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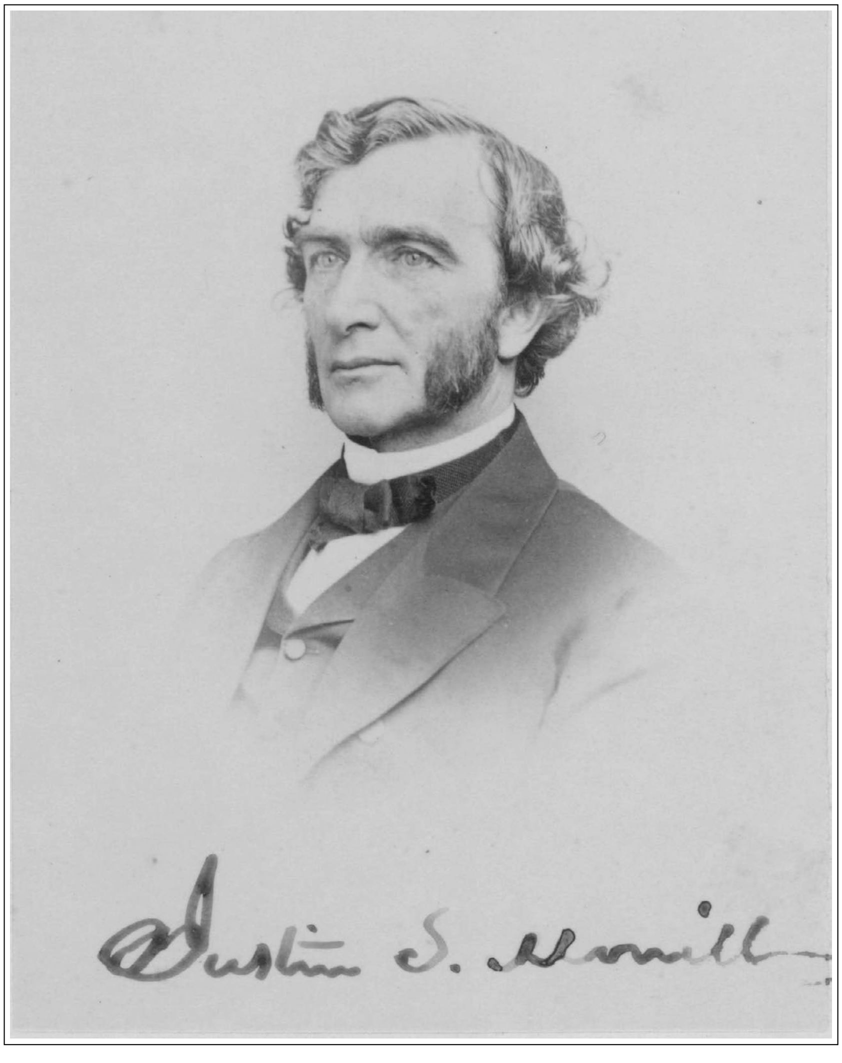

Senator Justin Morrill:
Chemistry at US Land Grant Institutions

BULLETIN FOR THE HISTORY OF CHEMISTRY

VOLUME 38 CONTENTS

NUMBER 1

NUMBER 2

150 YEARS OF THE MORRILL ACT

The Promise and Potential of the Land-Grant University

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In 2012, I served as president of the American Chemical Society, the world's largest scientific organization. During that year ACS celebrated the sesquicentennial of the Morrill Land-Grant Act—which gave federal lands to states as a means to raise money to establish colleges that focus on teaching agriculture, science, and engineering in addition to liberal arts—with a retrospective and a prospective look at chemistry.

On the prospective side, the ACS national meetings in San Diego and Philadelphia featured special symposia and events that included high-level federal officials and noted scientists and educators, to help ACS and its members focus efforts in addressing humanity's needs in a world of finite resources. In San Diego in March of 2012, the presidential symposia included Communicating Science to the Public, Production of Fuel Directly from Sunlight: A Grand Challenge for Chemistry of the 21st Century, and Catalysis, as well as a Presidential Keynote Address by then-National Science Foundation Director Dr. Subra Suresh on challenges and opportunities at the NSF.

At the Fall National Meeting held in Philadelphia in August of 2012, the presidential symposia included Communicating Chemistry & Public Engagement: Celebrating the 25th Anniversary of National Chemistry Week; Forensic Chemistry, Science and the Law Presents: Innocence! The Work of the Innocence Project; 150 Years of Chemistry at Land Grant Institutions: The Past as Prelude to the Future; Communicating Controversial Science: Symposium in Honor of Rudy Baum, and Celebrating the Sesquicentennial of the Land Grant College Act. The meeting's Presidential Plenary Keynote, given by UC-San Diego's Dr. Mario Molina, was on the subject of Chemistry and Climate Change. Videos related to the above are available online, including the Rudy Baum symposium, the Innocence Project symposium panel discussion, the press briefing on the National Chemistry Week anniversary, the press briefing on Dr. Molina's environmental work, and the press briefing on the Land-Grant Act sesquicentennial (1).

The important goal in this prospective look was to articulate the critical role of ACS as a scientific, educational, professional, and learned Society engaged in shaping the future of society as a whole. The Morrill Land-Grant Act sesquicentennial offered ACS and its members an opportunity to showcase what chemistry, chemists, and the ACS have done and are doing, and to use it as a platform to affirm the ACS Mission: "to advance the broader chemistry enterprise and its practitioners for the benefit of Earth and its people."

For the retrospective look at chemistry, I invited all institutions, whether land-grant or not, to publicize their achievements, making them available widely through the Web, as I have done on my website at scifun.org for the University of Wisconsin (2). The retrospective look at chemistry on the 150th anniversary of the Morrill Act continues in this issue of the *Bulletin for the History of Chemistry*. It features papers taken mainly from the Presidential Symposium mentioned above, organized by Stephen Weininger and Alan Rocke.

1. “ACS Presidential Symposium: Communicating Science that People May Not Be Ready to Hear,” http://vimeo.com/49235776; “The Innocence Project: Science Helping Innocent People Proven Guilty,” http://www.ustream.tv/recorded/24848172; “244th ACS National Meeting Press Briefing: Celebrating the Silver Anniversary of National Chemistry Week,” http://vimeo.com/47890259; “Nobel Prize-Winning Scientist Cites Evidence of Link Between Extreme Weather, Global Warming,” http://vimeo.com/48558467; “New Version of 150-year-old Law Could Ease Student Debt and College Funding Cutback,” http://vimeo.com/48558428; all accessed Jan. 9, 2014.
2. “The Promise and Potential of the Land-Grant University: Selected Accomplishments at University of Wisconsin-Madison, 1862–2011,” http://scifun.org/MorrillLandGrantAct.html (accessed Jan. 9, 2014).

Introduction

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On July 2, 1862, in the midst of the Civil War, President Abraham Lincoln signed the Land-Grant Colleges Act, commonly known as the Morrill Act after its principal sponsor. It provided for substantial grants of federal land to each state for the purposes of establishing colleges “whose leading object shall be, without excluding other scientific and classical studies … to teach such branches of learning as are related to agriculture and the mechanic arts ….” The Act notably prohibited discrimination on the basis of race or sex.

The Act’s mission statement ensured that, because of their perceived centrality to agriculture, chemistry and other natural sciences would have a predominant place in the curriculum. That perception, fostered by Justus von Liebig’s highly influential writings, would require several decades before becoming reality.

Many voices had been advocating scientifically-based agriculture before the Morrill Act. Among the most ardent and effective was Evan Pugh of Pennsylvania. Kristen Yarmey depicts him as pragmatic, patriotic and moral. His persuasive strategy utilized both demonstration and advocacy. A Göttingen Ph.D. with Friedrich Wöhler, Pugh became principal of the Farmer’s High School of Pennsylvania in 1859. Confronted with numerous doubters, skeptics and rivals, Pugh waged tireless publicity campaigns for his institution and his science. The High School became the Agricultural College of Pennsylvania in 1862; in 1863 it shared with Michigan Agricultural College the distinction of being the first institution designated as a land-grant college.

The following five papers, which derive from the ACS Symposium “150 Years of Chemistry at Land Grant Institutions: The Past as Prelude to the Future,” explore various consequences of the Morrill Act. Stephen Weininger makes clear that the land-grant institutions (LGIs) had anything but a smooth start. Student numbers were small, their preparation weak, faculty training was variable, state legislatures were stingy and graduation rates were scant. The Act left much to the discretion of the States; individual colleges fashioned different visions for themselves. Weininger tracks their divergent ambitions by focusing on course curricula and catalog rhetoric relating to qualitative and quantitative analysis, bedrock courses for numerous majors that provided students with marketable skills. By 1900 instruction was more uniform, enrollments and support were rising, and the LGIs were poised to fulfill their potential.

Applying chemistry to agriculture was an ambition initially well ahead of the technical means for realizing it. Alan Marcus reports that some early attempts were disastrous. Chemists then settled on a more modest goal—using their analytical skills to aid farmers by doing water, soil and fertilizer analyses. The idea of having a State Chemist began to spread. Nonetheless, chemists’ reach exceeded their grasp with respect to fertilizer analysis. They responded to trenchant criticism by organizing, upgrading their skills and enforcing standards. By the 20th century these analytical chemists had spawned a new, respected profession—the agricultural chemist. The transformation served as a template for the conversion of industrial chemists to chemical engineers.

Mark Finlay points out that like many other technical innovations, scientific agriculture was a mixed blessing. The expanded output it engendered caused a crash in farm prices, a problem further exacerbated by the Great Depression. One response advocated taking land out of production. An alternate cure involved further industrializing agriculture by having farmers raise crops intended as chemical industry feedstock, the basis of the *chemurgy* movement. The nation's agricultural colleges formed the arena where these two visions were championed by the Federal farm administration and chemical industry, respectively. While some farmers embraced chemurgy, others were convinced its main beneficiary would be industry. The divergence bespoke wide-ranging political differences, national and international. The chemurgic program gained some traction, but rising demand for farm products after war began blunted its impact. As Finlay perceptively notes, agriculture post-World War II became further industrialized and agricultural research became molecular, but now applied to new ends.

Chemical engineering's close connection to industry throughout its history has had major professional and societal consequences, according to Robert Seidel. MIT's unit operations curriculum, which promoted curricular uniformity during the early 20th century, also highlighted the necessity of students' direct contact with actual plant operations. Only industry was able to afford students such experience, thereby tying the academy closely to it. As with other science-based disciplines, World Wars I and II boosted the growth of chemical engineering. Post-World War II, the discipline metamorphosed into engineering science—highly mathematical and abstract. Process design became increasingly isolated from the public it was meant to serve. The rift became glaring after the tragic chemical accidents at Seveso, Italy, and Bhopal, India.

Weininger's paper had ended by noting the substantial number of female students in the chemistry laboratory. Unfortunately, women graduating with the same skills as male students had great difficulty finding professional employment. That was a major impetus for most science-oriented female students to major in home economics, where many subsequently found work as teachers. Various observers have asserted that home economics consequently hindered the movement of women into science.

Amy Bix tackles this issue head on. While acknowledging that home economics reinforced gender stereotypes, she counters that the field enabled many young women to study college-level science. Furthermore, their numbers "subvert[ed] the notion of women's scientific ignorance and technical incompetence." As home economics expanded its range of topics its emphasis on chemistry increased, creating space for female instructors in chemistry departments. Many home economics graduates found work in food-related fields, including journalism. The large number of women enrolled in science at the LGIs even opened a wedge for women in engineering, which widened considerably after World War II. The war had already spawned a demand for technically trained women, which the federal government strove to satisfy. Bix concludes that although the entry of women into science was slow, it would have been slower yet but for the efforts at many LGIs, including home economics.

As this issue was being prepared, our colleague and friend, Mark Finlay, was killed in an automobile accident. Mark was a dedicated teacher, gifted scholar and committed member of our professional community. He will be deeply missed. This issue is dedicated to his memory. (For more about Mark, please see About the Author at the end of his contribution.)

COMMUNICATING THE VALUE OF CHEMISTRY: EVAN PUGH, PENN STATE, AND PUBLIC CONFIDENCE AT THE TIME OF THE LAND GRANT

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In 2012, American Chemical Society president Bassam Shakhashiri set for the Society the dual goals of advancing chemistry and *communicating* chemistry: that is, communicating the values, roles, and benefits of chemistry to the public. Shakhashiri described widespread science literacy as a necessary characteristic of an informed citizenry (1):

> Science literacy enlightens and enables people to make informed choices; to be skeptical; to reject shams, quackery, and unproven conjecture; and to avoid being bamboozled into making foolish decisions where matters of science and technology are concerned.

Shakhashiri's presidential term also celebrated the Sesquicentennial of the 1862 Morrill Land Grant Act with "a *retrospective* and a *prospective* look" at its role in the development of chemical education. Shakhashiri proposed that "examining the accomplishments of chemistry and contributions of chemists to our country" would facilitate discussions about the present and future of science education. It seems timely, then, to consider how American chemists communicated the value of chemistry and chemical education in the years leading up to and immediately following the Morrill Act.

As both a chemist and a president of an early land grant institution, Evan Pugh of the Agricultural College of Pennsylvania (now the Pennsylvania State University) was an exceptional advocate for chemical education at the time of the Morrill Act. Pugh's efforts to communicate the value of chemistry to an often apathetic and antagonistic public were not unique, but his story exemplifies the monumental shifts and struggles in both higher education and science during the nineteenth century. Evan Pugh's campaign to win public confidence for the Agricultural College of Pennsylvania demonstrates the importance of individual action, communication, and personal relationships in inciting and implementing broad, lasting changes in science education.

Chemical and Agricultural Education in Mid Nineteenth Century America

Evan Pugh, born in 1828, came of age during a time of significant developments in chemistry, agriculture and higher education. Early in the 1800s, chemical education of any sort had been sparse in the United States (2, 3), but in the 1830s and 1840s, growing interest in science drew attention to chemistry and chemical education. Public lectures on science, particularly those featuring exciting chemical demonstrations, "inspire[d] young men to scientific careers" (4), and several educational institutions responded by incorporating chemistry into their curricula. At the same time, advances in chemical research were revealing new possibilities for applied chemistry. In his 1840 publication, *Organic Chemistry in its Application to Agriculture and Physiology* (5), German chemist Justus von Liebig posited a direct, rational relationship between science and agriculture, and in America this work was eagerly received by chemists and agriculturalists alike. Particularly in the northeastern states, where decades of farming had exhausted much of the region's tillable soil, the idea that chemistry could "solve the problems of agriculture" was tantalizing (6). In the late 1840s and early 1850s, interest in agricultural education ascended towards an apex. Advocates formed state societies of agriculture, leading to the 1852 founding of the United States Agricultural Society, and some began lobbying their state legislatures to make appropriations for agricultural colleges.

Although supporters of agricultural and scientific education were increasingly vocal, however, the movement was hardly widespread. Calls for agricultural education came primarily from middle-class, college-educated reformers, many of whom were "gentleman farmers" who dabbled in agriculture as a hobby and could "afford to experiment with scientific agriculture" (7). In contrast, "rank and file" farmers who made a living off of the sale of crops generally viewed agricultural science and agricultural education with indifference. At best, agricultural education was unavailable, unheard of, and uninteresting, but at worst, farmers viewed scientific agriculture and its advocates with suspicion and distrust (8). Some of this antagonism stemmed from class differences: "practical farmers" reacted with disgust when "book farmers" presumed to tell them how to run their farms.

Misunderstandings and inflated expectations also contributed to farmers' negative perceptions of agricultural science. Expecting to see experimental farms turn a profit, many farmers were disillusioned when Liebig's theories did not lead to immediate improvements in soil fertility and crop production (9). Scientists who, in their excitement over Liebig's research, had overstated the claims of agricultural science "suffered the embarrassment of finding themselves in error" when promises of better farming through chemistry failed to pan out on a favorable timescale (10).

Public confidence in agricultural science (and chemistry specifically) was further damaged by the soil analysis trend of the mid-1840s. In an 1843 publication, Liebig instructed farmers to "apply to the professional chemist" for information about their soil, suggesting that a chemical analysis of a soil sample would indicate what kind of fertilizer was needed. In response, American pseudoscientists began offering soil analyses as a service for farmers, often at a steep fee. (Neither were chemists innocent: Norton at Yale was a leading proponent of soil analysis, and his students analyzed samples for farmers at a cost of five to ten dollars each.) However, the analyses were not scientifically sound (they failed to account for inconsistencies in soil composition, for example) and generally proved useless (11). In many cases, all that a farmer gained in return for a costly analysis was a recommendation to purchase the analyst's own fertilizer. By the early 1850s, few farmers still considered the practice worthwhile, and scientists agreed: agricultural chemist Samuel W. Johnson announced his verdict of soil analysis as "always interesting, often valuable, rarely economical" (12). Johnson and several other chemists openly admitted the mistakes of their chemical predecessors, but resentment over money wasted on soil analysis remained fresh in farmers' minds for decades.

With this antagonism and distrust thus counterbalancing the interest and advocacy relating to agricultural chemistry and chemical education, mid nineteenth century American chemists faced extraordinary challenges in advocating chemistry and chemical education. They had to establish the credibility of the discipline such that "a chemically demonstrated fact should stand unassailable" (13) and that "more rather than less science" was needed to truly improve agriculture and aid farmers (14). They had to convince disinterested Americans to invest state and federal funding in scientific education and to fund costly, rigorous, long-term agricultural experimentation with little short term benefit. In order to win public confidence for themselves and their institutions, American chemists would need to communicate the value of chemistry.

