INFLUENCES OF HIST AND THE HISTORY OF CHEMISTRY ON THE COURSE OF CHEMISTRY, EXAMPLES OF SYNERGY (1, 2)

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Introduction

> "Every journal, as soon as it's published, is history of chemistry" (3).
>
> "C&EN is the product of the work of 55 full-time journalists, most of them trained as chemists, pursuing their profession. We're proud of the first draft of history we produce each week" (4).

Happy 85th Birthday to the Division of the History of Chemistry (HIST) of the American Chemical Society (ACS)! For many decades, HIST has served as a facilitator of the study of history of chemistry. I now postulate that HIST and historians of chemistry (5) are participants in the evolution of chemistry itself.

At occasions such as this, reflection is reasonable, useful and even obligatory. We have honored HIST's 85th birthday by hosting a special symposium at the 233rd American Chemical Society National Meeting in Chicago on March 27, 2007. As we look back at our activities, we serve as historical tools for our Division. Together, the presenters have communicated their visions and their fundamental understandings for HIST and for the history of chemistry to HIST's members and others. We were pleased to have the event covered by *Chemical & Engineering News* (6). By virtue of this specially dedicated issue of *Bulletin,* we also are providing an archival resource for future members of the Division and other scholars to understand who HIST is and was in 2007. Wouldn't it have been wonderful to have had documents authored by Edgar Fahs Smith, HIST's co-founder and first Chair, from the 1920s or by Ralph Oesper from the 1940s or by Sidney M. Edelstein anytime during his long rein (1948-1964) as Secretary-Treasurer, describing their views of the mission of HIST and the role of history of chemistry in the largest context of the chemical profession?

These are fitting concepts for me to explore, and it is a fitting time and occasion to do so. Having just completed two years as HIST's Chair and, previous to that, two years as HIST's Chair Elect, I have been immersed in the strategic planning, operational planning, and leadership of HIST's activities for more than four years. I have been an eager participant in HIST's activities for many years as well. I have also been active in the field of history of chemistry for over 25 years, publishing my first study—a review of the history of conformational analysis and chemical reactivity—in 1983 (7).

Explicit and Implicit Influences of HIST and the History of Chemistry on Non-Historians

HIST's first mission statement, reprinted on page 81 of this issue of the *Bulletin* (8), was adopted on February 14, 2006 by the HIST Executive Committee (EC). HIST's mission statement describes what the Division's leadership group considers to be HIST's major goals and objectives. This statement is both reflective and forward-thinking. In 2006, the HIST EC consisted of individuals who had been past HIST Chairs and ACS Councilors over

a time period of several decades. Thus, the EC's view of what HIST ought to be in the future certainly reflected what HIST had been doing – successfully, under their stewardship – in the recent and not-so-recent past. In addition, the mission statement reflects the insights of the EC based on the current environment including the new ACS mission and vision statements. When I assumed the Chair of the Division in 2005, HIST had just received the prized ACS Division Activity Committee's ChemLuminary Award for achievements by a technical division. HIST was further honored to receive a second ChemLuminary Award for its performance in 2005 and is nominated for a ChemLuminary Award for its achievements in 2006! Thus, from the perspective of its technically-oriented non-historian peers, HIST is and has been making significant contributions to the American Chemical Society and to its members for many years.

How do the activities of HIST and of historians of chemistry affect the course of science? We have all heard—and many of us have expressed—the standard "Mother and Apple Pie" value of history. That thesis is as follows: "Science is not performed in a vacuum. History helps us understand where we are and where we have come from. We must learn from the past, not repeat the mistakes of the past." As Mary Virginia Orna, a past Chair of HIST and one of HIST's ACS councilors for many successive terms, recently stated in reference to the "Proud to be a chemist – ask me why" program of the ACS, "Placing recent chemical achievements into a historical context underlies the enormous contributions that the chemical sciences have made to the well-being of billions worldwide" (9).

