How directly the topic relates to green chemistry or to more broadly defined sustainability issues is left to the discretion of the instructor.

If the lab or class discussion does not dictate that a specified topic be given to everyone on the class, a valuable learning component of the assignment is to ask the students to select relevant issues for themselves. Understanding the importance of the media in influencing the focus of public policy debates is an important part of this exercise and helps ensure that the students are choosing a timely and relevant topic. In particular, this may be advantageous for upper division courses where more time and attention can be devoted to this assignment. Asking the students to choose their own topic provides a great opportunity to encourage students to read the major newspapers, online sites, and certain magazines to familiarize themselves with popular science reporting and understand the public discourse on a topic. Although involvement in social media is popular among students, I have found few follow major news sources on a routine basis.

Within the 12 Principles, several stand out as more obviously related to issues on which one might wish to contact their representatives, namely, 1. Pollution Prevention, 3. Less Hazardous Synthesis, 6. Energy Efficiency, 7. Renewable Feedstocks, 11. Real-time Analysis, and 12. Accident Prevention. Current topics of interest can be found by perusing the science and technology as well as politics sections of national, state, and local news sources.

It also may be beneficial and more enjoyable from the student perspective to allow small groups to develop their particular topics and communication strategies. An example timeline would be to introduce the assignment early in the semester and allow two to three weeks for students to gather resources and refine their focus on a topic. This may begin with primary literature but ideally extends to a comprehensive review of the popular media and relevant facts and history that can be gathered from the Congress.gov site, other government agencies, and non-profit organizations. In a trial run of this assignment, the groups then described their issues in brief 5–10 minute formal presentations including key scientific findings, relevant policy context, and intensions for the letter to Member(s) of Congress. After these presentations, another week could be allowed for time to hone the final language and message in the letter supported by the gathered research materials and refined by any class or instructor feedback following these presentations. If introduced early, this should allow these letters to be sent roughly one month into the semester. Figure 1 depicts a sample timeline assuming the assignment is initiated in the second or third week of class. As responses are received by the groups, these can be shared with the instructor. Late in the semester, these compiled

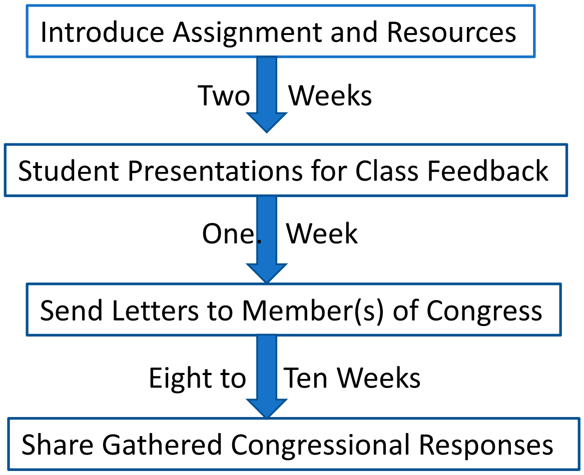

Figure 1. Sample timeline for class project contacting Members of Congress.

responses can be shared either virtually or discussed in class. It definitely makes this assignment more meaningful to allow time and a forum for "closing the loop" by sharing the responses, particularly if only a subset of students receive these.

Conclusions

Many physical science topics can seem very abstract and lack the emotional appeal that catapults other topics to the forefront of societal awareness. This can present a challenge to garnering interest and enthusiasm for focused public policy debates. However, such topics can present the advantage of having factual resources to develop strong logical arguments supported by measurable improvement strategies as in the case of green chemistry. It is important for science students to appreciate their civic rights as well as responsibilities in this regard. This adds a duty to us as scientists to improve our communication strategies and dialogue with the public and decision makers influencing not just funding of our individual research but, in a very real sense, working toward creating a just and healthy future for our world.