Evan Pugh and the Farmers' High School of Pennsylvania

In Pennsylvania as in other states, the 1840s and early 1850s were a period of growing interest in agricultural education. In 1850, two members of the Philadelphia Society for Promoting Agriculture published an "Address to the Farmers of Pennsylvania," calling for a state institution "to diffuse a general knowledge of improved systems of husbandry" (15). In response, interested reformers met in Harrisburg and organized the Pennsylvania State Agricultural Society. The Society's activities, especially its agricultural exhibitions, increased awareness of and interest in agricultural science throughout the state. At the first exhibition, held October 1851 in Harrisburg, Andrew Stevenson of the University of Virginia gave an address on agricultural science, declaring that "soils must be analyzed; and for this agricultural chemists are needed" (16). By March 1853, at another convention in Harrisburg, the members of the new State Society had resolved "with an unparalleled unanimity" to establish a "school for the education of Farmers" (17).

Evan Pugh was by this time the proprietor of a small academy in Chester County. Reflecting his interest in agricultural science, the Jordan Bank Academy curriculum included mineralogy, geology, botany, and chemistry.

Pugh's students used rudimentary apparatus to analyze soil and mineral samples, and Pugh himself conducted field experiments with fertilizers on his farm (18). He was thus captivated by the idea of agricultural education, and he quickly realized that schools for farmers would require professors with advanced knowledge of the sciences, particularly chemistry. Encouraged by his mentor Dr. William Darlington, who had once studied medicine under Benjamin Rush at the University of Pennsylvania, Pugh decided to make chemical education "the labor of [his] life" (19). He sold Jordan Bank Academy, and in September 1853, at the age of 25, Pugh sailed to Germany in pursuit of a world class scientific education.

He spent the next six years studying at Europe's most noteworthy universities and laboratories. He began at Leipzig, where he studied theoretical and applied chemistry with Otto Erdmann. He then transferred to Göttingen, where he studied with Friedrich Wöhler and earned a Ph.D. in chemistry and physics. In Heidelberg, Pugh spent several weeks studying gas analysis in the crowded laboratory of Robert Bunsen; in Paris, he attended lectures of prominent French scientists to observe their teaching abilities. In July 1857, at the invitation of English scientists John Bennet Lawes and Joseph Henry Gilbert, Pugh traveled to their well-known experiment station at Rothamsted and began a series of experiments on the origin of nitrogen in vegetables. In the next two years, Pugh's precise and painstaking experimentation won international interest and acclaim. With Lawes and Gilbert, he published a paper in the prestigious *Philosophical Transactions* (20) and presented his results before the Royal Society of London.

Despite the potential for a more lucrative career as a research scientist, Pugh's commitment to chemical education remained constant throughout his studies abroad. He regularly scanned American papers (especially imported issues of the *Pennsylvania Farm Journal*), and he was pleased to read in 1855 that the Pennsylvania State Agricultural Society's efforts to establish an agricultural college were succeeding; Governor James Pollock had signed a charter for the Farmers' High School of Pennsylvania. Pugh did not "doubt the success of a well-directed agricultural effort," but he felt strongly that the director of such a school needed to be a scientist, with a "proper combination of executive talent with intellectual power" (21); otherwise, the institution would be "like a well finished watch minus the mainspring" (22). The trustees of the Farmers' High School felt similarly. To fill the role of principal, they sought a man "with such scientific attainment and capacity to teach" who would also be a "good practical farmer" (23). In 1859, at the recommendation of Yale chemist Samuel W. Johnson (whom Pugh had befriended while studying in Leipzig), the trustees offered Pugh the presidency of the Farmers' High School. A few months later, after a whirlwind tour of Europe's agricultural institutions and chemical apparatus suppliers, Evan Pugh sailed home to Pennsylvania.

In October 1859, Pugh arrived at the Farmers' High School to find it operating under "unfavorable circumstances" (24). Only one of the three planned wings of the college building had been erected. Students were doubled up in their dormitory rooms, and the entire college took their meals in a drafty shanty. Pugh optimistically set a goal of raising $100,000 to complete the construction, but his hopes were quickly shattered; the Panic of 1857 had left little chance of donations or subscriptions from wealthy Pennsylvanians. The trustees were lobbying the Pennsylvania General Assembly for an additional appropriation, but eliciting state funding for higher education was increasingly difficult (25).

These financial concerns were intertwined with broader issues of public confidence and trust. Pugh knew that sustainable funding depended on public support; in 1859, he observed that where agricultural education had failed in America, it was due "in part because of the general feeling of mistrust with which the effort was viewed" by the public (21). His February 1860 inaugural address described this challenge (26):

> The unfinished state of our buildings, and the difficulties we labor under in consequence of their not being finished, point to the necessity of our demonstrating to a skeptical public and a hesitating legislature the practicability of our undertaking, and the necessity of our having material aid to complete the work here begun.

In order for the Farmers' High School to succeed, Pugh would have to articulate the need for agricultural education, demonstrate how the School effectively and efficiently fulfilled that need, overcome popular misconceptions and prejudices, and thereby prove the School worthy of state and local patronage. Each of these tasks required educating nonscientists about science: i.e., distinguishing science from pseudoscience, explaining scientific methods of experimentation, and publicizing the benefits of science not only to the Farm School's students but to the entire state of Pennsylvania.

Articulating the Need: Turning Apathy into Attention

The first barrier Pugh faced in his advocacy for the Farmers' High School and its scientific curriculum was widespread apathy from the public and particularly from "rank and file" farmers. The "gentleman farmers" of the Pennsylvania State Agricultural Society had been strongest advocates for the establishment of the School (27), but after the enthusiastic peak of the mid 1850s, many of Pennsylvania's state, county, and regional agricultural societies suffered from declining membership and disinterest among remaining members. As a result, Pugh found active support for the Farmers' High School in short supply. J. L. Darlington, president of the Chester County Agricultural Society, told Pugh in 1859 there was "so little sympathy" for the Farmers' High School that his fundraising efforts "fell 'still born'" (28). Complicating Pugh's efforts were the strains of a nation hurtling into civil war. "It certainly cannot be denied that it is not the best time possible to get a candid hearing upon a subject foreign to politics," he remarked in 1860 (29).

Pugh sought to convert this apathy into attention by articulating the need for science and scientifically trained farmers. To "arouse public sentiment and to stimulate public interest" in agricultural science, Pugh gave addresses at state fairs and other events (30). His best known was "What Science Has Done and May Do for Agriculture," an 1860 lecture before the Cumberland County Agricultural Society so persuasive that Charles F. Chandler, a former classmate of Pugh's, said he would "quote from it as long as I teach Ag. chem" (31). In this address and others, Pugh explained the problem of soil exhaustion, pointing out that decades of "practical" farming had led to decreased productivity. He argued that only science could restore fertility to American farms (32):

> The land is worn out, new land must be worked while it is 'resting.' It is well for us that we have new land. The time will come when the land must find rest by letting the people starve. Before that time comes, let us hope that science will be appreciated and her teachings heeded.

Pugh discussed both crop rotation and fertilizers as scientific solutions to agricultural problems, and he asserted that agricultural chemistry would help farmers understand and improve their farming practices. This argument resonated with Pennsylvania farmers, who struggled with decreasing soil productivity amidst increasing competition from the West (10).

In a similar strain, Pugh declared that America (and Pennsylvania) needed better farming, and therefore better educated farmers, to successfully compete with Europe. This theme was common among science educators; "the unblinkable fact of European scientific superiority inspired not humility and resignation but appeals to national honor" (33). In his addresses, Pugh highlighted Europe's advanced farming techniques, enumerated Europe's many agricultural schools and research laboratories, and recounted how farmers abroad employed chemists to analyze fertilizers to regulate the market and protect farmers from fraud.

This final point was also an appeal to farmers' pocketbooks. Chemistry was valuable to farmers, Pugh explained, because chemists could identify overpriced or fraudulently advertised fertilizers. In Europe, Pugh had studied fertilizers in detail "in order more fully to be prepared to give opinions upon the commercial values of manures" (34), and once at the Farmers' High School he experimented with different fertilizer products on the School farm. Pugh's friend Samuel W. Johnson also used this approach; beginning in 1853, Johnson had made a name for himself among agriculturists by analyzing fertilizers, calculating a monetary value for each based on its chemical components, and publishing his results in agricultural papers like the *Country Gentleman* (35). Both Johnson and Pugh were careful to explain that they were assigning costs to fertilizers based on the costs of their chemical components, not guaranteeing their efficacy on any given farm, but each promulgated systematic chemical analysis of artificial manures as a way of regulating the market.

As a final argument for the country's need for agricultural schools, Pugh portrayed the study of chemistry and agricultural science as virtuous and ennobling. The value of chemistry and chemical education to farmers was not solely monetary; Pugh presented it as a "morally superior" solution to social concerns, writing that the evils and temptations of city life, so dangerous to overeducated youth, would be "lessened" if only "a system of education, adapted to the wants of our agricultural community, were made available to the sons of every farmer" (21). This theme, consistent with agricultural education's roots in the reform movement, was generally targeted at gentleman farmers, many of whom believed that practical farmers were by nature ignorant and needed education and social uplift to escape their "lowly" status (36, 37).

The Farmers' High School's manual labor requirement was an especially powerful selling point in this regard. Pugh characterized manual labor as inherently moral, heatedly contrasting the "enterprising and industrious mechanic and farmer of the north" with the indolent slaveholder of the South (38). He argued that manual labor instilled in young men the dignity of hard work (21):

> Agricultural labor would be dignified, by being intimately associated with profound subjects of thought; it would be made agreeable by affording a pleasant exercise for the cultivated mind, in connexion with all its duties; it would be recognized as honorable, because of its usefulness, and because of the high moral and intellectual standing of those who were following it for a livelihood; they would combine the intellectual qualities of our colleges, with the morality of country life.

While these moral arguments were an appeal to reformers, they also reflected Pugh's own views of science. Like Samuel W. Johnson, Pugh was deeply religious, and both men seemed to consider chemical education a form of "moral heroism" (39).

Demonstrating Value

Having established the need for an agricultural college, Pugh then devised ways to raise awareness about the Farmers' High School's activities, thereby publicizing the value and relevance of its work. One channel for disseminating information was the School's catalog, published yearly in December. While the college catalogs were ostensibly aimed at students, Pugh's catalogs were strategically "devised to inform the general public as much as prospective students" (40). Just two months after his arrival, Pugh prepared and published the 1859 catalog, which included an impassioned essay on Pennsylvania's need for an agricultural school, a summary of the School's progress to date, an outline of its curriculum, and plans for the 1860 term. Pugh sent copies to every member of the Pennsylvania state legislature, each of the "prominent colleges" in the country, and all of the newspapers in Bellefonte and Philadelphia (41).

Seeking broader exposure, Pugh also built relationships with newspaper editors in Harrisburg, Philadelphia, and New York in order to secure "favorable notices" of the School in the mainstream press (42). To ensure that all Pennsylvanians would hear of the School's work, he encouraged his students to write columns about their studies and experiences for their hometown newspapers. He also leveraged the agricultural press, which at the time was an influential information channel for agricultural news, politics, and gossip (43). Even prior to his presidential appointment, Pugh had reached out to the editor of the *Pennsylvania Farm Journal* to "feel him gently" on the subject of arranging a formal connection between the *Journal* and the nascent Farmers' High School: "Our practical farmers… patronize the paper, and to have access to its columns would give us access to them" (44). Throughout his presidency, Pugh contributed columns, letters, and news items to agricultural papers like the *Farmer and Gardener*, the *American Agriculturist*, the *Genesee Farmer*, and the *Country Gentleman*. At his encouragement, several students in Pugh's advanced chemistry classes also contributed to these papers, publishing the results of their experiments and analyses. Pugh hoped that the publication of these laboratory investigations might induce a wealthy donor to endow a professorship but felt that, at the very least, "their parents would be 'mightily' pleased with their efforts" (22).

Pugh also publicized the Farm School's activities via voluminous correspondence with his many friends and colleagues. His most valuable contacts were former classmates from his studies abroad, many of whom became key players in chemistry and chemical education in the United States: Samuel W. Johnson, William H. Brewer, and George Brush all took positions at Yale; Charles F. Chandler was at Union College and then followed another classmate, Charles F. Joy, to Columbia; George C. Caldwell and H. A. Warriner both taught at Antioch College and later served in the United States Sanitary Commission; and James P. Kimball was Pugh's contact at the unsuccessful New York State Agricultural College. Pugh was closest with Johnson and Caldwell, but he maintained at least informational correspondence with all of these colleagues throughout his presidency, finding "truth [in] the old proverb that 'in union there is strength'" (45).

As president of the Farmers' High School, Pugh expanded his network, seeking out other influential American chemists. As he had told Johnson in 1855 (46):

> I think we should endeavor to form intimate acquaintances with all the really scientific agriculturalists in our country and keep each other posted upon our plans… as by doing so greater results may be accomplished.

He strengthened these relationships by regularly visiting other educational institutions, including Yale, Columbia, Maryland, and the Free Academy of New York (where he met Oliver Wolcott Gibbs). In 1860, he attended the American Association for the Advancement of Science's meeting in Newport, where he met with Benjamin Silliman Jr., William Barton Rodgers, Joseph Henry, Benjamin Gould, and "others of the American scientific corps"

(47). At each meeting as with every letter, Pugh shared copies of the latest Farmers' High School catalog or report, informing his colleagues of the School's progress. He was especially proud in December 1861 to announce the School's first graduating class, proclaiming that the eleven recipients of the Bachelor of Scientific Agriculture degree had "graduated upon a higher scientific educational standard than is required at any other agricultural college in the world" (48).

Similarly, Pugh frequently invited scientists, educators, and political and social "influentials" to visit the School "to see the class of student we have… [and] to see what we might do if our buildings were completed and all our professorships properly filled upon the basis which our organization anticipates" (49). Visitors to the Farmers' High School were invariably impressed by Pugh and his students and departed with a high opinion of the institution. Such visitors often described what they had seen in newspaper columns or meetings of their professional or social organizations, further promulgating information about the quality and value of the School's work. One early visitor observed that the students looked "cheerful and contented… more healthy than is presented by the usual appearance of boys subjected to the restrictions and studies of the classroom" (50).

Still, both farmers and legislators sought more immediate, practical results out of the state's investment in agricultural education. As one agriculturist wrote in a letter to the *Country Gentleman*, Yankee farmers cared only for "the CORN," and therefore would dismiss any science or scientific institutions that did not directly increase their crop productivity: "Why? *Because they won't bring the corn*" (51). Others more generously allowed that agricultural colleges should get "a little money to spend on books, apparatus, and fitting up," but then drew a line: "let them know they shall have more as fast as they can show results" (52). In response, Pugh had to repeatedly explain to the public that agricultural science was in a "youthful stage" and required "step by step… patient research" (53). He reminded the public that "it must not… be supposed that these results will manifest themselves at once, or that they will pay as experiments are being made: as well might the farmer expect to reap his crop the day he sows his grain" (54). Like his friend Samuel W. Johnson, Pugh called for the establishment of experiment stations as the next step in agricultural improvement. He envisioned a dialogue in which farmers who had learned "how to observe, and what to observe" at an agricultural college would share their observational data with a nearby experiment station, thus contributing to and benefiting from the advancement of agricultural science and scientific education.

Overcoming the Prejudice of the Public

During his presidency, Pugh contended with popular prejudices against chemistry, science, and higher education in general. At the time, classical colleges were believed to produce graduates contemptuous of industrial work, and there was public concern that higher education of any kind would drive farmers' sons away from agriculture as a vocation. An early statement by the School's trustees articulated this fear (55):

> It is a fact universally known, that the literary institutions of the country, as at the present constituted, educate young men to a state of total unfitness not only for the pursuits of a farmer but as a companion for his parents, brothers, and sisters, with whom he is expected to spend his life. He is therefore driven from them—from his father's estate—and into a profession for which he has perhaps little capacity, and where he is subjected to all the temptations of an idle life.

The trustees saw the Farmers' High School's manual labor requirement as an important selling point for an agricultural college, and indeed it was a popular concept (56). The name the trustees chose for the institution, Farmers' High School, was likewise a conscious effort to set the School apart from classical colleges.

Much of the School's curriculum, too, was a reaction to prejudice against traditional colleges. From its inception, the Farmers' High School trustees aimed to "enrich and ennoble the life of the farmer," but they set careful limits for this social uplift (57). The trustees established the School to teach "that which is valuable for a farmer to know;" they explicitly did not want to prepare students "for the professional pursuit of scientific subjects" (58). Pugh agreed that subjects taught should be useful for agriculturists, but in his view the principles and methods of science were themselves useful (59):

> Was it desirable that the farmer should have such a knowledge of agricultural science, as would enable him to investigate and develop agricultural principles, or was it simply desirable to teach him to practice those rules, which others deduced for him from principles he could not understand?

However, in his first year at the Farmers' High School, confronted by criticism from agriculturists, Pugh conceded and followed a more vocational curriculum. As he confessed to Johnson, he "adopted a somewhat popular plan not because we did not appreciate and desire a plan more scientific, and consistent with the dignified reserve of science but because the necessities of the times have required the course at our hands which we have followed" (60). Still, while graduates of the School were expected to return to practical farming, Pugh envisioned them as community leaders who would "by the influence of precept and example... infuse new life and intelligence into the several communities they enter" (61).

In addition to prejudice against colleges, Pugh also confronted prejudice against scholars and scientists. "Practical farmers" in Pennsylvania and elsewhere tended to view agricultural scientists as "book farmers" or "men in silk gloves" who had no practical knowledge of farming (62). Pugh thus had to establish his credibility and demonstrate his competence as an agriculturist. His background as a native of rural Pennsylvania served him well on this question; unlike most chemists, Pugh could boast of spending his youth in "almost constant contact with the farmers" (19). Also convincing was his physical appearance. Far from a stereotypically atrophied, lusterless intellectual, Pugh was handsome and robust, with an athletic, strapping build. At six feet, one inch, he was also unusually tall, often referred to as "giant." His appearance immediately dispelled the notion of the "pimply-faced professor" (63); instead, his physique inspired respect among manual laborers and his Farmers' High School students. Legends were told of his displays of exceptional strength, and Pugh himself acknowledged the benefits of working with his students on the college farm: "I could spare you 15 times as much as Shylock wanted for his bond and have 200 lbs. of flesh left" (64).