For all of us in the chemical sciences, the broader our knowledge and understanding of the historical context of our work, the better we are to obtain the necessary funding and other required resources, the better we are to perform our research, the better able we are to communicate our research results to others, and the better they are to understand and value our work. The shift of interest in the history of chemistry from the classical period(s) to the 20th Century makes historical context even more relevant and consequently more available psychologically and scientifically to today's research chemists. This shift, of course, is due to at least two related factors. First, that research chemists – often in the latter stages of their careers – become actively involved in the history of their own fields of chemistry. Second, younger chemists have become interested in the history of their own fields of chemistry and validate, through their enthusiasm, the history of chemistry.

I posit that the influence of HIST and of the history of chemistry on the chemical profession extends beyond these traditional roles. These influences can be either (a) explicit activities that have direct and specific intent to influence research in chemistry; or (b) implicit activities that subconsciously provide influence. In our lives, background activity is often subtle yet can be substantive and consequential. HIST's activities extend past HIST members and touch many individuals worldwide. I shall review both explicit and implicit influences, with the understanding that there are instances of overlap, i.e., the distinction I am making is often more gray than black-and-white.

Explicit Influences of HIST on Non-Historians of Chemistry

I believe that few HIST members consider themselves to be historians of chemistry (but many could, considering my definition (5) of this term!). Clearly, many HIST members have a serious interest in and value and enjoy learning history of chemistry. By virtue of their choice of HIST membership, they explicitly seek HIST's benefits to enrich and broaden their lives. I believe that one of HIST's most valuable tangible products is *The Bulletin for the History of Chemistry.* This technical journal, published twice a year, contains a wide range of high quality scholarly research articles, essays, and book reviews. It is fully appropriate that the major source of income to the Division – the yearly membership dues – goes directly and exclusively to the publication and distribution of *The Bulletin*. Of course, other explicit influences of HIST include the consequences of HIST activities, from participation in technical meetings and symposia to serving in leadership positions and involvement in HIST awards nomination and selection committees. As the Immediate Past Chair, I know that the HIST Executive Committee is eager to welcome participation and new ideas at all levels.

Implicit Influences of HIST and History of Chemistry on Non-Historians of Chemistry. Examples

Table 1 lists a range of implicit influences of HIST on non-historians of chemistry. Also included in Table 1 are actions that HIST can undertake to increase the effectiveness to these stimuli. I shall now provide a detailed discussion of two examples of implicit influences in which I was personally involved. One involves the new HIST award program, the Citation for Chemical Breakthrough

award (10, 11); the second deals with my own recent research on the Woodward-Doering/Rabe-Kindler total synthesis of quinine (5, 12, 13).

A. Citation for Chemical Breakthrough Award Program

Work on this award program began several years before the first Citation for Chemical Breakthrough award was given (2006). It was absolutely necessary to touch a number of bases before a definitive proposal for the Citation award program could be brought before the HIST Executive Committee for formal approval. Each step raised the awareness and credibility of HIST and indirectly the awareness and credibility of the history of chemistry (see Table). Numerous members of the ACS staff, at the highest levels, and Chairs of ACS committees were contacted regarding the draft of the award program. Proposals were written and funded by two ACS grant programs, the ACS Division Activities Committee's Innovative Grants and the ACS Corporate Associates. One individual also made a substantial donation. In total, $13,000 was raised, sufficient to fund four or more years of awards. HIST's ability to influence the profession of chemistry increased with the strong support received from these financial sources and other supporters.

A majority of the members of the first two years' Citation award committee are chemists, not historians of chemistry. The majority of the nominations came from chemists, not historians of chemistry. Several of the 2006 awardees had symposia at their institutions which highlighted the Citation award program. A few hundred chemists attended the first award presentation at Harvard's Department of Chemistry and Chemical Biology. As can be seen from the Harvard symposium agenda (Fig. 1), the audience was educated and entertained by lectures by three Nobelists and several other illustrious chemists, including members of the U.S. National Academy of Sciences and that year's Priestley medalist. History was the topic but it was presented in the form and shape of science. Linda Wang, Associate Editor of *Chemical & Engineering News* wrote an article (10) on the event and thus, the award program reached countless other chemists. A subsequent program to honor Bruce Merrifield's development of solid phase peptide synthesis also was reported in *Chemical & Engineering News* (11). Award ceremonies of different types and flavors were held for all of the awardees (14), always arranged by the awardees' institutions, usually with the active assistance of HIST.