Notes on contributors

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Disclosure statement

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References

[1] Anastas, P.T.; Warner, J.C. *Green Chemistry: Theory and Practice*; Oxford University Press: New York, 1998.
[2] Erythropel, H.C.; Zimmerman, J.B.; de Winter, T.M.; Petitjean, L.; Melnikov, F.; Lam, C.H.; Lounsbury, A.W.; Mellor, K.E.; Janković, N.Z.; Tu, Q. The Green ChemisTREE: 20 years after taking root with the 12 principles. *Green Chem*. **2018,** *20*, 1929–1961. For a recent review, see.
[3] American Chemical Society Green Chemistry Home Page. https://www.acs.org/content/acs/en/greenchemistry.html (accessed Dec 18, 2018).
[4] Beyond Benign Curriculum Home Page. https://www.beyondbenign.org/curriculum/ (accessed December 18, 2018).
[5] Andraos, J.; Dicks, A.P. Green chemistry teaching in higher education: a review of effective practices. *Chem. Educ. Res. Pract*. **2012,** *12*, 69–79.
[6] Schwager, P.; Decker, N.; Kaltenegger, I. Exploring Green Chemistry, Sustainable Chemistry and innovative business models such as Chemical Leasing in the context of international policy discussions. *Curr. Opin. Green Sustain. Chem*. **2016,** *1*, 18–21.
[7] Tickner, J.A; Becker, M. Mainstreaming green chemistry: The need for metrics. *Curr. Opin. Green Sustain. Chem*. **2016,** *1*, 1–4.
[8] Burgman, M.; Tennant, M.; Voulvoulis, N.; Makuch, K.; Madani, K. Facilitating the transition to sustainable green chemistry. *Curr. Opin. Green Sustain. Chem*. **2018,** *13*, 130–136.
[9] Hahn, T.; Figge, F.; Pinske, J.; Preuss, L. Trade-offs in corporate sustainability: you can't have your cake and eat it. *Bus. Strat. Environ*. **2010,** *19*, 217–229.
[10] Welton, T. Editorial Overview: UN Sustainable Development Goals: How can sustainable/green chemistry contribute? There can be more than one approach. *Curr. Opin. Green Sustain. Chem*. **2018,** *13*, A7–A9.
[11] For recent news example, see in Science Magazine. http://www.sciencemag.org/news/2018/04/2018-march-science-will-be-far-more-street-protests (accessed Dec 18, 2018).
[12] Wilson, M.P.; Schwarzman, M.R. Toward a New U.S. Chemicals Policy: Rebuilding the Foundation to Advance New Science, Green Chemistry, and Environmental Health. *Env. Health Perspec*. **2009,** *117*, 1202–1209.
[13] US Environmental Protection Agency, Assessing and Managing Chemicals under TSCA. https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/frank-r-lautenberg-chemical-safety-21st-century-act (accessed Dec 18, 2018).

[14] Reibstein, R. A more ethical chemistry. *Curr. Opin. Green Sustain. Chem*. **2017**, *8*, 36–44.
[15] US Environmental Protection Agency, Information about the Green Chemistry Challenge Home Page. https://www.epa.gov/greenchemistry/information-about-green-chemistry-challenge (accessed Dec 18, 2018).
[16] US Environmental Protection Agency, Green Chemistry Challenge Winners Home Page. https://www.epa.gov/greenchemistry/presidential-green-chemistry-challenge-winners (accessed Dec 18, 2018).
[17] US Environmental Protection Agency, P2 Recognition Project Home Page. https://www.epa.gov/reviewing-new-chemicals-under-toxic-substances-control-act-tsca/p2-recognition-project (accessed Dec 18, 2018).
[18] California Laws AB 1879 (Feuer, Chapter 559, Statutes of 2008) Leading to the Safer Consumer Products Program https://www.dtsc.ca.gov/SCP/index.cfm (accessed Dec 18, 2018) and SB 509 (Simitian, Chapter 560, Statutes of 2008) Establishing the Toxics Information Clearinghouse https://www.dtsc.ca.gov/SCP/TIC.cfm (accessed Dec 18, 2018.)
[19] Advancing Green Chemistry: an Action Plan for Michigan Green Chemistry Research, Development, and Education, September 2008 https://www.michigan.gov/documents/deq/deq-ess-p2-chemistry-actionplan_236382_7.pdf (accessed Dec 18, 2018).
[20] World Commission on the Ethics of Scientific Knowledge and Technology, UNESDOC UNESCO Digital Library, The Precautionary Principle, Document Code SHS.2005/WS/21, 2005, 1-52. http://unesdoc.unesco.org/images/0013/001395/139578e.pdf (accessed Dec 18, 2018).
[21] United States Congress Home Page. https://www.congress.gov/ (accessed Dec 18, 2018).