Farmers' distrust of science and scientific men extended beyond appearance, however. Pugh blamed the pseudoscientific "quacks" who cheated them: "Quacking has already done our cause no little harm and hundreds of farmers are disgusted at what they (with too much reason) term scientific humbug" (19). Pugh thus sought ways to distinguish scientists who used principled methods of analysis from "charlatans." At the same time, he perceived an opportunity to build public confidence (22):

> We could keep up an intimate connection or correspondence with the farmer, and all the humbug chemical salts and quack manures and superphosphate of gypsum!! e.g., etc. that were sent out to the farmer we would make a business of examining and exposing to censure or recommending thus we could secure the confidence and friendship of the farmer, and let him learn that he could depend on us for such information.

In 1860, a newspaper scuffle erupted when fertilizer manufacturer James J. Mapes, angered by Samuel W. Johnson's unfavorable chemical analysis of his product, accused Johnson of slander (65). In a *Country Gentleman* column (66), Pugh came to Johnson's defense with a vindication of his results. Pugh concluded that out of twelve fertilizer samples he analyzed, "the greatest cheat in the whole lot is that of Mapes' so-called nitrogenized superphosphate," which "is sold for nearly three times as much as it is worth." Such dishonesty, Pugh continued, "points out the necessity of our having some means of protecting the farmer from the shameful imposition that sales of such manures inflict." He thus leveraged the "Mapes affair" as an opportunity to set up a dichotomy between himself and Johnson as selfless, public servants of science and Professor Mapes as an archetypal, dishonest quack. This "great stir" brought significant publicity to agricultural chemistry in general as well as Johnson and Pugh specifically. Another manufacturer, whose product had more favorable results in Pugh's analyses, took to including a quotation from his report in their advertisements (67).

Securing Public Support

Having demonstrated the need for science education and his ability to meet that need, Pugh's final challenge was to convince the public that the Farmers' High School deserved and required financial support. After Justin Morrill introduced his land grant bill into Congress for the second time in December 1861, Evan Pugh monitored the progress of the legislation carefully, conscious of the financial impact it could have on the Farmers' High School of Pennsylvania. Pugh himself did not play a prominent role in lobbying for the land grant—he felt he did not deserve "any especial mention on the matter" (68)—but the combined contributions to the effort made by the Farmers' High School's trustees and friends were significant. Pugh later claimed that "without their aid the bill would not have passed" (69).

Pugh's own efforts instead focused on drawing explicit, public connections between the Farmers' High School and the Morrill Act legislation in order to prove that the School merited a land grant endowment. Very few agricultural colleges were in successful operation at the time, and thus Pugh sought to position the Farmers' High School in the public and Congressional view as a model of agricultural education. As he had in the past, Pugh again procured timely "favorable notices" in several prominent newspapers, even persuading Horace Greeley to print an article about the Farmers' High School in the *New York Tribune,* which had a national audience (70). Pugh sent a clipping of the article to one of the College trustees, along with a note of triumph: "I have received 10 letters today in response to it. I think that with all these and others that will come, we shall be full next session" (71).

In February 1862, Pugh suggested renaming the Farmers' High School as the "Pennsylvania State Agricultural College," a title that reflected the School's advanced level of coursework while also mimicking the title commonly used for the proposed "Agricultural College Bill" (72). The trustees officially settled on "Agricultural College of Pennsylvania" at their May 1862 gathering. At the same meeting, desiring that Pennsylvanians should know how Agricultural College flourished "notwithstanding the disturbed state of the times, while all other attempts of a similar character have failed in this country," the trustees resolved to "secure a full statement" of the Agricultural College's institutional history (*73*). That fall, Pugh published *The Agricultural College of Pennsylvania; Embracing a Succinct History of Agricultural Education in Europe and America, Together with the Circumstances of the Origin, Rise and Progress of the Agricultural College of Pennsylvania; as also a Statement of the Present Condition, Aims and Prospects of this Institution, its Course of Instruction, Facilities for Study, Terms of Admission, &c. &c.* The *History* documented the College's difficulties and accomplishments and asserted its entitlement to Pennsylvania's land grant endowment, concluding that there could be "no doubt of its ultimate success… now that… the Agricultural College bill has passed Congress." Pugh described how the College would use the land grant funds to support agricultural experimentation on the College grounds, and he also offered an early view of how the "mechanic arts" might be integrated into the College's curriculum. In the chemical course, as Pugh now described it, the student studied the science first and its "practical application to agriculture and the industrial arts" second. Each student would learn laboratory methods of analysis for agriculturally relevant compounds (fertilizers, for example) but also industrial compounds like ores, slags, alloys, and metals.

Pugh's efforts to prove the College worthy of financial support culminated with seeming success on April 1, 1863, when Pennsylvania Governor Andrew Curtin signed a bill accepting the terms of the federal land grant and designating the Agricultural College of Pennsylvania as the recipient. As soon as the Pennsylvania General Assembly reconvened in 1864, however, several other Pennsylvania colleges challenged the bill, vying to win part of the land grant designation for themselves (25). Pugh thus needed to unequivocally demonstrate that the Agricultural College met the requirements of the Morrill Act more robustly than any other Pennsylvania institution.

In January 1864, he produced another strategic document, a 35-page monograph titled *A Report Upon a Plan for the Organization of Colleges for Agriculture and the Mechanic Arts, with Especial Reference to the Organization of the Agricultural College of Pennsylvania, in View of the Endowment of This Institution by the Land Scrip Fund, Donated by Congress to the State of Pennsylvania* (69). Ostensibly addressed to the College trustees but distributed widely, the Report outlined in detail the Pugh's vision of a "first class Industrial College" and calculated the level of financial support it needed to thrive. Pugh concluded that the land grand endowment would be "barely sufficient" to support one agricultural institution, let alone several, and he pointedly criticized the "literary colleges" that made a "general scramble for a share of the spoils" to which "they had not the slightest legitimate claim." On March 3, 1864, Pugh revisited these arguments point by point in a long address to the General Assembly's Judiciary Committee, and later that month he hosted a dinner for the legislators and their wives on the College campus.

This intense advocacy took a physical toll on Pugh. In April 1864, while drafting yet another address to the state legislature, Pugh was seized with a "violent chill." He gave a final chemistry lecture to his senior students before retreating to Bellefonte for rest and medical care. He was diagnosed with typhoid fever and died within a week. As his assistant later wrote, "It is only marvelous to me that he did not sooner sink under the burden" (74).

Legacy

Perhaps the best indication of the importance and extent of Pugh's ability to communicate the value of chemistry and chemical education is the despair that followed in his absence. Without his guiding vision, the Agricultural College of Pennsylvania fell into a seventeen year era of "drift" and "strange transmutations" (75). Pugh's "ability was everywhere recognized; he enjoyed the confidence and esteem of the Trustees, of the student body, and of the public," and thus his death was "a disaster from which it took years to recover." Although continued wrangling did retain the land grant designation for the Agricultural College of Pennsylvania, financial issues remained a constant concern and embarrassment. Only a few years after Pugh's death, the Agricultural College of Pennsylvania lost the public confidence he had worked so hard to earn.

Further muddying the path Pugh had set for the institution, his first few successors made abrupt and significant changes to the College's curriculum. The College's scientific courses soon crumbled, undermining the themes of Pugh's advocacy. Pugh's former classmate George C. Caldwell filled the chemical chair for a short time, but he could not forestall the decay of Pugh's scientific vision. By the 1870s, much of the chemical apparatus Pugh imported from Europe was in storage, and some had even been burned as kindling. In 1874, President James Calder changed the institution's name to the Pennsylvania State College, saying that the Agricultural College name "misled many persons as to its real character" (76).

In the 1880s, Evan Pugh's legacy was reclaimed by men who shared his devotion to science education and his talent for communicating its value to the public. In 1881, a team of Pennsylvania State College faculty members reorganized Calder's curriculum into a progressive program that recalled Pugh's broad vision of blending the practical and the scientific. Two of the faculty members involved were Whitman H. Jordan, a former student of Samuel W. Johnson, and C. Alfred Smith, Pugh's former student and assistant (77). Concurrently, the trustees appointed George Atherton, an experienced administrator, to the College presidency. Atherton had close ties to Justin Morrill and would be instrumental in the passage of the 1890 Morrill Act, which provided desperately needed supplementary funding to Penn State and other struggling land grant institutions (78). Atherton considered science education a high priority and early in his committed funding for the construction of a new chemistry and physics laboratory building. In 1888, Atherton hired George Gilbert Pond as the head of the College's Department of Chemistry. Pond had studied chemistry and mineralogy at the University of Göttingen, like Pugh, and under his thirty years of leadership, student enrollment in Penn State chemistry classes increased tenfold.

Intrigued by the story of his predecessor, Pond tracked down and recovered for the College as much of Pugh's apparatus, correspondence, and library as he could find, compiling it into a small museum honoring the past president. The centerpiece of the collection was an enormous canvas diagram that Pugh had used to present his experiments on nitrogen fixation to the Royal Society of London. Securing this diagram was a "long, hard struggle," but Pond "felt it to be the greatest treasure the College could possess" (79). The diagram now hangs in Penn State's Physical and Mathematical Sciences Library, a fitting tribute to a scientist and educator who dedicated his life to advancing and communicating the value of chemistry.

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CHEMISTRY FOR THE “INDUSTRIAL CLASSES:” LABORATORY INSTRUCTION, MASS EDUCATION AND WOMEN’S EXPERIENCE IN MID-WESTERN LAND-GRANT COLLEGES, 1870-1914 (1)

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The Confluence of Two Academic Transformations

Chemistry is the laboratory science par excellence, as many commentators have affirmed (2). In fact, it was chemists who created the laboratory as a separate, enclosed space devoted only to experimental investigation. In light of that fact, it is surprising that laboratory *instruction* did not become a standard part of the undergraduate curriculum until several decades into the 19th century in Europe. Once incorporated into the university curriculum, however, laboratory instruction had a momentous impact on chemistry in that century and thereafter.

The movement to have undergraduates undergo systematic laboratory training began in several German universities. It was pursued most vigorously and spread most effectively by Justus Liebig, then at the University of Giessen, where the innovation attracted increasing numbers of chemists to Giessen from Germany, Europe and eventually the United States (3). It was adopted by other German academics, such as Friedrich Wöhler (Göttingen) and Robert Bunsen (Marburg and Heidelberg), whose laboratories were also prized destinations for American chemistry students seeking advanced instruction (4). The “Giessen model” was widely promulgated outside Germany by English translations of laboratory manuals written by Liebig’s coworkers; influential examples include Heinrich Will’s *Outlines of the Course of Qualitative Analysis followed in the Giessen Laboratory* (English eds. 1847-62) and, especially, several manuals of analytical chemistry by C. Remigius Fresenius (5).

A prominent conduit to the US for the Liebig program was the American, Eben Horsford, who matriculated at Giessen in 1844. After returning to the US he taught chemistry in the Liebig mode as Rumford Professor at Harvard’s Lawrence Scientific School, which had opened in 1847 and specialized in applied science (6). Harvard College undergraduates, however, had to wait half a decade longer before a select few had the opportunity to undertake laboratory work in a cramped room without gas and running water under the new Erving Professor, Josiah Parsons Cooke Jr. (7). One of those fortunate undergraduates was Charles W. Eliot, who spent the years 1863-65 studying European teaching practices and then accepted a professorship in Analytical Chemistry at the newly established Massachusetts Institute of Technology (8). In his four years at MIT Eliot coauthored, with Francis H. Storer, two laboratory manuals that were instrumental in advancing the cause of laboratory instruction in chemistry (9, 10).

While the drive to revolutionize chemistry by making laboratory work integral to chemical pedagogy gathered steam in the East, the country as a whole was embarking on the most revolutionary experiment ever undertaken in higher education. In 1862, during the second year of the Civil War, President Lincoln signed the Morrill Act, which mandated the establishment in every US state of a land-grant college, whose

> leading object shall be, without excluding other scientific and classical studies … to teach such branches of learning as are related to agriculture and the mechanic arts … in order to promote the liberal and practical education of the industrial classes in the several pursuits and professions in life (11).

The land-grant institutions (LGIs) differed substantially from their older, classical (and mostly Eastern) counterparts in several ways:

- They laid as much stress on applying as on accumulating knowledge, especially scientific and technical knowledge
- Their potential enrollees often had fewer preparatory educational resources available to them
- The academic staff was less likely to have studied abroad
- They were coeducational at the time or within a few years of their first adhering to the Morrill Act, since it forbade discrimination based on race or sex.

Furthermore, after a few decades the newly minted colleges and universities started growing at unprecedented rates: in 1870, the 20 LGIs had 1,413 students and 144 academic staff; by 1914, the 69 LGIs had 61,212 students and 6,734 academic staff (12). For all these reasons it could be anticipated that the laboratory curricula at the LGIs would differ significantly from those of their predecessors, yet that possibility has not been pursued. This paper focuses on laboratory curriculum development at a group of Midwestern LGIs, the varying perceptions of chemistry's role and value in pre-World War I American society, and the experience of female students amidst all these fluctuations.

Chemistry at Some Midwestern LGIs: Differing Visions, Varied Circumstances, Diverse Approaches

One difficulty in studying chemistry at the LGIs is their sheer number and diversity. Six land-grant institutions were chosen for this study according to the following criteria:

- That the states in which they were located be relatively distant from the Eastern seaboard
- That the college or university had been designated a land-grant institution by 1870
- That the states involved would differ with respect to degree of urbanization (13).

Table 1. Institution and year it obtained land-grant designation

Illinois Industrial U	1867
Iowa State Agricultural College (IAC)	1864
Kansas State Agricultural College (KSAC)	1863
Michigan Agricultural College (MAC)	1862
University of Missouri Columbia	1870
University of Wisconsin	1866

Table 1 lists the six institutions, along with the year in which they obtained land-grant designation (14). They all shared a great enthusiasm for laboratory work as a central element of their chemistry curriculum. Already in 1857, Lewis R. Fiske started teaching chemistry, including laboratory work, at the Agricultural College of the State of Michigan (15). At most LGIs chemistry was initially a two-year program, beginning in the second year. At Iowa State qualitative analysis was taught in the second year and quantitative analysis in the third (16). Illinois pioneered the four-year chemistry program, with qualitative analysis offered in the first year, quantitative analysis the second (17); the first Professor of Theoretical and Applied Chemistry, A. P. S. Stuart, brought with him "the new concept of 'hand-on' [*sic*] laboratory work" from Harvard in 1868 (18).

These institutions embraced the chemistry laboratory for a variety of reasons: some were common to educational institutions throughout the country; others aligned strongly with the LGIs' conception of their particular mission. The conviction that teaching laboratory early brought substantial pedagogical benefits was quite widespread. Frank W. Clarke, author of a highly regarded study of US chemistry and physics teaching, asserted, "Three months of laboratory work will give more real insight into any science than a whole year's study of the printed page. To study chemistry from books alone is like learning a language from its grammar only, without attempting to translate or to write exercises" (19). Numerous scientists and educators in the 1870s and 1880s found benefits in laboratory instruction beyond the pedagogical: "For many of them the laboratory was, first and foremost, a place to mold character, to inculcate in young men virtues of honesty, perseverance, and fidelity in the little things, and to instill respect for painstaking manual labor" (20).

The emphasis on respect for manual labor resonated strongly among the LGIs. John A. Anderson, second president of Kansas State Agricultural College, remarked, "The natural effect of exclusive headwork, as contradistinguished from handwork, is to beget a dislike for the latter" (21). Similar sentiments found expression in institutional mottoes and college requirements (22). Furthermore, the notion of shared manual labor was certainly compatible with the democratizing tendencies in these institutions (23).

In addition to origins and commitments, the LGIs shared a number of problems as well, one of the foremost being low enrollments in their early decades. All were chronically underfunded, and several almost closed their doors in the 1880s (24). Inadequate student preparation was also an enduring concern for many years. "In 1890, only between six and seven percent of the population of youth fourteen to seventeen years old was attending secondary school" (25). While chemistry was one of the more widely offered high school sciences through the end of the 19th century, no more than 10% of high school students were taking it at any one time (26). The extent and nature of their laboratory experience was dependent on the size of their municipality and even the size of their high school (27). Nonetheless, the diversity of their high school chemistry preparation seems to have had little impact on their admittance to and performance in college. High school chemistry was not an entrance requirement nor considered a substitute for college chemistry (28). The greatest effect of this diversity seems to have been on the colleges themselves. As Eddy points out, "This period [1880-1897] was marked more than any other by a struggle within both old and new Land-Grant Colleges to maintain and, if possible, to raise standards. The chief difficulty remained the lack of preparatory education" (29).

The LGIs had much in common, yet differed in substantial ways. While the Morrill Act favored the teaching of "agriculture and the mechanic arts," it did so "without excluding other scientific and classical studies." The balance between those two goals at each institution was affected by its location, its various constituencies and, especially, the presence or absence of a competing classically oriented state college or university. These in turn strongly influenced the choice of faculty and curriculum.

When Illinois Industrial University was founded in 1867, the only other public institution of higher education was the Normal School. It became clear quite early that IIU (later the U of Illinois) would serve both classical and technical constituencies (30), and that its chemistry department would be more than a handmaiden to agriculture. Of the first four Illinois Chemistry professors, two had studied at Harvard, Stuart (1868-74) and A. W. Palmer (1889-1904); two had studied in Germany, H. A. Weber (1874-82) with Liebig, and Palmer with Hofmann and V. Meyer; and Weber, W. McMurtrie (1882-88) and Palmer each had Ph.D.s in Chemistry (31). As proclaimed in the 1874-75 *Catalogue*, the object of the School of Chemistry was (32)

> to impart such theoretical and practical knowledge of Chemistry as to enable the student to apply the principles of the science to any of the related arts, and to fit him *not only for research*, but for the practical business of the Druggist and Practical Chemist [*emphasis added*].