The Citation award plaques have been designed to reflect the image of the actual paper, patent or book being honored. For example, the first award plaque (Fig. 3), now placed prominently at Harvard, speaks to the history of chemistry. Excerpts from the front page of the 1965 Woodward-Hoffmann paper (15) form the thrust of the plaque. A carefully selected graphic from the publication adds to the visual appeal of the design. The plaque honoring Molina and Rowland's 1974 publication in *Nature* on the destruction of ozone by fluorochlorocarbons includes the title exactly as it appeared in the original article: with its typographic error! In response to seeing a draft of the plaque design, Rowland said, "I have no objections to the inscription for the plaque. I will comment specifically that the article in *Nature* was printed with a misprint in the title, as reproduced here" (16). The Gomberg plaque, honoring his evidence for and postulate of the free radical, includes the words "This work will be continued and I wish to reserve the field for myself," exactly as they appeared in *The Journal of the American Chemical Society* over 100 years ago.

An important aspect of the Citation award program is that the award is presented to the institution at which the breakthrough science was performed, not to the scientists or inventors themselves. Consequently, the plaques are being placed permanently in highly visible permanent, public locations rather than in the offices or, ultimately, homes of individuals. In addition to the motivational component of seeing these plaques, there is an educational component as well. Students will want to know more about the achievements of faculty and other students at their own institutions. Thus, history can stimulate and enhance the educational process.

Countless students, faculty, and visitors will pass by and see these plaques for years into the future. Pride will be an overt response, boosted by this historical perspective. Our hope and HIST's intent is that energy and enthusiasm for chemistry, in particular, and science, in general, will be stimulated by seeing these plaques. Some evidence is already in hand to support these goals. I have attended several receptions that followed the award ceremonies. Students and faculty alike spoke to me in glowing terms of history of chemistry and the human side of chemistry, perhaps without themselves even realizing their own excitement.

I conclude that awards, award plaques, award ceremonies, and the consequential publicity are all powerful and yet subtle influences of the history of chemistry on chemical education and chemistry itself.

Table. Areas of Implicit Influence of HIST on Non-Historians of Chemistry and the Field of Chemistry

Area Actions that HIST Can Take to Increase the Influence

The Bulletin for the History of Chemistry

- Increase circulation of The Bulletin, including to institutional libraries; encourage readership outside HIST members and historians of chemistry.
- Increase the number of reviewers for submissions, to include non-historians.
- Encourage non-historians to submit articles. Identify high value author-candidates, e.g., senior scholars, researchers who often author review articles.
- Publish '"modern history" special topic-driven dedicated issues of The Bulletin.
- Encourage authors to distribute copies of their published paper to non-historians. The Bulletin allows authors free rights to distribute their papers.
- Increase the number of papers that have chemical structures, thereby attracting chemists who have an interest in history.

HIST awards

- Create and strongly support awards that have significant and continuing public visibility. For example, the Citation for Chemical Breakthrough award plaque is intended to be placed in the hall outside a laboratory where a major chemical breakthrough occurred. Passers-by recognize the importance of that event and the connection with their own lives (e.g., their own undergraduate or graduate school).
- Increase nomination awareness; invite nominations from non-historians.
- Place non-historians on award selection committees.
- Have public award ceremonies. Involve non-historians in the award ceremonies, e.g., incorporate lectures or an on-site symposium into the ceremony. Encourage publicity of the award by recipient institution.

Scientific symposia

- Initiate and participate in the organization, planning and hosting of symposia outside the HIST ACS National meeting agenda. Symposia held in the meeting rooms of other ACS technical divisions will be most effective in communicating history to scientists.
- Invite non-historians to participate in history-oriented symposia, thereby creating interest in the invitees and in the audience.

Chemical & Engineering News and other technical and non-technical media

- Inform and encourage journalists to cover historical events and HIST awards.
- Interact with journalists (and congratulate them!) regarding articles they have written that either have or did not have (inform them, graciously) substantive historical context.a

As part of writing an article in the history of chemistry

- Interview and otherwise interact with non-historian chemists involved in this area of chemistry.
- Invite non-historian(s) to be collaborators in the project.
- Include sufficient chemistry and chemical structures to attract the attention of non-historians.
- Distribute reprints liberally.

A related educational experience was recounted by Jim Bohning, my fellow co-organizer of this symposium, past Chair of HIST, current HIST Historian and Archivist, and noted scholar, who recalled (17):

> I wanted students to become more aware of their surroundings and their history. The intent was the same: to increase awareness in students of their heritage and that discovery doesn't happen in a vacuum. I used to have a display on the 'Chemist of the Month' to achieve the same thing that the Citation for Chemical Breakthrough award does. Students prepared the displays as part of their course assignments. The display case was in a hallway where a lot of students passed, not just chemistry majors. I used to watch to see if anybody was reading the display, and I was not disappointed. When I taught the chemical literature course, I told the students that every time they did a literature search they were doing history, and that cumulative history would then influence how they would proceed.

In 2005, Chemical & Engineering News received HIST's Certificate of Appreciation award. See: http://www.scs.uiuc.edu/~mainzv/HIST/awards/ChemEngNews_Certificate_of_Appreciation.pdf

The Division of the History of Chemistry
American Chemical Society
Citation for Chemical Breakthroughs
Harvard University
Department of Chemistry and Chemical Biology
Friday, June 16, 2006
Introduction and Description of the Award
Jeffrey I. Seeman, Chair, Division of the History of Chemistry
American Chemical Society
Introduction of Frank Westheimer
George Whitesides
Message from Jeremy Knowles
Congratulatory Remarks from the University of Chicago
H. F. Fisher, E. C. Conn, B. Vennesland, F. H. Westheimer
J. Biol. Chem. 1953, 202, 687–697
R. Stephen Berry
Frank H. Westheimer

Presentation of Plaque
Introduction of Roald Hoffmann, Memorial to R. B. Woodward
R. B. Woodward and R. Hoffmann J. Am. Chem. Soc. 1965, 87, 395-397
William Lipscomb
"Breakthrough into Collaboration"
Roald Hoffmann
Presentation of Plaque to Harvard
Classics in Science and in Life
Dudley Herschbach
Reception to Follow

Figure 1. Symposium agenda for the presentation of the Citation award to Harvard University, June 16, 2006. As Frank Westheimer was on the faculty of the University of Chicago when he submitted his Citation award-winning 1953 paper cited above, he was "handed" the plaque, received applause and recognition, and then Westheimer gave the plaque to the University of Chicago where it now hangs. Frank Westheimer passed away less than one year later on April 14, 2007 at the age of 95 (36). A Citation award ceremony was held at the Department of Chemistry, University of Chicago on March 26, 2007.

Many textbooks and some teachers insert historical context into their courses. One motivation is to add the human side to the atoms and bonds and reactions of chemistry. Perhaps more historical context would be more frequently used in undergraduate teaching, and perhaps even in high school teaching, if there were more abundant, well-organized and compact, relevant free internet-based sources of information. My vision is that educational material would be provided with increasing levels of detail, technicality and sophistication. This could be done by hyperlinks clearly indicated with descriptive labels just as hikes at National Parks are described with labels of increasing difficulty! Perhaps this is an opportunity for the educational arm of the Chemical Heritage Foundation or for those academic scholars such as Carmen Giunta (18) who already have developed and maintain useful and informative history-of-chemistry websites.

B. The Woodward-Doering/Rabe-Kindler Total Synthesis of Quinine

There is much to be gained by a thorough knowledge of history, philosophy and sociology of science—be it from a formal educational experience or years of participation and study of these fields. Examples of implicit influences on non-historians of chemistry can be cited as a result of publications that have historical content. At a basic level of analysis, all scientists practice some history of science when they write the introduction section of their publications and grant applications.

Figure 2. *Roald Hoffmann and Frank Westheimer holding the Citation plaques that honor their breakthrough publications, with Jeff Seeman, at the reception following the award ceremony, Harvard, June 16, 2006. Photo courtesy of Linda Wang, Chemical & Engineering News. Copyright 2006 American Chemical Society*