Similar patterns of faculty preparation are present for Wisconsin (33) and Missouri (34). While their chemistry departments did not neglect their agricultural responsibilities, like Illinois they clearly aspired to a much wider disciplinary reach.

The portrait of the Kansas State Agricultural College faculty is strikingly different. When KSAC was founded in 1863, it became the first LGI under the Morrill Act. Almost simultaneously, the legislature established the University of Kansas at Lawrence. Thus, those who wanted KSAC to concentrate on agriculture and the mechanic arts could assume that the liberal arts would be served at Lawrence. In 1873, the KSAC Regents issued an emphatic statement about the direction of their college (35):

> Prominence should be given to those branches [of learning] in the degree that they are actually used by the farmer or mechanic. As against the opinion that the aim of these [land-grant] colleges should be to make thoroughly educated men, we affirm that their greater aim should be to make men thoroughly educated farmers.

In 1873, W. K. Kedzie was appointed Professor of Chemistry and Physics at KSAC. His undergraduate degree was from MAC; those of his successors, G. H. Failyer (1878-97), and J. T. Willard (1897-1918), were from KSAC. Each of the three had had some graduate training in the US (Kedzie at Yale, Willard at Johns Hopkins) but none had studied abroad or attained the Ph.D. (36). At Michigan Agricultural College, a similar picture presented itself. The Professor of Chemistry from 1863 to 1902, Robert C. Kedzie, was a Civil War surgeon with an M.D. degree from the University of Michigan, who was succeeded by his son, Frank (37). In both these colleges, the teaching of chemistry was tightly bound to its agricultural applications. As Johnson points out, "Where brand new institutions were founded under the Morrill Act, particularly if they were separated from the state University, agriculture generally fared better; and in some places it was clearly dominant." He lists Michigan and Kansas as two of those places (38).

Laboratory Curricula, Laboratory Manuals and the Function(s) of Chemical Education

The different faculty profiles and sense of mission among the college chemistry departments would be expected to lead to noticeably different curricula. Since the emphasis of this paper is on the chemical laboratory, I have chosen to search out those differences by comparing the laboratory manuals in use for qualitative and quantitative analysis (39). These were invariably stand alone courses not tied to any particular lecture material that were offered in every LGI. Furthermore, these courses were bread and butter subjects that provided both background for higher level courses *and* marketable skills (40).

At Illinois, textbooks were first mentioned in the 1874-75 *Catalogue* (32). The texts for the analysis courses are those by Fresenius and Douglas and Prescott (41). They each ran to several hundred pages and had extensive discussion, and were still listed in the 1884-85 *Catalogue*. One especially intriguing feature of Fresenius's *Qualitative Analysis* is his justification for the study of analytical chemistry (42):

> … we have to look upon it [chemical analysis] as one of the main pillars upon which the entire structure of the science rests; since it is almost of equal importance for all branches of theoretical as well as of practical chemistry. This consideration would be of sufficient reason to recommend a thorough study of this branch of science, even if its cultivation lacked those attractions which it possesses for every one [*sic*] who ardently pursues it. The mind is constantly striving for the attainment of truth; it delights in the solution of problems; and where do we meet with a greater variety of them, more or less difficult of solution, than in the province of chemistry?

The conception of chemistry embodied in this one statement accords very well with the Illinois School of Chemistry's conception of its purpose.

Around 1880, Missouri and Wisconsin also used Fresenius for both quantitative and qualitative analysis (43). Missouri offered qualitative analysis in the first semester, junior year, followed by quantitative analysis. At Wisconsin, qualitative analysis was given in the second semester, sophomore year, followed by quantitative analysis at the beginning of the junior year. By contrast, Illinois required qualitative analysis for the first two terms of their freshman year; quantitative analysis began in the third term of that year.

Once again, the program at MAC and KSAC differed markedly from the others in this survey. In 1869, Robert C. Kedzie wrote a very condensed handbook of qualitative analysis, only 56 pages long, that consisted of little more than a series of operations, without much discussion and no equations (44). Kedzie's motivation may have been partly economic—it was less expensive for the students than Fresenius or Douglas and Prescott—but I believe his main consideration was pedagogical. His book was tailored to a clientele for whom analytical chemistry was purely a tool. The Kedzie manual was also adopted at KSAC, where Robert's son William taught for five years. In the mid-1880s, it was replaced by a 100-page outline coauthored by William Kedzie's successor, American-educated George Failyer, and his assistant, J. T. Willard (who would in turn succeed Failyer). Its purpose was more to familiarize the student with chemical compounds and properties than "to make an analytical chemist of him" (45).

Chemistry at Iowa State Agricultural College (IAC) was also closely connected with agriculture from the start (46). Nonetheless, several department heads built up its chemistry offerings. T. E. Pope (1876-1884), an alumnus of Harvard and the Massachusetts Institute of Technology (Ph.D.), was called to the Professorship of Chemistry at IAC in 1876. He instituted a new option, the Special Course of Instruction in Chemistry, which permitted seniors "to drop one of the specified studies [agricultural chemistry; foods for domestic animals] and devote twice the usual time to chemistry" (47). The students often assisted Pope in making analyses of soil and food samples for external parties (48). In the 1882-83 *Biennial Report* Pope noted that (49)

> The proficiency attained by these students is often very high, and I have had calls each year from the leading institutions at the East for chemists, not one of whom has so far failed to retain his place, and add to the reputation of the Department.

While less scientifically noteworthy than Pope, his successor, A. A. Bennett (1885-1913), maintained his commitment to the chemistry laboratory. He made a point of inserting programmatic statements about the value of laboratory practice and chemistry itself in his contributions to the Biennial Reports. In the 1886-87 Report, he maintained that "The aim and character of the instruction is two-fold; first and foremost to give mental training, and second to give a practical knowledge of the subject as it is related to the various industries." Less than a decade later, his views had a somewhat different emphasis (50):

> The study of analytical chemistry serves two purposes. It … develops the reasoning faculties by applying the general knowledge already gained to analytical processes. It increases the student's power of generalization and makes the theoretical conceptions peculiar to the subject clearer and more useful. A second purpose of the study of analytical chemistry is its use as a means of investigation in scientific and technical studies. No chemical investigation can be carried out without resort to its method (1894-95).

The programmatic statements, curricular contents and textbook choices adopted by each institution paint a picture of substantial diversity with respect to institutional mission and the role of chemistry in achieving it. One major point of difference, for example, was how closely the study of chemistry should be tied to its specific applications, especially agricultural. In addition, the various laboratory manuals and curricula emphasized different benefits of laboratory work: as mental discipline; as foundation for a professional chemical career; as gateway to applications in agriculture and engineering; and as demonstrating the empirical basis of chemical laws and theories. In all cases, the value of laboratory immersion was not questioned. However, a prominent chemist outside the land-grant community voiced some serious reservations. J. P. Cooke, who had championed laboratory instruction at Harvard, raised alarms in 1892 over the dangers of excessive reliance on the laboratory for chemical pedagogy (51):

> I have before noticed … the demand in College for purely technical courses and the technical spirit in which our technical courses are often studied …. Take for example our course in quantitative analysis, a course which … could never be recommended as a course of liberal culture were it not an essential preliminary to all advanced chemical study …. Science can never take a high place in a course of liberal culture unless the tendency to empiricism is resisted.

Among the LGIs, disagreements over the essential nature and function of chemical education and laboratory instruction can be traced in part to the oft-times conflicting expectations of their diverse constituencies (52). Furthermore, the chemists themselves often had multiple allegiances: to their local institutions, to the local and/or state communities, to their professions as teachers and as chemists (53). By the mid-1890s, however, the fortunes of the LGIs, the chemistry profession and American agriculture (which was emerging from a three-decade long depression) were all looking brighter. The Second Morrill Act of 1890 provided for direct and continuing federal support for the LGIs, which had generally received scant funding from their home states (54). As the new century began, the LGIs devoted increasing efforts to accommodating their rapidly accelerating enrollments and devising an appropriate education for their women students.

One of the pressing problems facing the LGIs around the turn of the century was their vertiginous rise in enrollments, due in large part to swelling immigration (55). In 1871 the undergraduate enrollment at Wisconsin amounted to 457, of whom 131 were preparatory students; it reached "over two thousand at the century's turn" (by which time the preparatory program had ended) (56). At KSAC the total enrollment jumped from 647 in 1895 to 1,321 in 1900 and thence to 1,690 in 1905; it reached 3,089 in 1914 (57). This pattern was typical among all the LGIs in this study. A very large fraction of land-grant students was required to take at least some chemistry, including laboratory, regardless of major; at IAC chemistry became essentially compulsory for all (58). The demand for laboratory space rose in concert with the rising enrollments and became something of a nightmare for faculty and students (59):

> By 1910, twelve hundred students were taking chemistry courses each term, 756 enrolled in general chemistry. That laboratory had 625 usable permanent lockers. Several benches installed in the aisles provided 49 more lockers, but these benches lacked running water, a sink, and ventilation …. The remaining 80 students were dependent on apparatus boxes.

Nonetheless, these difficulties and dislocations could bring rewards, especially for the chemistry majors. Employment opportunities for chemists rose steadily from 1890 (60); analytical laboratory techniques were specially valued. Louis Kahlenberg, Director of Wisconsin's Course in Chemistry, informed potential majors "the University has thus far been utterly unable to supply a sufficient number of trained chemists" to meet the demand. Kahlenberg specifically sought to attract women to chemistry, claiming "in lines like analytical, physiological, sanitary and food chemistry, there is a growing field of work for women" (61). He had little success, and his 1912 report to the Dean makes clear why: "… hitherto it has been rather difficult for women to secure positions as chemists" (62).

In fact, most women in the LGIs, including those interested in chemistry, were not following the same curricula as their male counterparts. Those curricular differences were intimately tied to different expectations *for* and *by* men and women, and lay at the root of the women's inferior job opportunities.

"We Must not Confine it [Education] to Our Boys Alone, but Must Teach the Girls as Well"

Because the 1862 Morrill Act forbade discrimination based on sex, women students constituted a substantial part of the LGI enrollments from the earliest days. Although coeducation was a controversial topic in the 1860s and 1870s, its inescapability eventually provoked similar reactions among the LGIs (63). Women were first admitted to KSAC in 1863, constituting 50% of the entering class of 52 (64). For the next 10 years the curriculum contained many classical courses and no courses explicitly aimed at women. In 1873 the trustees and president undertook a sharp change in direction, emphasizing the practical and immediately applicable. Their new vision included a course in Household Chemistry, a Sewing Department and a Woman's Course (65). The 1873 Missouri *Catalogue* announced that young women would be admitted to any "of the University classes for which they may be qualified, and have the special care and supervision of the professors or teachers when they attend" (66). In 1879 Missouri introduced a "Girls Course in Arts" that granted a new degree, the A.D.B. (*Artius Domesticarum Baccalaurea*) (67).

One of the earliest, unequivocal statements favoring the college education of women came from the IAC Board of Trustees in 1868 (68):

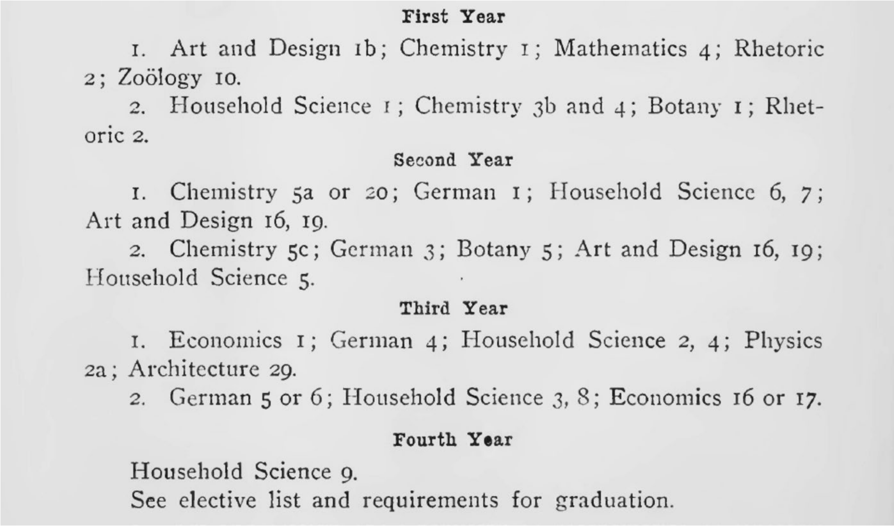
> If young men are to be educated to fit them for successful, intelligent, and practical farmers and mechanics is it not as essential that young women should be educated in a manner that will qualify them to properly understand and discharge their duties as wives of farmers and mechanics? ... If we would elevate the laboring classes by affording them … an education equal to that of the professional man, we must not confine it to our boys alone, but we must teach the girls as well ….

The first president of the IAC, Adonijah Welch, was a firm believer in the intellectual capability of women and the necessity of their being educated; his wife, Mary B. Welch, believed even more fervently in that position. She persuaded the president to institute a "Ladies Course" in 1872. The Welches took seriously the notion that the intended educational outcome required a large fraction of science courses. The freshman year was identical to that for the Agricultural Course; in the following two years the women took three courses in chemistry, one each in mineralogy and geology, botany, and physics, and two in anatomy and physiology, as well as a course in Domestic Economy (69). The centrality of science, especially chemistry, for women's courses was recognized at the other LGIs as well. In 1882 a course in Domestic Chemistry was offered for A.D.B. students at Missouri, and by 1885 they had to satisfy the same chemistry requirements, seven courses in all, as those in the Course in Science (70, 71).

In 1883, the Welches left IAC, and Mrs. Welch wrote an extended, valedictory report to the trustees about the Department of Domestic Economy. Much of it was given to what Mrs. Welch saw as misconceptions about the "household arts" and their relation to misconceptions about agriculture: "It is very much with housework as it has been with agriculture. Muscular ability was thought to be the only ability needed by the farmer. Robust health and a strong right arm have been considered the chief essentials in a cook." Her refutation of both disparagements was vigorous (72).

Women were not required to enroll in women's courses (under whatever name they were known) at any of the LGIs. Depending on what subjects were available at each campus, some women would opt for the Agricultural, Normal or Science Course. At Wisconsin, which had done away with its Female College in 1874, there was no Department of Home Economics until 1903 (73). In some cases the women students themselves pressed for a special program tailored for their perceived needs. MAC did not have such a program until 1896; in 1879 its first female graduate, Eva Coryell, "challenged her alma mater to 'substitute in place of agriculture some study to a girl's education,' which she said would result in 'an excellent ladies course'" (74).

By the turn of the 20th century many LGI women's programs were revaluating their roles within academia and society. Those programs had primarily aimed at partnering scientifically-trained farmers with scientifically-trained spouses; secondarily, they provided the skills for economic self-sufficiency among single and widowed women. These initiatives—variously called Domestic Science, Domestic Economy and, ultimately, Home Economics—were conceived in terms of individual women and individual families. Coincident with their rising appeal, however, the nation was undergoing a number of major social and economic upheavals. An agricultural depression that lasted several decades, and the pressures of market economics, resulted in consider-



First Year

1. Art and Design 1b; Chemistry 1; Mathematics 4; Rhetoric 2; Zoölogy 10.

2. Household Science 1; Chemistry 3b and 4; Botany 1; Rhetoric 2.

Second Year

1. Chemistry 5a or 20; German 1; Household Science 6, 7; Art and Design 16, 19.

2. Chemistry 5c; German 3; Botany 5; Art and Design 16, 19; Household Science 5.

Third Year

1. Economics 1; German 4; Household Science 2, 4; Physics 2a; Architecture 29.

2. German 5 or 6; Household Science 3, 8; Economics 16 or 17.

Fourth Year

Household Science 9.

See elective list and requirements for graduation.

Figure 1. *Required Courses in Household Science, U of Illinois, 1903-04*

able rural poverty (75). Meanwhile, soaring immigration was a prime cause of increased overcrowding, disease and malnutrition in the cities (76).

These events led some female activists to propose that the scientifically-based knowledge and skills developed in home economics programs could significantly ameliorate some of the problems roiling American society. One of the first and certainly the most influential person to advance that thesis was Ellen Swallow Richards (77). Having graduated from Vassar in 1870 at age 28 with a degree in chemistry, Ellen Swallow sought an industrial position without success. She then entered MIT and received a B.S. degree three years later. She remained at MIT where, in 1884, she became an instructor in the newly established Laboratory of Sanitary Chemistry, a position she held until her death in 1911. The laboratory's work resulted in the first water-quality standards for any state in the nation. (Swallow had married R. H. Richards of the MIT Mine Engineering Department in 1875.) Ellen Richards' books and articles, as well as her personal example, convinced many that the study of nutrition, sanitation, ventilation and housing were worthy of the same regard and support as those afforded other academic pursuits (78).

One of Richards' colleagues, Isabel Bevier, professor of Household Science at Illinois, had also had extensive training in chemistry (79). Bevier abandoned the "cooking and sewing" parts of household science and emphasized its scientific basis, including laboratory study (Fig. 1) (80). She envisaged household science "as an interdisciplinary enterprise that required social, economic, aesthetic, and technical knowledge …" (81). Such a multidisciplinary vision was quite unusual for a subject with such substantial scientific content, and had the potential to disturb the prevailing social order.

Indeed, this possibility may have affected the career of Wisconsin's first Professor of Home Economics, Caroline Hunt. A Northwestern University alumna who had done graduate work in chemistry, Hunt required of applicants to the Home Economics program a prior year of college chemistry as well as a minimum of 47 credits in science for graduation. At the same time, "Hunt consistently advocated for the role of home economics in bringing about social justice." After initial expressions of enthusiasm, the University Regents became concerned that the program was not focusing enough on preparing students for teaching and/or housewifery. Hunt was dismissed in 1908, only five years after she had been hired (82).