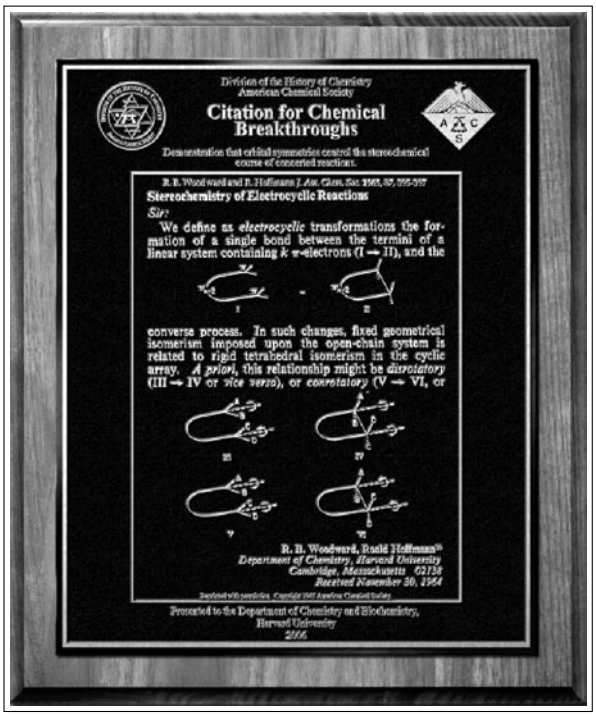

Figure 3. *Citation for Chemical Breakthrough award plaque presented to the Department of Chemistry and Biochemistry, Harvard University, on June 16, 2006 to honor the first Woodward-Hoffmann paper on orbital symmetry. The design of this plaque (raised metal etching on a walnut base, 15" x 18") is similar to others presented in this award program. These plaques are intended to be placed in the halls near the location of the original discoveries.*

Certainly review articles – and the entire series *Organic Reactions* -- are written by many research chemists who would never consider themselves historians of chemistry, yet these reviews fit within the umbrella of history of science. *Chemical & Engineering News* includes historical context in many of their feature articles and publishes numerous articles and even special issues focusing on the history of chemistry. C*&EN*'s readers are scientists and engineers within the broadly defined discipline of chemistry. The series of autobiographies of eminent organic chemists, *Profiles Pathways and Dreams* that I edited was produced primarily for the practicing chemist, not for the historian of chemistry, though over the long term, the latter will be the eventual beneficiary.

Consider the implicit influences of my recent publication "The Woodward-Doering/Rabe-Kindler Total Synthesis of Quinine: Setting the Record Straight" published in the scholarly research journal *Angewandte Chemie* (12). The most evident theme of this paper is the question, did R. B. Woodward and William Doering achieve the total synthesis of quinine (**1**) as they claimed in their 1944 communication and 1945 full paper entitled "The Total Synthesis of Quinine"? This reported synthesis shown in Fig. 4 was universally accepted until 2000-2001 when the eminent chemist Gilbert

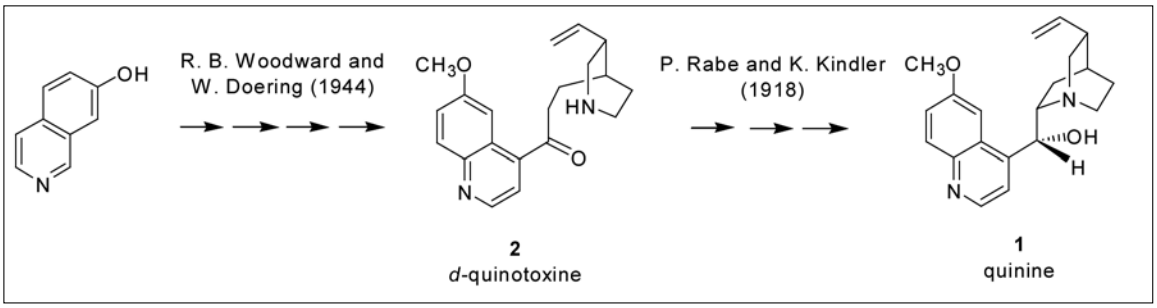

Figure 4. *A summary of the Woodward-Doering formal total syntheses of quinine and the relationship between quinine and d-quinotoxine.*

Stork asserted that it was a "myth" (19-21). Based on interviews with Gilbert Stork and others, *Chemical & Engineering News* reported in 2001 that Stork "Set the Record Straight" (22). But as Rudy Baum, current editor of *Chemical & Engineering News*, recently stated, "Journalism is often described, accurately I think, as the first draft of history" (4). Is the Woodward-Doering representation a fact or a myth?