Of one thing there can be little doubt—the popularity of home economics among the women students. At Illinois the Household Science enrollment quadrupled from 20 to 80 from 1900 to 1904 (83). (By contrast, women claimed a mere *nine* chemistry degrees out of the 369 awarded between 1872 and 1914 by the Illinois Chemistry Department, one of the major ones in the Midwest (84).) IAC recorded an increase in total enrollment of 1,082 between 1912-13 and 1914-15, "chiefly in agriculture and domestic economy" (85). Spring term, 1904 at Wisconsin began with 34 enrollees in Home Economics; the following fall it jumped to 113 (86).

The accelerating flight of young college women into domestic science after the turn of the century, and their consequent abandonment of the physical sciences had multiple causes (87). The incursion of domestic science into the growing number of high schools provided potential employment for women at both the high school and college/university levels (88). In addition, the arrival of these opportunities coincided with increasing resistance to women's employment in what were considered men's fields, which now included the natural sciences. This interplay of economic forces and restraints took place in a cultural matrix that increasingly labeled the sciences, especially physical sciences, as unfeminine and inappropriate for women. The assumptions underlying these stereotypes had become increasingly embedded in the educational system itself.

Epilogue

By the first decades of the 20th century chemical laboratory instruction, that mid-19th century German import, had become thoroughly established throughout the US. Its format had been adapted for a mass, expanding clientele with a variety of career trajectories to an extent probably unimaginable by its German originators. The same manuals were being used by male and female students alike in the same undergraduate chemistry laboratories, which enrolled more women than anywhere else in the world. These laboratories even provided gender-integrated spaces on campuses where a good deal of gender separation was otherwise enforced (89). However, the range of employment to which these skills gave access was markedly wider for men than for women. In fact, the great majority of scientifically inclined LGI alumnae ended up practicing home economics, mostly in their own homes. Thus, it seems undeniable that despite its scientific content, home economics reinforced prevailing attitudes with respect to gender-specific skills, aptitudes and destinies; it may also have deflected women who would otherwise have pursued careers in the more established and prestigious sciences.

That is not, however, the entire story. Home economics enabled substantial numbers of women for the first time to obtain broad backgrounds in science and use them for employment and self-employment. In addition, it significantly nourished the growth of some new scientific fields such as nutrition, which had its roots in Liebig's scientific work. In these areas, women could find gainful employment (90). The fact that subjects like nutrition did not rate the same academic status as the mainstream sciences such as chemistry was a direct consequence of its high proportion of female practitioners—a familiar outcome for women (91).

The Morrill Land-Grant Act of 1862 initiated one of the great experiments in mass higher education. The mission of the LGIs put chemistry directly at the center of that initiative and led rapidly and almost inevitably to the enthusiastic adoption of laboratory instruction. Over time, the expanding group of land-grant institutions adapted it to the requirements of hundreds of thousands of diverse students who demonstrated, in a very different ways, the lasting significance of Liebig's scientific and pedagogical innovations.

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Archival materials are courtesy of the following sources:
- Special Collections Department, Iowa State University Library (hereafter Iowa State Archives), Series 7/6/3 Department of Chemistry, General Subject Files, Box 1, Folder: Biennial Reports;
- University Archives, University of Wisconsin-Madison (hereafter U of Wisconsin Archives);
- University of Missouri catalogs are all contained in Series C: 0/51/1, University Archives, University of Missouri;
- Kansas State Agricultural College catalogs are available online at the Internet Archive, http://archive.org/search.php?query=collection%3Akansasstateuniversitylibrariescatalog&sort=-date
- Catalogs for the Illinois Industrial University and University of Illinois are available online from the University Archives, University of Illinois at Urbana-Champaign, Record Series 25/3/801, http://archives.library.illinois.edu/e-records/index.php?dir=University%20Archives/2503801/ (1867-1900) and http://libsysdigi.library.uiuc.edu/OCA/Books2010-02/annualregister/ (1879-1947).

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4. Ref. 3, 103-106; P. R. Jones, "Contrasting Mentors for English-Speaking Chemistry Students in Germany in the Nineteenth-Century: Liebig, Wöhler, and Bunsen," *Bull. Hist. Chem.*, **2012**, *37*, 14-23.
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7. C. L. Jackson, "Josiah Parsons Cooke: Biographical Notice," *Addresses in Commemoration of Josiah Parsons Cooke, LL.D.*, Wilson, Cambridge, MA, 1895, 1-13; qualitative analysis became a regular Harvard College elective in 1857.
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9. The two books were *A Manual of Inorganic Chemistry, Arranged to Facilitate the Experimental Demonstration of the Facts and Principles of the Science*, Cambridge Press, Boston, MA, 1867, and *A Compendious Manual of Qualitative Chemical Analysis*, Van Nostrand, New York, 1869. Cooke also wrote a laboratory manual, intended for beginning students (*Laboratory Practice*, Appleton, New York, 1891).
10. Harvard was not the first American institution at which students were given chemical laboratory instruction; that distinction belongs to the Rensselaer School (later the Rensselaer Polytechnic Institute), of which Horsford was an alumnus (H. S. van Klooster, "The Beginnings of Laboratory Instruction in Chemistry in the U.S.A.," *Chymia*, **1949**, *2*, 1-15). The influence of Eliot's program was due in large part to the laboratory manuals he coauthored with Storer. While scholars are increasingly turning their attention to the importance of textbooks in shaping the course of chemistry, instructional laboratory manuals have received much less attention. A 1977 symposium on textbooks gave rise to two brief articles about them: P. J. Elving, "Texts in Analytical Chemistry: An Uneasy Transition State Complex of Theory, Laboratory and Social Demands," *J. Chem. Educ.*, **1977**, *54*, 269-270; B. R. Siebring and M. E. Schaff, "The Purpose and Nature of Laboratory Instruction From an Historical Point of View," *J. Chem. Educ.*, **1977**, *54*, 270-271.
11. E. D. Eddy, Jr., *Colleges for our Land and Time: The Land-Grant Idea in American Education*, Harper, New York, 1956, 32-45.
12. H. Hale, "The History of Chemical Education in the United States from 1870 to 1914," *J. Chem. Educ.*, **1932**, *9*, 729-744. The availability of these data for 1870 was one reason for choosing this year as the starting date for this study. By this time virtually all the states had "accepted and taken measures to secure the grant of land which was offered by Congress" (US Bureau of Education, *Report of the Secretary of the Interior*; *Being Part of the Message and Documents Communicated to the Two Houses of Congress at the Beginning of the Second Session of the Forty-Second Congress*, Vol. 2, Government Printing Office, Washington, DC, 1872, 429-434 (429)).
13. The degree of urbanization is pertinent to this study because it could affect the preparation of incoming freshmen and the curriculum, depending upon the extent to which the state economy was dependent on agriculture.
14. Several of the institutions had been in existence for some years before they obtained land-grant status: MAC was founded in 1855 and first admitted students in 1857; Missouri had been founded in 1839 and admitted students in 1840; Wisconsin had been founded in 1848 and admitted students in 1849. Illinois Industrial University became the University of Illinois in 1885, IAC is now Iowa State University, KSAC is now Kansas State University, and MAC is now Michigan State University.
15. W. J. Beal, *History of the Michigan Agricultural College, and Biographical Sketches of the Trustees and Professors*, MAC, East Lansing, 1915, 39; K. R. Widder, *Michigan Agricultural College: The Evolution of a Land-Grant Philosophy, 1855-1925*, Michigan State, East Lansing, 2005, 19.
16. *Fourth Biennial Report of the Board of Trustees of the Iowa State Agricultural College and Farm to the Governor of Iowa* (hereafter *Fourth Biennial Report, IAC*, and similarly for other reports in the series), Edwards, Des Moines, IA, 1872, 43-44. In describing "The New Laboratory" the Biennial Report of 1875 asserted that "Both Physics and Chemistry can be taught to as good advantage as in any of the Eastern Universities .... The student who actually handles the apparatus and performs the experiments in chemistry for himself gets therefrom a knowledge which cannot be obtained from books .... The new education teaches the hand as well as the head" (*Sixth Biennial Report, IAC*, 1875, 81-82). By 1876, the chemistry course had been extended to three years.
17. *Third Annual Circular of the Illinois Industrial University, 1869-1870,* Urbana, Champaign County, IL, 13. Under the heading, Department of Mechanical Philosophy & Engineering, the *Circular* notes that machine shop instruction "bears the same relation to mechanical instruction that laboratory work does to instruction in chemistry" (p 11).
18. E. P. Rogers, "An Anecdotal History of Chemistry [at the University of Illinois] Prior to 1950," http://chemistry.

illinois.edu/about/history/rogers.html (accessed Dec. 20, 2013). Since many students left college before completing degree requirements, the issue of when laboratory instruction was to begin had a major effect on whether these students left with some laboratory experience or none.

19. F. W. Clarke, "A Report on the Teaching of Chemistry and Physics in the United States," *Circulars of Information of the Bureau of Education*, No. 6—1880, Government Printing Office, Washington, DC, 1881, 17. Ref. 16 expresses similar sentiments.
20. J. W. Servos, "Mathematics and the Physical Sciences in America, 1880-1930," *Isis*, **1986**, *77*, 611-629, p 613.
21. J. D. Walters, *History of the Kansas State Agricultural College*, College Printing Department, Manhattan, KS, 1909, 48.
22. The mottoes of some LGIs reflect the value placed on manual work and experiential learning: Illinois, "Learning and Labor;" Iowa State, "Science and Practice." In their early decades, most LGIs either encouraged or required student work as part of the academic program—men on the model farm, women in the college kitchen. One of the objects of the Michigan State Agricultural College was "To afford to its students the privilege of daily manual labor. As this labor is to some degree remunerated, it might seem intended only to lessen the expense of the student. Its first use, however, is educational, being planned and varied for the illustration of the principles of Science" (*Catalogue of the Michigan State Agricultural College*, Published by the College, Agricultural College, MI, 1870, 13).
23. "Whereas there had been a wide gulf between the teacher and the student in the secure old colleges, the struggle in the new colleges was to bring the two closer together…. The circumstances and atmosphere made a contribution to the democratizing of higher education" (Ref. 11, 79-80).
24. E. L. Johnson, "Misconceptions About the Early Land-Grant Colleges," *J. Higher Educ.*, **1981**, *52*, 333-351. Reprint available online at http://ed-share.educ.msu.edu/scan/ead/mabokela/document12.pdf (accessed Dec. 20, 2013).
25. H. M. Kliebard, *The Struggle for the American Curriculum, 1893-1958*, 2nd ed., Routledge, New York, 1995, 7.
26. P. J. Fay, "The History of Chemistry Teaching in American High Schools," *J. Chem. Educ.*, **1931**, *8*, 1533-1562, pp 1540-1542. As Clarke notes, "In the great majority of cases mere text book work is done, only a few experiments being performed by the teacher. In some instances, the scholars have laboratory practice … The work in chemistry extending through a full school year and including the outlines of analysis" (Ref. 19, pp 15-16).
27. Ref. 26 (Fay), p 1549.
28. I thank the referee for clarifying these points.
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applying analytical techniques to detecting adulterants in fertilizers and to investigating issues related to public health.

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46. See e.g. Ref. 16, *Fourth Biennial Report, IAC*, 45.
47. *Seventh Biennial Report, IAC*, Edwards, Des Moines, IA, 1877, 93-96.
48. *Eighth Biennial Report, IAC*, Edwards, Des Moines, IA, 1879, 186.
49. *Tenth Biennial Report, IAC*, Edwards, Des Moines, IA, 1883, 58.
50. *Twelfth Biennial Report, IAC*, Edwards, Des Moines, IA, 1887, 78; *Sixteenth Biennial Report, IAC*, Edwards, Des Moines, IA, 1895, 66.
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61. *The University of Wisconsin Catalogue, 1910-1911*, Madison, WI, 252-253.
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63. A. G. Radke-Moss, *Bright Epoch: Women & Coeducation in the American West*, U of Nebraska, Lincoln, 2008, 21-23.
64. J. T. Willard, *History of the Kansas State College of Agriculture and Applied Science*, KSAC, Manhattan, 1940, 547, 24.
65. Ref 64, 36-37, 39-40. Nellie Sawyer Kedzie was the first head of the Department of Domestic Science at KSAC and the first female professor in Kansas. She was the widow of Robert C. Kedzie's son, Robert F., who had taught classes at KSAC when his brother William was on leave. She was a pioneer among women in academia and in the home economics movement ("Nellie Kedzie Jones," Topics in Wisconsin History, Wisconsin Historical Society [Online], http://www.wisconsinhistory.org/topics/jones/ (accessed Dec. 21, 2013).
66. *University of the State of Missouri, Report by the Curators to the Governor containing Catalogue, Announcements, and other matter pertaining to the University, Year ending 26 June, 1873*, Studley, St. Louis, 1873, 99.
67. *Catalogue of the Missouri University, Columbia, Missouri, 1879-1880*, Reagan & Carter, Jefferson City, MO, 127.
68. E. S. Eppright and E. S. Ferguson, *A Century of Home Economics at Iowa State University: A Proud Past, a Lively Present, a Future Promise*, Iowa State U. Home Economics Alumni Association, Ames, 1971, 4.
69. Ref. 68, pp 2-3. Mary Welch also recognized that single and widowed women needed skills that allowed them to be self-supporting (Ref. 63, pp 145-151).
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71. This is less surprising than it may at first appear. In

antebellum America, science was considered a suitable subject for girls and young women, who often outnumbered boys and young men in school science classes. That situation persisted into the 1870s and 1880s: Kim Tolley, *The Scientific Education of American Girls: A Historical Perspective*, RoutledgeFalmer, New York, 2003, 35-74.

72. Ref. 49, p 59. She wrote further that "A good farmer of to-day is not he who knows simply how to plow, or even how to raise and gather crops. To be successful he must be versed in the manifold duties of a business which embraces as many details and as diverse employments as the home …. So the housewife must be more than a cook, a nurse and a seamstress. She must be practically and specifically acquainted with these arts, but she must be ready also to influence character, take her place by her husband's side as a social force, and if need come, assume his duties as a person acquainted with affairs" (p 61).
73. *Catalogue of the University of Wisconsin for 1903-1904*, Madison, 1904, 166-167, 186-188; R. D. Apple and J. Coleman, "The Beginning, 1903-1908: 'The final test of the teaching of home economics is freedom,'" in R D. Apple et al., *The Challenge of Constantly Changing Times: From Home Economics to Human Ecology University of Wisconsin-Madison, 1903-2003* [Online], Parallel Press, Madison, WI, 2003, 1-14, http://digital.library.wisc.edu/1711.dl/UW.Change02 (accessed Dec. 21, 2013).
74. Ref. 15 (Widder), p 100. According to Widder, "Eva Coryell envisaged an M.A.C. where men and women would follow courses of study suited to equip them for what society perceived as the role of each gender, but where both sexes read the works of great literary figures, performed some of the same laboratory experiments, and heard the same lectures in history and philosophy" (p 101).
75. A. H. Sanford, *The Story of Agriculture in the United States*, Heath, Boston, 1916, 224-234.
76. J. A. Riis, *How the Other Half Lives: Studies among the Tenements of New York*, Scribner's, New York, 1914.
77. S. Stage, "Ellen Richards and the Social Significance of the Home Economics Movement," in S. Stage and V. B. Vincenti, Eds., *Rethinking Home Economics: Women and the History of a Profession*, Cornell, Ithaca, NY, 1997, 17-33.
78. Richards was not only a founder of the field of Home Economics; she founded its principal scholarly organ, the *Journal of Home Economics*, where one can find the following definition of the field: "Home economics, as a distinctive subject of instruction, includes the economic, sanitary and esthetic aspects of food, clothing and shelter …. Instruction in this subject should be based on scientific principles…." ("Report on College Courses in Home Economics," **1911**, *3*, 25-28).
79. P. A. Treichler, "Isabel Bevier and Home Economics," in L. Hoddeson, Ed., *No Boundaries: University of Illinois Vignettes*, U of Illinois, Urbana, 2004, 31-54.
80. *The University of Illinois: Announcements, 1904-1905; Register, 1903-1904*, Urbana, IL, 1904, 135.
81. Ref. 79, p 32.
82. Ref. 73 (Apple and Coleman), pp 3, 6-11.
83. Ref. 79, p 37.
84. "Directory of the Alumni of the Department of Chemistry," Alumni and Faculty of the Department of Chemistry of the University of Illinois, Series 15/5/801/3, University of Illinois Archives.
85. "The chief reason why Iowa State College needs additional support," *Iowa State Student*, March 27, 1915, p 6, Record Series 7/2/0/0, Office of Admissions, Newsclippings, Box 1, Iowa State Archives.
86. Ref. 73 (Apple and Coleman), p. 6.
87. Ref. 71 (Tolley), pp 35-74.
88. Over the period 1867-1913, KSAC graduated 929 women out of a total of 2,402 degree earners. Sixty-three of these alumnae went into teaching at the college level, 53 of them in domestic science. Another 320 taught at the high school level or below, 149 in domestic science. Of the remainder, six became nurses and six physicians: [H. J. Waters], *Record of the Alumni of the Kansas State Agricultural College, 1867-1913*, KSAC, Manhattan, 1914, 271. When it came to placing alumnae in college level teaching positions in traditional scientific fields, the LGIs were clearly outshone by the Eastern women's colleges: M. W. Rossiter, *Women Scientists in America, Vol. 1: Struggles and Strategies to 1940*, Johns Hopkins, Baltimore, 1982, 168-175.
89. Ref. 63, pp 48-54. The classes and laboratories associated with home economics were, by contrast, spaces of strict gender separation.
90. S. Stage, "Home Economics: What's in a Name?" in Ref. 77, 1-14; L. K. Nyhart, "Home Economies in the Hospital, 1900-1930," in Ref. 77, 125-144; K. R. Babbitt, "Legitimizing Nutrition Education: The Impact of the Great Depression," in Ref. 77, 145-162.
91. M. W. Rossiter, "Which Science? Which Women?" *Osiris*, **1997**, *12*, 169-185.