In order to illustrate the influences of this historical study of quinine on the sociology of chemical research, I needed to use chemical structures, the universal language of chemistry. Atoms, bonds, molecules and reactions are the vocabulary of chemists! I reflect with amusement that the *Bulletin's* current Instructions to Authors states that "Chemical formulas [are] to be kept to a minimum" (23). In fact, I now assert that encouraging prospective *Bulletin* authors to include more structures would positively influence the substance of some of the articles, possibly increasing the number of submissions, and possibly increasing the readership of the *Bulletin* and membership in HIST. Chemists often first look for structures when examining a journal, not titles! In fact, many journals now include a graphical table of content in a front section of each issue.

Woodward and Doering clearly stated in their publications in 1944 (24) and 1945 (25) that they did not prepare any quinine. Rather, they synthesized *d*-quinotoxine (**2**) from simple starting materials (Fig. 4). As they said in the last sentence of their full paper, "In view of the established conversion of quinotoxine to quinine [by Rabe and Kindler] (26), with the synthesis of quinotoxine the total synthesis of quinine was complete." The use of a so-called "relay compound" such as *d*-quinotoxine and the combination of experimental work produced in two or more laboratories (Laboratory #1 converts A → M; Laboratory #2 converts M → Z) together is today termed a "formal total synthesis" (i.e., A → Z).

The problem was, and will remain forever, that Rabe and Kindler never reported the experimental details for their conversion of *d*-quinotoxine to quinine. In 1918, Rabe and Kindler (26) provided the reagents used and some important physical properties of the products. In 1911 and 1932, Rabe (27, 28) provided experimental details for analogous reactions. These facts led Stork to conclude that the assertion of a total synthesis of quinine is a myth (19-22).

There would have been no polemic had Woodward and Doering converted *d*-quinotoxine to quinine following the either information provided by Rabe and co-workers (26-29) or their own imaginative sequence—or had Rabe and Kindler reported their own experimental details. My conclusions on this controversy can be found in both my publication (12) and in the news article that appeared in *Chemical & Engineering News* (13). With this background, I now indicate several influences on chemical research that stem from my historical research.

a) I have been told that several organic chemists are considering or have begun to "repeat" the Rabe-Kindler conversion of *d*-quinotoxine to quinine.

b) As reported in *Chemical & Engineering News*, Princeton's Eric Sorensen stated, "After reading the Seeman article, I don't think I would rely on a formal synthesis. I would reproduce what was reported. I think any scientist would want to avoid any suspicion that what they did wasn't reproducible" (13).

c) Several academics have indicated to me that they intend to use my historical article as a teaching tool. For example, Sorensen wrote, "This will be required reading in my graduate course on complex chemical synthesis" (30).

d) Paul Rabe was the Professor of Chemistry at the University of Hamburg when he published his research with Kindler. I contacted the current Pro-

fessor of Organic Chemistry at Hamburg, Wittco Francke, inquiring if Rabe and Karl Kindler's notebooks were in their archives. While these could not be located, Professor Francke wrote me, "Now among the legacy of [the department chemical archives], I recently found a collection of voucher samples of quinine derivatives etc. (carefully sealed in glass ampoules) which may be important as they carry the names of Rabe and Kindler (apart from some others which I suppose may be names of PhD students etc.). I think this may be a rather exciting (and important) discovery; several of these samples look as if they are in perfect shape, and one could analyze at least part of them by using modern NMR etc. What do you think" (31)? When I recently inquired of these samples, Francke wrote, "I'll have a look at the samples" (32).

e) I recently received an email from Robert Volkmann, Chair-Elect of the Division of Organic Chemistry (ORGN) of the ACS. He wrote, in part (33):

> 2008 is the 100th anniversary of a number of divisions in the American Chemical Society including the Society's largest division, the Organic Division. I along with others have been wondering how best to commemorate 100 years of scientific advances and discoveries in the field of organic chemistry. One thought would be to have a symposium and to invite leaders in the field to give presentations/stories which capture advances in their particular areas over the years and thoughts about the future. The reason for this email is because of your interest and success in capturing the rich history of our discipline. I personally think that this project might be a lot of fun and captivate the interest of our ACS membership.