About the Author

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CHEMISTRY UNDER THE MORRILL ACT: AGENCY THROUGH SERVICE (1)

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In 1930, Arthur Klein, Chief of the US Office of Education's Collegiate and Professional division, surveyed and ranked American land grant colleges and universities. The agency employed a simple metric to measure the quality of the various schools. Chemistry was that analytic tool, especially the quality of a university's faculty and library holdings in that area. The reasons were clear. "Chemistry is a fundamental science upon which agriculture and engineering are based," the report noted. "Chemistry should be one of the strongest departments in land-grant institutions" (2).

That was quite a profound change from the Morrill Act's intent. The law made no provision for anything chemical, much less chemistry departments. Yet chemistry departments would emerge as a critical discriminant in evaluating these schools. That transformation was neither inevitable nor abrupt. To a large degree, it originated with the chemists themselves. They achieved this central position through service, especially service to agriculture.

The Morrill Land Grant College Act was one of four seminal acts passed in 1862 to help fulfill the promise of American democracy. The other three acts—the Homestead Act, the Act to create the USDA and the Act to establish a transcontinental railroad system—provided in the parlance of the time the infrastructure to pursue success. This infrastructure broadened opportunity to participate in the fruits of American society. The Morrill Act was no different. It aimed to open education beyond the well to do—to the sons and daughters of farmers and mechanics—and facilitate entrée into whatever fields they chose to pursue (3).

The new colleges were given an extensive yet concrete mission: "to promote the liberal and practical education of the industrial classes in the several pursuits and professions of life." But Congress had added a kicker. They were to do so "in such a manner as the state legislatures may respectively prescribe" (4).

That last statement was critical. Leaving it up to the states to decide how to reach that objective meant that these institutions would be exquisitely sensitive to political machinations and varied interpretations of how to achieve the law's goals. A few in the northeast immediately wanted the nascent colleges to be specifically industrial: "to advance and disseminate scientific knowledge for the aim of agricultural and industrial development." These "National Schools of Science" would provide "instruction and researches in the mathematical, physical, and natural sciences, with reference to the promotion and diffusion of science" (5).

That model, with its desire to establish a scientific elite to join the traditional elites of clerics, lawyers and doctors, never went anywhere. Slightly more successful was to have these schools mimic longstanding private colleges. These older schools had served the children of the elite as the path into medicine, law, the clergy or business. They provided classical studies—Greek and Latin languages, literature, morals, oratory and ethics—to train and discipline the mind. This approach was about creating mental discipline, not providing specialized knowledge. Replicating that course of instruction in the new schools would enable the new constituency to acquire the same talents as the children of the privileged and so enter those restricted professions (6).

A far more common way, and the form that almost all the land-grant colleges initially took—was to graft some new subjects on what had been the traditional curriculum. Most early land-grant schools supplemented classical studies with a course or courses—not a course of study—in the mechanic arts, in science, and in French and in German, the modern languages. Here the goal was to provide a broad based education appropriate for virtually any endeavor—for the several pursuits and professions of life. As Jonathan Turner, an influential partisan of what would become the University of Illinois, said about these new colleges "the student will not only read the lofty verse of Vergil's [*sic*] 'Georgics,' but will reduce his rules to practice while following the 'trailing-footed' oxen spoken of by Homer. The Differential and Integral Calculus will commingle with the ring of the anvil and the whir of the machine shop. The mechanic's toil will be diversified by the Histories of Tacitus or the eloquence of Cicero and Demosthenes" (7).

In practice, a mere one or two professors handled a wide variety of subjects. For example, Eugene Hilgard, a pioneering soil chemist, taught the following courses during the same year: descriptive botany, economic botany, agricultural operations and implements, chemistry of plants and their products, chemistry and physics of soils, including maintenance of fertility, and chemistry and physics of housekeeping. At the Florida land grant, the sole chemist did not teach anything chemical per se. He taught agriculture, horticulture and Greek (8).

That educational vision did not long dominate. By the 1870s, complaints began to be heard about the new Morrill land-grant colleges. Farmers were the most vociferous complainers. In retrospect, that was not surprising. America was predominantly rural and agricultural. About 80% of the population in 1860 lived in places with populations under 2,000. The vast majority of state legislators were farmers. Farming was seasonal. Legislatures met in the winter when farm duties were few (9).

As the biggest single constituency and the most numerous and most influential contingent in state legislatures, farmers had tremendous political clout and the ken to use it. They often saw land grant curricula as a repudiation of farm life. Training farm children "in the several pursuits and professions of life" contributed to what they recognized as an epidemic of children fleeing farms and moving to cities. It also brought into question the quality of farm living. Education should enhance farming and farm life by enabling the head to guide the hands. The new land-grant education ought to encourage children to remain on farms by making agriculture an intellectual activity. They should lessen the physical burden of farming and increase farm efficiency and profitability (10).

Introduction of a new cadre of technicians, chemists, had accompanied the earliest years of the land grant movement, before the Morrill Act's passage. Their leading lights championed the new German laboratory approach and the assumption that agricultural and life processes could be reduced through laboratory analysis to chemical constituents. Selling their services directly to farmers as soil analysts constituted the chemists' initial venture.

Ideally, the chemists would test the soil and determine what nutrients it lacked for proper crop growth. That proved disastrous, however. Recommendations based on their analysis rarely correlated to optimum growth. In some cases, applying the chemists' concoctions transformed fertile into barren soil (11). With that kind of record, the chemist as soil analyst boom quickly burned out. These now discredited chemists were not without resources. Several claimed that their analytical skills could be put to use analyzing fertilizers. They could indicate if a fertilizer manufacturer sold a product at a price consistent with its nutritional elements. These analyses were quite telling. Analysis after analysis suggested that manufacturers routinely offered products far more costly than their constituents merited. Chemists dramatized these results, which found their way into the many agricultural periodicals, and proclaimed that the nation was awash in an epidemic of fertilizer frauds (12).

The chemists' scathing indictments led rural dominated state legislatures in state after state to create the office of state chemist. Manufacturers were required to submit to these state chemists every fertilizer sold in a state. The chemists then analyzed the materials and placed on each bag a tag detailing their analyses. Armed with this information, farmers then chose fertilizers by rational means, where the tag and price most nearly matched.

Institutionalized in an official capacity, these chemists usually found corresponding employment as professors at the new land-grant colleges. There they accepted a diverse teaching load similar to what Hilgard had taught in Mississippi and California. Their land-grant affiliations initially had little to do with teaching; the chemists' analytical skills secured their posts. In North Carolina, for instance, the state chemist office was created to prevent fertilizer frauds but quickly the legislature added additional tasks: ascertain which fertilizers were "best suited to the various crops of the state, what crops were most advantageous to the soil of the state," and to make analyses for the courts of law, for the geological survey and the superintendent of health, including analyzing "viscera and fluids of the body," tasks required during necropsies (13).

This broad agenda was soon joined by other attempts to demonstrate utility to farmers. State chemists aimed to develop means to increase farm yields and reduce costs. Again in North Carolina, Charles William Dabney, the Göttingen-trained state chemist and later president of the University of Tennessee, went to agricultural society meetings, attended college-sponsored farmers institutes and published bulletins to teach farmers how to mix stable manure with other waste products for a rich nitrogenous fertilizer, to press the otherwise discarded cottonseeds to create an oil to enrich cow feed or to replace olive oil in salad dressing, to burn those seed hulls for potash, and to detect and mine natural phosphate deposits in exposed marl sites (14).

Each activity was to demonstrate the chemists' centrality to farm operations and the land-grant colleges' responsiveness to its politically most powerful constituency. Only one thing hampered this ambitious program, however. Chemists could not provide the services that they claimed the expertise to offer. This proved especially egregious when it came to fertilizers, the very task state chemists' offices were formed to pursue. Analyses run by various state chemists on the same fertilizer samples repeatedly differed in analysis by factors of 10 or more!

The remarkably disparate, inconsistent analyses caused fertilizer manufacturers to howl and their own European-trained chemists vehemently to dispute the state chemists' analyses. Much to the state chemists' credit, they understood the cause of the problem. They were incapable of providing service because they lacked the requisite skill and technique.

In the years after 1880, state chemists took dramatic action. They acquired the expertise required for the jobs they already held. They met, formed a national association in 1884 and then diligently agreed to establish rigorous, consistent analytical standards. The state chemist group standardized what was analyzed—for example, whether calcium, aluminum and iron phosphates were water soluble and should be considered available phosphates. They standardized reagents and nomenclature. They standardized laboratory techniques. They standardized members' training and minimum competencies. In short, they made themselves capable of achieving the analyses necessary for their posts. State chemists' analyses would be consistent, dependable, reproducible.

This new state chemist group was called the Association of Official Agricultural Chemists. (We know it today as the Association of Official Analytical Chemists and it mandates the government-sanctioned methods of analysis for virtually everything we eat, drink or breathe.) Its formation greatly enhanced state chemistry and provided its members stability at land-grant colleges. It also mollified fertilizer manufacturers. Consistent regulatory analyses enabled manufacturers to compound materials that would pass official muster and so regularized the fertilizer industry. The state chemists' standardization efforts also created a vibrant market for chemists. Before 1890, many of the students who had studied with land grant/state chemists found lucrative employment with fertilizer manufacturers, easily the largest industrial employer of chemists nationwide (15).

The chemists' regulatory success so delighted their farm constituents that it was not surprising that when Congress passed the Hatch Agricultural Experiment Station Act in 1887 chemistry benefited greatly. The Hatch Act created and funded institutions for agricultural experimentation and investigation in each state. Virtually all of these entities were placed at land-grant schools both fortifying the relationship of these schools to agriculture and the chemists' position within them. Now firmly entrenched, chemists had gained more than a modicum of agency through their service (16).

The Hatch Act's encouragement of research in support of agriculture ensured that the well-established pattern of agency through service would persist. In chemistry, dairies became the next point of public intersection. In state after state, dairymen complained that creameries were not offering fair value for their milk. Rather than pay for quality, which was measured by butterfat content, they paid for quantity; unscrupulous entrepreneurs added water to their milk to increase its volume and thus adulterated the milk to get a greater price. Land-grant college chemists in most dairy states turned their attention to rectifying this distressing situation. They labored to develop a simple dairy- and creamery-administered butterfat test. Several were developed. The University of Wisconsin's Steven M. Babcock's test proved the most convenient and therefore successful. It was said to do more to make men honest than the bible (17).

Academic administrators recognized the chemists' importance to the preservation and furtherance of their institutions. For years after he announced his useful technique, Babcock accompanied the University of Wisconsin's president whenever the president addressed or lobbied the state assembly. In this case, the chemist served as testament to the land-grant university's agricultural importance and the importance of the college to the public weal (18).

The many regulatory or analytical activities that land-grant college chemists did in service to agriculture—their regulatory orientation—made chemists indispensible to the land-grant enterprise. Recognition of their centrality by university administrators and state legislatures ironically provided them something they had initially lacked, a measure of autonomy. Chemists used the new freedom to embrace original, fundamental research. That research quickly paid off for their academic and political constituents and for American society generally. Land-grant chemists uncovered the essential amino acids, most of the vitamins, and general principles of nutrition. Their scrutiny of humus transformed soil bacteriology—a set series of chemical reactions—into soil microbiology—the chemical reactions of any given soil population. Forays into pharmaceuticals happened a bit later; land-grant and other chemists were hamstrung by the broad range of longstanding German chemical patents, which were only abrogated during and after World War I. Despite that obstacle, they contributed mightily to antibiosis theory and antibiotic synthesis (19).

Imitation was the sincerest form of flattery and the chemists' agricultural success became a roadmap for another emergent group, the industrial chemists. Industrial chemists, later known as chemical engineers, were generally located within land grant chemistry departments through 1920. Many of these industrial chemists in the Midwest and South recognized the power of the agricultural lobby and fit comfortably among their colleges' prevailing farmer-centric ethos. It was not uncommon for them to work with agricultural wastes to create new farm income-raising industries. Orland R. Sweeney at Ohio State and then North Dakota State was symptomatic of these Midwesterners. He destructively distilled corncobs by grinding and drying them and then heating them in a retort. He collected the gases as fractions and sold these harvested organic chemicals to make plastics and adhesives. Sweeney also developed a soybean oil paint and established a process for making disposable baby diapers composed of peat (20).

Most land-grant chemistry departments remained closely affixed to agriculture through the 1920s. In the northeastern part of the United States, the situation was a bit different. Although it remained until 1920 for Americans living in places of over 2,500 to outnumber those in smaller venues, great manufacturing cities had begun to emerge in the 1870s and were increasingly gaining political clout. Legislatures, still rural-controlled, began to recognize and understand the new economic calculus. So too did northeastern land-grants and their industrial chemists. Rather than concentrate of agricultural- and farm-related questions, these chemists examined chemistry-based industrial processes. Many designed entire facilities around a single product. MIT's Arthur D. Little offered a compelling alternative. He created the concept of unit operations in 1916, which deconstructed industrial processes into component parts. These parts, then, could be assembled as was necessary. Each varied industrial manufacture was constructed from these stock standard parts, which speeded production capacity, increased flexibility and reduced waste (21).

This was the state of land-grant chemistry in 1920. There was every reason for the Office of Education a decade later to single out chemistry departments to measure land-grant quality. Chemists had been very savvy. From a relatively minor position, they capitalized upon the fundamental political nature of land-grant universities. Always service institutions, whether to promote democracy, the working classes, agricultural life or industry, the land-grants ultimately delivered to their most influential political backers. A curious kind of symbiosis marked the early chemist-land grant relationship. Land grants owed a large measure of their success to chemists and chemists would owe considerable success to their affiliation with land-grants. Chemists and land-grant colleges and universities secured positions for themselves by being useful, by successfully undertaking those tasks for which there was substantial political support—even if they had to create that support through their endeavors. Only then could they add additional functions and, in the case of chemists, expand their professional repertoire. In almost every case, however, the new tasks needed to help advance the institution's already extant service mission.

References and Notes

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1930, No. 9, GPO, Washington, DC, 1930, 656-658.

3. This is an argument I have been working on for a quarter century. Historians tend to study each of these seminal acts separately, as if they occurred in a vacuum. See A. I Marcus, "The Wisdom of the Body Politic: The Changing Nature of Publicly Sponsored American Agricultural Research since the 1830s," *Agric. Hist.,* **1988**, *62*, 4-26, especially 12-14. Discussion of the land-grants as democracy's colleges is far more common. Best is E. D. Ross, *Democracy's College: The Land-Grant Movement in Its Formative State*, Iowa State College Press, Ames, 1942. Useful is G. N. Rainsford, *Congress and Higher Education in the Nineteenth Century,* University of Tennessee Press, Knoxville, 1972.
4. *Statutes at Large of the USA*, 12 (1863), 503-505.
5. N. M. Sorber. "Agriculturalists, Scientists, and Officers of Industry: The Origins of the New England Land-Grant Colleges," presented at The Legacy and the Promise: 150 Years of Land-Grant Colleges Symposium, University Park, PA, June 2011.
6. A. I Marcus, "If All the World Were Mechanics and Farmers: Democracy and the Formative Years of Land-grant College in America," *Ohio Valley Hist.,* **2005**, *5*, 23-36. For the case of Pennsylvania, see R. L. Williams, *The Origins of Federal Support for Higher Education: George W. Atherton and the Land-Grant College Movement*, Pennsylvania State University Press, University Park, 1991, 1-54.
7. Ref. 6 (Marcus). For the quotation, see Ref. 3 (Ross), pp 25-26.
8. H. Jenny, *E. W. Hilgard and the Birth of Modern Soil Science*, Industrie Grafiche V. Lischi & Figli, Pisa, 1961, 83; E. H. Beardsley, "The Rise of the American Chemistry Profession, 1850-1900," *University of Florida Monographs, Social Sciences*, **1964**, *23*, 44-45.
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10. A. I Marcus, *Agricultural Science and the Quest for Legitimacy: Farmers, Agricultural Colleges, and Experiment Stations, 1870-1890,* Iowa State University Press, Ames, 1986, 7-26.
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CHEMURGY AND THE LAND GRANT COLLEGES: BRIDGING AGRICULTURE, INDUSTRY AND CHEMISTRY IN THE 1930S AND BEYOND (1)

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Since the Morrill Act was passed one hundred and fifty years ago, one of the creeds of the land grant universities has been the promise to deliver on an adage that first appeared in *Gulliver's Travels* in 1724, to "make two ears of corn, or two blades of grass, to grow upon a spot of ground where only one grew before" (2). By the 1930s, this goal had been achieved, as the yields for many crops had indeed more than doubled over the previous 75 years; by most measures, the application of science and technology to American agriculture had proven triumphant. But these production successes brought unintended consequences for American farmers, as continuous surpluses caused lower prices and an agricultural depression that began almost a decade before the Wall Street crash of 1929. Meanwhile, the rapid growth of the American chemical industry seemed to promise yet another jump in farm productivity, but also additional potential problems for rural America. Thanks to the apparent triumphs of American chemistry, optimists boasted that vast quantities of useful products could now be produced where *none* had grown before: indoors, in chemists' laboratories and in massive factories that produced rayon, synthetic rubber, and other items that had little connection to the soil (3). Thus two threads came together in the 1930s: the crisis on the farm, and the emerging power of American chemistry.