This invitation to participate in the celebration of ORGN's 100th Birthday and bring the history of organic chemistry to its members is a very welcome indication of the interest and receptivity that studies in the history of chemistry can make on the research community.

Conclusions

Many of the activities of HIST and of historians of chemistry can have significant influences on the practice of chemistry and on chemical education at all levels. Including non-historian chemists into history-oriented projects can have mutually beneficial, symbiotic values. The quality and value of the projects themselves will be enhanced. Non-historians will have a broader understanding of the context in which their work has evolved. Historians will gain a broader understanding of the details of the science. Adding history content to the classroom will have similar benefits. The stimuli for these associations can come from HIST, from chemical historians, and from practicing research chemists and engineers. HIST has traditionally been oriented an outlet for its more active members. By proactively seeking collaborations with the non-history communities, HIST and its membership as well as chemical historians can have the opportunity to enhance their own activities and those of the broad chemical profession. Through collaborations among these disciplines and as a consequence of both explicit and implicit types of influences, the practice of history of chemistry and chemistry itself are being and will further be enhanced.

Coda

A reviewer of this paper stated that

> "You should clarify the difference between 'historians' and 'chemists.' I used to have a colleague in the history department at my university who publicly said that as a chemist, I had no business doing history, an attitude I have encountered more than once. Many 'professional' historians of science actually had earned undergraduate degrees in science before they went the history route. And if a scientist has done history for 20 years, is his work any less than that of the 'professional' just because he doesn't have the formal training? I think many professional historians actually look down on the work of HIST because we are 'just' chemists."

As described in Ref. 5, I believe that the most appropriate measure of a scientist is his/her professional accomplishments rather than the specifics of a scientist's formal educational heritage. In fact, one can be guilty of scientific McCarthyism (34) if one judges scientific performance on personal facts such as where an individual studied or works or was born or one's age or race "or by any other characteristic other than the content" (34). Formal education and experience merge as teachers about our universe.

I do acknowledge that I often find treatises in fields such as philosophy of science extremely difficult to understand. I attribute my difficulties in part to the 'language' used as well as to the complexities of the substance; I do wonder if my lack of formal education in these fields contributes to my bewilderment. Similarly, I can well understand that historians may not understand the 'language' of chemistry: the names of compounds,

the meaning of functional groups, the capabilities of analytical methodologies, the specificities of different theories, and the vocabularies of different disciplines. Communication barriers exist between chemists from different sub-disciplines. I believe that one needs more than a passing knowledge of chemistry to fully understand, appreciate, evaluate and communicate the history of chemistry.

Surely there is a relationship between one's education experience and one's perspective. At least initially, a chemist interested in historical studies may not have the broad understanding of place and context. However, there is likely to be as much variation about the mean value of knowledge and performance among a subgroup of historians of chemistry, all of whom having history-oriented educational backgrounds, as among all historians of chemistry regardless of their educational background.

The strengths of any one discipline—indeed, of any one person—may well be the weaknesses of another. The ability to solve today's most complex problems in science and technology requires multidisciplinary teamwork, a skill not typically taught in the educational paradigms of the past but the focus of current theories in chemical education (35). Indeed, graduate students and non-tenured faculty members are taught the reverse: how to perform independent research and how to gain tenure by building one's own reputation and standing in the community.

The synthesis of these ideas strongly supports the call for collaborations among the various disciplines. Indeed, it is that call that serves as the underpinning of my paper. I believe in the value of synergy and have experienced and witnessed the development of trust and respect as a result of interdisciplinary research programs.

ACKNOWLEDGMENTS

The author thanks Professors Jim Bohning, Carmen Giunta, Seymour H. Mauskopf, and E. Thomas Strom for very helpful discussions on this manuscript and one reviewer for his frank and revealing comments quoted in the Coda.

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2. Dedicated to the memory and spirit of Vladimir Prelog and to the continued influence of our mutual friend Albert Eschenmoser.
3. J. L. Mack, personal communication to J. I. Seeman, Barnesville, GA, November 7, 2005.
4. R. M. Baum, "First Draft," *Chem. Eng. News*, February 26, 2007, 85, 3
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