Important debates about these trends and their implications took place on the campuses of the nation's land grant colleges and universities. Land grant university presidents and agricultural college deans found themselves as negotiators in these deliberations, forced to balance the competing claims and interests of applied chemists, farmers, government officials, and their own university constituencies. By the late 1920s, agricultural economists on both sides of the issue lobbied land grant university leaders for support for one of two opposing positions: pull farmers off of marginal lands, reduce production, and contract the size of the farm population, or expand production, with the aim of keeping farmers prosperous through the conquest of new and untapped markets. That the land grant schools were in such a position is not such a surprise, for debates about the role of chemistry at the agricultural colleges has had a long and complicated history. Since their founding in 1862, the land grant institutions had been tasked with building the bridge between farming and the mechanic arts through practical and democratic forms of postsecondary education. But the foundation of that bridge often stood on shaky ground. Agricultural scientists had fought for their own research facilities, agricultural experiment stations, and funding, which made them relatively independent of farmers' wishes and demands for specific kinds of applied research. Major discoveries in soil chemistry, bacteriology, nutrition and other disciplines emerged, but their benefits to practicing farmers were not always so apparent. These scientific successes notwithstanding, there could be little doubt by the 1920s that agricultural prosperity was in decline. The farm depression also brought enrollment drops, reductions in state funding, and other crises for the deans and presidents of the land grant institutions (4).

Meanwhile, the American chemical industry rose along a somewhat divergent track. For good and ill, World War I has been dubbed "The Chemists' War," as four years of naval blockades and trench warfare demonstrated that artificial fertilizers, the base chemicals for explosives, and poison gases all were crucial factors on the modern battlefield. Chemistry was also a decisive issue in the postwar peace, as Article 297 of the Treaty of Versailles guaranteed the signatories' "free use of German patents" (5). Although the United States did not ratify that treaty, it nevertheless organized the seizure of about 4500 German patents and chemical know-how through the Chemical Foundation, a vast quasi-public organization formed in 1919. For nearly two decades, the Chemical Foundation distributed patents and other privileges to many emerging American chemical corporations. These developments also brought new clout and publicity to the American Chemical Society (ACS). The Chemical Foundation's longtime head, Francis Garvan, provided the ACS with an endowment of $20 million, launched the *Journal of Chemical Education*, and sponsored essay contests in which over two million school children wrote on the importance of chemistry in the modern world (6). Chemists also lobbied for tariff legislation that helped protect to the nascent dye, explosives, and other industries. Such moves had geopolitical importance, as other nations responded with their own efforts to develop and protect the chemical sector of their economies. Many authors seized upon these political implications, warning that the United States risked falling behind the nations like Fascist Italy and Nazi Germany that were blatantly committed to autarky, or self-sufficiency, through applied chemistry (7).

The chemists' newfound power and prestige also brought them into closer engagement with agricultural issues. In 1921, for instance, former ACS President Charles Holmes Herty urged his colleagues to get "into the farm problem" as an adjunct to their systematic promotion of organic chemistry (8). In 1926, the Chemical Foundation published *Chemistry in Agriculture*, a celebration of the "hives of activity" on the agricultural college campuses and experiment stations that were helping solve "one of the greatest problems of all time"—feeding the human race (9). Then in October of that year, William Hale, Director of Research at Dow Chemical Company, published "Farming Must Become a Chemical Industry" in Henry Ford's newspaper, *The Dearborn Independent*, which boldly called for new "agricenters" in rural America, massive chemical factories that bore little resemblance to the traditional farm. The Chemical Foundation appreciated this proposal and sponsored a press run of 500,000 article reprints. That same month, Wheeler McMillen, editor of the journal *Farm and Fireside*, published an editorial that took a slightly different tack, stressing the non-food uses of existing farm products as a promising solution to farm problems. Hale, McMillen and Herty soon met one another in Washington, where they agreed to further publicize their program of using renewable resources as the basis for both industrial growth and farm relief (10). Some of this research, often funded directly by the Chemical Foundation, had impacts at the land grant universities. Orland R. Sweeney and his colleagues at Iowa State College, for instance, found that cobs, corn stalks, sugar beet pulp, sugar bagasse, and similar farm wastes could yield chemicals useful in the production of plastics, paper products, dyes, feeds, films, and fuels (11). On the whole, many agreed with the notion that applied chemistry could be part of the answer to the agricultural depression.

Federal policy went in another direction during the early years of the New Deal, however. Through the Agricultural Adjustment Administration (AAA), Secretary of Agriculture Henry A. Wallace launched production control policies designed to artificially reduce the supply of crops and livestock as a way to raise farm prices. Research funds dedicated to the industrial utilization of farm products languished. In contrast to the protectionist leanings of the young American chemical industry, New Dealers were eager to reduce tariffs and expand international trade. Washington officials' interest in social programs and investments in rural America also diverged from the industrialists' priorities. For the most part, New Deal programs were popular among farmers, and also with land grant institutions, which had benefited from student aid programs that staunched the bleeding of declining enrollments and through the hundreds of public works projects that funded new buildings on the campuses, which countered the collapse of state-level appropriations (12).

Thus the New Dealers and many chemists stood on the opposite side of the political divide. These conflicting visions came into clear relief in May 1935, when—after some planning meetings held at the ACS meeting (13)—Dow Chemical's William Hale and other industry leaders came to Dearborn, Michigan, to found what came to be known as the chemurgy movement. As explained in his 1934 book, *The Farm Chemurgic*, Hale had coined the word chemurgy (from the root words for chemistry (*chemi*) and work (*ergon*)), to describe the large-scale industrial utilization of agricultural products (14). As suggested by one of their oft-repeated statements—"the human stomach is inelastic, but the human demand for the products of manufacture is never satisfied," chemurgists believed that the growing of farm products to serve industry—in massive quantities, at ever lower prices—should replace the growing of edible crops as American agriculture's primary objective. Chemurgy's enthusiasts promised full employment, national economic independence, and new scientific solutions to the farm crisis. Their program was bold and wide ranging, rooted especially in the promise of power alcohol (i.e., biofuels derived from grain surpluses) and other applications of farm products (15).

The Dearborn meeting prompted widespread public discussion of the chemurgists' and New Dealers' approach to the farm crisis, as well as a heated and fundamental debate about the proper place of chemistry in the academic research conducted at public universities. As one dean of engineering reported immediately after the Dearborn meeting, he may "wish it were true," that fuel from plants would be cheaper than gasoline, but that he "cannot make it so." Pointing to the politically charged rhetoric of the chemurgists' program, C. C. Williams of the University of Iowa stressed that chemical research has "no favorites, it works for everyone impartially;" sometimes it may help agriculture, sometimes it may hurt it, but academics needed to follow the facts of nature; not what "we might wish them to be" (16). Other scholars promptly objected to the chemurgists' call for an overhaul of the rural economy. Within days of the Dearborn meeting, Iowa State's chemical engineer Orland Sweeney dismissed out of hand the chemurgists' promise that power alcohol would make the nation free from imported petroleum. Scientists' first priority, Sweeney insisted, must be the utilization of existing agricultural surpluses. Above all, he wanted a program that realistically considered the farmer's need to make a decent living, not industrialists' interest in cheap raw materials (17). Meanwhile, another circumstance also brought new attention to the land grant colleges: Congress passed the Bankhead-Jones Act in June 1935, which called for expanded investment in agricultural research at the land grant schools, particularly research on new agricultural crops that might be adapted to industrial utilization (18).

It is significant, then, that leaders of the new Farm Chemurgic Council (FCC) understood that winning the support of agricultural school deans, experiment station directors, and chemical engineering professors would be essential for the promotion of their agenda. In the words of Harry E. Barnard, the FCC's Director of Research, regardless of Sweeney's antipathy toward power alcohol, "it is only though men such as [him] that we will get at the real facts" (19). As a result, within weeks of the Dearborn meeting, chemurgy's supporters approached the land grant institutions to spread their message. In July, FCC Vice President Wheeler McMillen wrote to the deans of each of the nation's forty-eight agricultural colleges with an offer of a fellowship program for research on chemurgic topics. Like Barnard, McMillen also toured several of these campuses. At the University of Georgia, for example, he explained that it was "tremendously important that we insist," that the land grant colleges and experiment stations work on agricultural research projects that served industrial markets (20).

Even more significant, the FCC's Managing Director Carl Fritsche also sought the cooperation of the land grant schools, signs that he regarded them as influential and essential to his mission. Fritsche's highest priority and first stop was to see the University of Kentucky president, Frank L. McVey. McVey was also the sitting president of the National Association of Land Grant Colleges and Universities (NALGCU), and committed to raising the stature of the land grant schools and their access to research dollars. Fritsche dined at McVey's home, explained the FCC's program and agenda, and appointed McVey to the FCC's Education Committee. He also secured his two specific objectives: he won McVey's support for the FCC's research fellowship program and the promise that chemurgists would have a place on the agenda at the next NALGCU convention in November (21).

Fritsche then embarked on a tour of more land grant campuses across the Midwest and Rocky Mountain states. At each place, he preached the gospel of chemurgy and sought the "ammunition which can be acquired only by personal contact" (22). In many cases, his message found a ready audience. Few deans could turn down the offer of fellowship funds for student research, and many were desperate for any program that could offer some relief from the long farm crisis. Some also agreed with the chemurgists' ideology. For instance, Christian Larsen, the Danish-born dean of agriculture at South Dakota State College, was convinced that the next war would be fought over access to food and other resources. In fact, he had already been in regular contact with Italian officials who shared his commitment to "national economic independence" (23). Dean E. P. Sandsten at the University of Colorado, another native of Scandinavia, agreed with the chemurgists' call for autarkic policies and fears of geopolitical conflict over agricultural resources (24). Some Mormon leaders in Utah concluded that the chemurgic message was in tune with their denomination's values of independence, perseverance, and self-sufficiency. Moreover, chemurgy offered potential practical benefits, because many Mormon leaders owned beet sugar mills that were idle much of the year, and thus were attracted to the chemurgists' enthusiasm for power alcohol (25). Dean H. L. Walster of the North Dakota Agricultural College was also receptive, suggesting that his state needed chemurgic ideas more than any other. North Dakotans, Walster explained, were very interested in new crops like safflower and also sought new ways to utilize existing crops like flax and durum wheat (26).

But Fritsche also found that several land grant college deans were skeptical of the chemurgists' program. In Wisconsin, for instance, agricultural college officials expressed "absolutely no" interest in power alcohol message, arguing that biofuels were a boondoggle that put corporate interests ahead of those of farmers. Indeed, at least one University of Wisconsin dean proposed tax policies that would discourage the production of grains for non-food uses. In Minnesota, Fritsche found that supporters of power alcohol had been silenced by the university president (27). In Montana, Fritsche met with F. B. Linfield, Dean of the Agricultural College, who embraced the widely held notion that rapid, excessive, and inhumane adoption of new technologies lay at the root of the depression's unemployment crisis. Linfield had no interest in what the chemists had to offer, and instead blamed the "wealthy few" for bringing new hardships to the American farmer (28).

Meanwhile, it is clear that the Secretary Wallace and his allies also saw land grant colleges as essential for the dissemination of their message. In the fall of 1935, USDA officials hosted meetings on the campuses of Utah State College, Iowa State College, the University of Connecticut and the University of Georgia to present new developments in New Deal farm policy. When his tour took him to Logan, Utah, Fritsche snuck into one of these meeting uninvited. Fritsche later said his "blood boiled" as he heard the presentation; the New Dealers, he reported, were attempting a "fascist political campaign" to inculcate land grant college officials with an anti-industrial message. The USDA, he continued was bringing an "almost religious flavor" in support of the expansion of Washington's power, all part of a slide toward "Russian collectivism" (29). In short, the land grant college campuses were on the front line of battles over chemists' proper role in agriculture.

Similar discussions took place in the mainstream of American society as well. In an article entitled "Chemistry Wrecks the Farm" that appeared in *Harper's Magazine* in August 1935 (and soon was reprinted in the even more widely read *Reader's Digest*), authors Wayne Parrish and Harold Clark touted chemistry's "invasion into agriculture" as a triumph. The authors embraced what might be called the "synthetic narrative," or the assumption that synthetic substitutes for the natural ensured consumers access to products uniform in quality, unaffected by seasonal trends in availability, and less dependent upon a skilled labor force. Parrish and Clark further explained that thanks to chemical triumphs like the Haber-Bosch process of producing synthetic ammonia, soil fertility soon would be ensured and four-fifths of American farmers could be eliminated. The authors also suggested that with synthetic substitutes for scarce imported commodities, the United States could free itself from foreign trade and achieve national self-sufficiency through farming. Particularly because of its successes in generating domestic agricultural sources of raw materials, the authors asserted, chemistry "has practically doomed large foreign trade" (30).

In this context, the 1935 meeting of the NALGCU proved an important locale for discussions of the place of chemistry and chemurgy on the college campus. In his presidential address, Kentucky's Frank McVey did not mention the FCC directly, but he did speak of the vital role land grant colleges played in the modern world and hinted that he opposed outsiders trying to shape their research agendas (31). Meanwhile, Chemical Foundation head Francis Garvan arranged a private meeting with McVey, in another attempt to sway the land grant college leader and convince his association to create a committee to study the chemurgic project. This effort seems to have failed. According to his diary entry, McVey dismissed these efforts as "nationalistic propaganda," for he did not accept Garvan's proposition that "national isolation was the only policy to follow" (32).

The next day, the director of Iowa State's agricultural experiment station, Robert E. Buchanan, took the stage to deliver a bold rebuttal to the *Harper's* magazine article and the chemurgic message in general. In a talk entitled "Chemistry: Friend or Foe?" Buchanan directly attacked the Chemical Foundation as the "mouthpiece of organized industrial chemistry," and that it had the potential of "developing into one of agriculture's greatest enemies" (33). "One is indeed astonished and perturbed," Buchanan charged, "when one reads of some of the economic reasoning sponsored by the Chemical Foundation … and occasionally even those of the editors of some journals of the American Chemical Society." Buchanan then dismissed the "synthetic narrative" point by point: 1) the chemurgists' focus on an autarkic, self-contained economy flew in the face of widespread evidence of the necessity of international trade; 2) natural products like sugar, wool or others natural products were synthesized "many million times" more efficiently than the tedious labors that went into making synthetic substitutes in the laboratory; and 3) farmers were the true producers of useful products, and for just pennies a pound. Buchanan conceded that chemistry might help the farmer in some ways, but he pleaded for his land grant college colleagues to "call the chemist our friend, but agree to keep an eye on him" (33).

The next day, the FCC's Wheeler McMillen delivered a speech at the NALGCU convention that attempted to salvage the chemurgic program. Indeed, although he baldly asserted that the FCC had "no concern with political questions," his talk had an agenda of its own. In an attempt to distance himself from Garvan and the Chemical Foundation, McMillen denied the charge that chemurgy would only serve the interests of the American chemical industry. As McMillen put it, he wanted land grant colleges, experiment stations, and extension agents—not those from "non-agricultural groups"—to lead the chemurgists' search for "new markets capable of unlimited expansion, unrestricted by the capacity of the human stomach and immune to the costly vagaries of foreign commerce" (34).

Both speeches generated plenty of attention, and the tensions surrounding them made it difficult for land grant college officials to know how to proceed (35). Dean Edward Johnson of Washington State College, for instance, said he would be happy to accept funds for chemurgical research if it supported his school's research priorities and the famers' interests. He was "not at all interested," however, to simply follow new research threads because of the media "ballyhoo" that the chemurgists had generated (36). Johnson was also under pressure to host a meeting on chemurgic issues for the northwestern states, but he was quite leery of having any connections with the FCC. In March 1936, then, Johnson wrote to colleagues at land grant colleges around the nation asking for their "frank" assessment of the movement. A few admitted that industrialization of farm products could be a useful thing; others warned Johnson to keep his distance. But tellingly none of these replies were enthusiastic, some asked not to be quoted, and one—the agricultural dean at McVey's University of Kentucky—asked to discuss the matter only by telephone (37).

Nevertheless, by May 1936, when the chemurgists held their second national meeting in Dearborn, it was apparent that several scientists at the land grants had been active in research on the industrial applications of agricultural products. ACS president and University of Illinois chemist Roger Adams served on the chemurgic council's Governing Board. Scholars from Iowa State, Nebraska and Illinois helped lead research on the Jerusalem artichoke as a potential source of power alcohol or levulose sugars. Researchers from Purdue and Illinois led work on soybeans, and those from universities in Florida and Texas served on committees for tung oil, a promising paint and varnish ingredient. By 1936, the FCC's research and education committees included scholars from land grant colleges in Idaho, Nebraska, Kansas, Pennsylvania, New Jersey, Ohio, Kentucky, Georgia and California (38).

Political pressures also helped to reduce tensions between the land grant colleges and the chemurgic movement. As chemurgy threatened to become an issue in the 1936 presidential campaign, Agricultural Secretary Wallace sent a somewhat conciliatory letter to Chemical Foundation head Garvan, promising healthy cooperation with the chemurgic movement (39). Thanks especially to the Bankhead-Jones funds, Wallace could point to several examples of the chemurgic research already underway within the USDA and on the land grant college campuses. Yet Wallace also questioned the fundamental goals of chemical research: "By the very nature of his work," Wallace explained, "the chemist cannot help destroying as well as creating farm markets." Just as synthetic dyes decimated production of indigo and similar crops, and the automobile put horse breeders and oat farmers out of business, chemistry would have similar impacts in the future. Thus while Wallace promised support for the chemurgists' agenda of linking science, agriculture, and industry, he predicted that advances in chemistry offered no real solution to the Depression in rural America (40).

Yet compromise was coming. Under continuing political pressures, the USDA threw its support behind a bill that would create new research laboratories devoted to the industrial utilization of crop surpluses (41). The idea for the government's own laboratories dedicated to chemurgic projects emerged from Mississippi Senator Theodore Bilbo, who in 1935 led the call for a new federally-funded laboratory devoted to the utilization of cotton surpluses. Hearing warnings that the United States had fallen behind Japan, Italy and Germany in the utilization of chemical expertise, this idea became widely accepted by 1937. According to one proposal, Congress might create as many as forty new crop utilization laboratories across the country, most to be located near the campuses of the land grant colleges. Eventually, Congress appropriated funds for four Regional Research Laboratories (RRLs), each one a million dollar research facility with an annual research budget of a million dollars per year thereafter. Each was dedicated to finding new ways to utilize the crop surpluses of four regions in the United States (42).

The prospect of millions in federal funds set off a frenzy among chambers of commerce and university presidents' offices across the nation. Nearly one hundred and fifty cities submitted bids for the RRLs, with many in land grant college towns among the most eager to stake their claim. Alabama's boosters, for instance, claimed that Auburn was the "best agricultural school in the world," and Tuskegee the "greatest negro school in the world," part of an extensive lobbying campaign that inundated USDA offices with pleas on Auburn's behalf (43). Similar campaigns came from Ames, Iowa, Athens, Georgia, and Urbana, Illinois, just to name a few (44). In the end, however, USDA officials decided explicitly to make these facilities "entirely independent of … the Land Grant Colleges" and to locate them in Philadelphia, New Orleans, Peoria, and Albany, California. The latter site was approved only after President Roosevelt himself concluded that this East Bay city was far enough away from the influence of the Berkeley campus (45). This attitude might seem surprising, but a confidential memorandum sent to Agricultural Secretary Wallace reveals one of the real reasons: a study of voting results in the 1938 Congressional elections proved that precincts closest to the land grant college campuses voted largely for Republican candidates. The Roosevelt administration decided to not "feed the hand that bites it" (46).

The government's creation of the RRLs signaled that the battles were coming to an end by the late 1930s. Both chemurgists and New Dealers had to abandon their focus on farm surpluses as world demand for American farm products returned. In all, as World War II approached, Americans' enthusiasm for bio-based raw materials was on the wane. The most controversial political aspects of the chemurgy movement also changed, and some of its most strident members had died or otherwise left the limelight. Others returned to the land grant campuses: for instance, Leo Christensen, a chemist who had left Iowa State in 1935 and threw his lot with the FCC, launched a new state-funded Chemurgy Project at the University of Nebraska in 1941. During the war, chemurgy was less of an activists' issue, but participants on all sides of the issue could claim they had come together, as research at the RRLs, on the land grant campuses, and in the private sector had contributed to innovative applications of agricultural products in the war effort.

After the war, however, geopolitical battles rarely centered on the products of agriculture, and much of the chemurgists' message began to seem out of touch. Postwar developments, meanwhile, helped to engrave the "synthetic narrative" into American culture, as nylon replaced silk, DDT proved more effective than natural pesticides, and synthetic rubber contributed to the Allies' victory. Few chemurgic products successfully competed with non-renewable feedstocks as the basis for the paint, detergent, industrial alcohol, and other chemical industries. For several decades, American accepted the rhetoric that synthetic products were inexpensive, uniform in quality, and not subject to the fluctuations of agricultural markets (47).

So the chemurgists may have lost some battles in the 1930s, but perhaps they won the war thereafter. Postwar farm policy became guided more by the interests of large corporations and industrial food processors, and less by those of individual and small family farmers; similar shifts took place with the research agenda on college campuses. Just as agricultural policymakers chipped away at New Deal production control policies, land grant university research also embraced a paradigm that made maximizing farm production its highest priority. University presidents also promoted the postwar aims of using the distribution of food surpluses as tools for world peace, even if it meant low prices on the farm. Actual farmers became increasingly distant from the aims of those who funded research in applied chemistry (48).

Generally speaking, research on bio-based materials at the land grant colleges shifted focus from the macro-level search for simple agricultural substitutes to the micro-level search for valuable components within agricultural products. The case of soybeans illustrates this trend. Researchers no longer touted the soybean as simply a component of animal feeds and vegetable oils, but now also as a source of lecithin, glycerin, alkyd resins, proteins, and the like, products that became raw materials for plastics, adhesives, fire retardants, and ingredients in various prepared food products. Further, most land grant schools participated actively in the Green Revolution, helping to export the entire package of American industrial agriculture to many parts of the developing world.

Now there are signs that new definitions of chemurgic concepts—now better labeled as biotechnologies—

may be making a comeback, and perhaps supported by a different political agenda. The "synthetic narrative" has been called into question, for it seems that applied organic chemistry has not always delivered on its promises. Green chemistry, organic farming, and sustainability are new buzzwords in the hunt for research dollars. A recent ACS publication suggests that two areas of research may become increasingly significant: 1) the search for value in the byproducts of food production, and 2) research on plants specifically grown as non-food sources of biomass and raw materials (49). Moreover, many citizens are now embracing a broader view of agricultural research, one that suggests that the goal of rural and dietary improvement can outweigh that of simply increasing farm productivity. Some observers wonder if we may have gone far enough in our search for ever more emulsifiers, binding agents, flavor extracts, and manipulated sugars and proteins from corn and soybeans. Once again, questions about how farm products are to be used, who is to profit from their production, and who decides, are issues at the center of popular and political debates over science policy.

Thus the history of the chemurgy movement offers a useful illustration of the challenges involved in the integration of science, agriculture, and industry on the land grant college campuses. The debates that took place in the 1930s suggest that chemurgy was not a minor movement dominated by a few idiosyncratic personalities in the chemical industry, but something that land grant university presidents and college deans needed to carefully consider. Also, questions over the fate of chemurgy at the land grant institutions addressed fundamental questions regarding the place of chemistry and other sciences at the public universities, and they therefore remain pertinent today. Nowadays, with the land grant schools enrolling nearly five million students and landing nearly two-thirds of the federal research dollars, these institutions are again at the center of the links between agricultural and scientific research (50). In today's political climate, with public funding for higher education hanging from an ever thinner thread, it might be worthwhile to reconsider the original aims of the Morrill Act, to respect the healthy discussions over chemurgy and related issues of the 1930s, and to hope that there may be ways to keep the interests of chemists, farmers, and other constituents in some kind of balance in the future.

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About the Author: *In Memoriam*

"Mark Finlay is a Professor of History at Armstrong Atlantic State University. His publications include articles on Justus von Liebig, on the chemurgy movement, and on other aspects of the history of agricultural science. His 2009 book, *Growing American Rubber: Strategic Plants and the Politics of National Security* won the Theodore Saloutos Memorial Award as the best book published that year in the field of agricultural history." Those were the author's own words about himself, requested by the editor to put at the end of his contribution to this issue. His unexpected and untimely death in October 2013 calls for additional words of remembrance and appreciation.

Mark Finlay was born in 1960. He received his collegiate and post-graduate education in Iowa, at Grinnell College and Iowa State University respectively. Since 1992, he was a member of the history department at Armstrong Atlantic State University in Savannah, Georgia. He rose through the academic ranks, making and maintaining an impressive reputation in agricultural history. At the same time, he founded and directed the university's honors program and served as Assistant Dean of Arts and Sciences. He was co-winner of the Liebig-Wohler Friendship Prize in 1995 for his contributions to the study of the history of German chemistry. In 1999 he was selected from all of the professors at Georgia's public universities as the winner of the State of Georgia's Regents' Teaching Excellence Award. His service to the profession included the positions of book review editor of *Agricultural History* and affiliation with the National Historic Chemical Landmarks (NHCL) program of the American Chemical Society. He was killed in an automobile accident on his way back home after an NHCL meeting in October 2013.

Mark Russell Finlay was survived by his wife of 26 years, Kelly Applegate, and two sons, Greyson and Ellis. A Visiting Lecture Series has been established at Armstrong Atlantic in his memory.

CATALYST OR SYNTHESIS? CHEMICAL ENGINEERING IN THE LAND-GRANT COLLEGE (1)

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Chemical engineering emerged in the land-grant college system in the early 20th century. The field is a particularly successful example of the fulfillment of the purpose of the Morrill Act of 1862, "to promote the liberal and practical education of the industrial classes in the several pursuits and professions in life" (2). Although the elements of what would become the profession of chemical engineering—chemistry, mechanical engineering and mathematics—were prominent in "liberal and practical" education in the 19th century, it was not until the 20th century that the modern discipline of chemical engineering synthesized in its contemporary form. Land-grant colleges and universities provided a catalyst for this synthesis.

MIT catalyzed the introduction of chemical engineering as a discipline, half a century after its founding as one of Massachusetts' land-grant colleges. After World War II, Minnesota and Wisconsin's chemical engineering departments catalyzed the transformation of chemical engineering into an engineering science. Other land-grant colleges and universities emulated and extended the field to meet the needs of their states with engineering experiment stations and other innovations in applied research. At the end of the century, the environmental consequences of chemical engineering presented a challenge to the field's ability to control the unanticipated consequences of the design and operation of chemical plants, which may provoke a new synthesis in land-grant colleges and universities.

A 19th Century Miscellany

In the 19th century, chemical engineering instruction was a bricolage of coursework in chemistry and engineering, so much so that by the early 20th century chemical engineers found it difficult to define what distinguished their field. At MIT in 1888, Lewis Norton offered the first integrated chemical engineering course "to meet the needs of students who desire a general training in mechanical engineering, and at the same time to devote a portion of their time to the study of the applications of chemistry to the arts, especially to those engineering problems which relate to the use and manufacture of chemical products" (3). The course was a specialty within mechanical engineering, "designed to turn out mechanical engineers with an acquaintance with chemistry" (4).

Elsewhere, schools of mines and metallurgy developed courses in chemical engineering to fit their particular needs. With the advent of electrochemistry, some electrical engineering departments adopted it as a subspecialty. A more typical mixture exemplified at the University of Minnesota, comprised "industrial and applied chemistry" courses that covered "the greater part of technical and analytical chemistry" and offered "the newest and best apparatus." In order to validate the school learning, excursions were "made to the various industrial and manufacturing establishments in order that the student may become acquainted with the practical and commercial side" (5). At Wisconsin, Engineering Dean J. B. Johnson noted in his 1899 inaugural lecture that

"Chemistry, like electricity, now enters largely into nearly all manufacturing processes." However, he continued, "It is one thing to perform a chemical experiment in a laboratory, in a small way, where the economy of the operation does not enter at all, and an altogether different thing to devise ways and means by which the same thing can be done continuously, on a large scale, in a factory, at such a cost as to make the operation profitable. The man who can do both of these things is the chemical engineer" (6). Administrative recognition of the distinction between chemistry and chemical engineering was an essential ingredient in the resolution of its academic status.

Unlike the German system, where chemists and mechanical engineers collaborated in building the industry (7), most American chemical engineering programs emerged from the disciplinary traditions of chemistry but incorporated elements of other engineering disciplines, metallurgy and mining, that had been earlier responses to industrial developments in the United States. Engineering schools had created new fields in step with the appearance of new technologies, catalyzed by the federal investment in land-grant colleges and universities. Civil engineering spawned mechanical engineering as the triumph of the railroad over the canal required engineers to design as well as drive locomotives. Electrification required electrical engineering as alternating current replaced direct current in order to permit a larger scale of distribution than Edison's Pearl Street station. The late 19th-century growth of heavy chemical industry and steel making spurred the movement of industrial chemists from the laboratory to the pilot plant and factory. In some land-grant colleges, engineers moved to engineering experiment stations.

Engineering Experiment Stations

The association of agriculture with Jeffersonian democracy was an ideological mainstay for land-grant colleges during the first half of their existence. The agricultural experiment stations funded by the Hatch Act of 1887 sought to bring agricultural research to the aid of farmers (8). Some land-grant institutions sought to reach out to industry in similar fashion by creating their industrial analog, the engineering experiment station. Unfortunately, the Association of American Agricultural Colleges and Experiment Stations, which focused on agriculture, did not support the Hale-Dayton bill of 1896 or succeeding attempts to establish engineering experiment stations. Failing to win federal funding, Illinois, Iowa State, Michigan and a score of other land-grant schools established them in cooperation with state government and industry (9). Unlike traditional industries, however, chemical manufacturers operated at a scale that could not be duplicated and was often difficult to reduce to university laboratories, even if the proprietary equipment used was available. MIT's School of Chemical Engineering Practice used industrial facilities identified by trustee A. D. Little and his erstwhile partner, William H. Walker, who became a professor there in 1902 and revamped the Applied Chemistry curriculum. Although some universities built laboratories with half-scale equipment, others relied upon local businesses to show students machinery they would later have to design, maintain, and improve.

For example, Minnesota was unusual in its urban siting for a land-grant university, as was MIT. The agricultural setting of most of the colleges and universities precluded access to the chemical industry, which was heavily concentrated on the eastern seaboard. Minnesota relied upon "the alkali industry, the preparation and use of mordants, soap-making, sugar-making, the production of fertilizers, paints [and] disinfectants" as the staples of their instruction (10).

Illinois, Iowa, and Wisconsin engineering experiment stations focused on agribusiness, which was at least regionally accessible. Farm products converted into an increasingly large number of consumer goods—symbolized by A. D. Little's silk purse from a sow's ear—provided research in a wide variety of subjects (11). In Minnesota, engineers examined uses of marl—an abundant natural resource—for road construction and use in Portland cement (12). Heat transfer processes were also an important subject for the Minnesota engineers, since cold weather was an abundant natural resource (13). By the time Minnesota's engineering experiment station was organized in December 1921, the *Engineering Experiment Station Record* listed over 100 projects in universities throughout the land-grant college system (14). Two years later, the *Record* reported (15)

> The Public is becoming interested and newspapers speak now of engineering research as an actual public necessity rather than a fad or pastime for wizards of science who shut themselves in their laboratories for days at a time and whose results are illustrated in Sunday supplements. Public opinion is being reflected even in these economical days by increased support for engineering investigation and research by the various legislatures now in Session.

The University of Minnesota "Engineering Experiment Station and Bureau of Technological Research" was explicitly modeled on the engineering experiment stations at Illinois and Iowa State, which were supported by appropriations of $90,000 and $45,000, respectively, at that time (16). In 1922-23, the state of Minnesota provided $7800 for its station, of which $4500 came from a "Marl Investigation Fund." The work of the experiment station won early support from a construction company interested in better insulation and from the state highway department (17). Then, as now, winter and road repair dominated the engineering agenda in Minnesota.

MIT School of Chemical Engineering Practice

The architects of the School of Chemical Engineering Practice at MIT were A. D. Little and William H. Walker. Walker came to MIT from Pennsylvania State University in 1900 as an instructor in analytical chemistry. He left MIT to join A. D. Little's consulting firm, where the MIT-trained chemist had already established strong ties with the chemical industry, and after two years returned to MIT to become a professor there. He established a chemical engineering laboratory that rivaled his colleague Alfred A. Noyes' Research Laboratory of Physical Chemistry and eventually eclipsed it (18). A. D. Little served as a member of the Institute's visiting committee for the department of chemistry beginning in 1912 and as its chairman in 1915 reported to MIT's president (19)

> ... the training of chemical engineers involves many problems of unusual difficulty and complexity. The demands upon the members of this comparatively new profession are extraordinarily severe and varied and there is at present no place in the world where a training adequate to these demands may be secured.

Little and Walker led the reformation of the MIT chemical engineering program and in so doing provided a model curriculum for universities throughout the United States. The reform followed a professional campaign to synthesize a new discipline in the American Chemical Society (ACS), the first of many such Divisions the Society embraced in the 20th century.

ACS "Embraces" Chemical Engineering

The ACS was at first reluctant to recognize the hybrid discipline of chemical engineering. It had consolidated regional chemical societies into a national organization in the early 1890s. The ACS claimed to "to represent industrial and commercial chemistry" (20) as well as all other academic branches of chemistry. The rapid rise of chemical engineering in the land-grant schools upset the balance between "pure" and "applied" chemistry and confronted the association with schismatic pressures.

ACS President William F. Hillebrand acknowledged this in his presidential address of 1906. Several specialized chemical societies, including the American Electrochemical Society, had already formed. A new journal, *The Chemical Engineer,* had begun to agitate for a society of chemical engineers. While acknowledging that "technical chemists" were underrepresented both in the society and in its publications, Hillebrand dismissed attempts to form smaller societies as ineffective, recommending instead that the ACS assimilate them and form divisions relevant to their interests. This led in 1908 to the creation of the first ACS Division of Industrial Chemistry & Chemical Engineers (21). It also led to the publication of the *Journal of Industrial and Engineering Chemistry* in the following year. "The Society desires to enlist the cooperation of the Industrial Chemist in this Journal," T. J. Parker wrote in the first editorial. "It does not seek the publication of confidential matters, or the secret processes of any company or works, but it believes that a certain liberality in publishing broader information on subjects of manufacturing interest will be beneficial" (22). Not surprisingly, most American firms had little to offer along these lines. As a result, the first volume of the *Journal* covered a hodge-podge of topics in applied chemistry, including agricultural and food chemistry as well as commercial and industrial topics.

Simultaneously, Little, Walker and a number of practicing chemical engineers created the American Institute of Chemical Engineers (AIChE), which offered membership only to those who had substantial experience in the operation of chemical works (23). Although their creation of the AIChE might have splintered the nascent profession, its exclusive criteria simultaneously neutralized any threat to the larger society. The AIChE provided a separate forum for defining chemical engineering as a discipline, while retaining allegiances to the growing ACS, which provided the means to disseminate specialized knowledge about industrial chemistry and chemical engineering to a much larger audience.

Under the guidance of A. D. Little, the chair of the Division, the *Journal of Industrial and Engineering Chemistry* was reoriented in 1910 to educating American chemists about developments abroad, where the techniques of chemical engineering had enabled the growth of the synthetic chemical industry and propelled Germany to world leadership. Little reported to the society in 1910 that the *Journal* contained articles on chemical analysis, food and agricultural chemistry that did not meet the needs of industrial chemists (24).

Little became ACS president in 1912. He and Walker launched the new discipline of chemical engineering at MIT, beginning with Little's formulation of the "unit operations" concept. It transcended chemical engineering practice and became the basis of the definitive text, *The Principles of Chemical Engineering,* written by Walker and two junior colleagues, Warren K. "Doc" Lewis and William H. Evans (25). Walker and Little persuaded MIT to set up a separate department of chemical engineering after World War I.

Alliances in War and Peace

The "Chemists War" called chemical engineers to manufacture chemicals previously supplied by German factories and to respond to the challenges posed by chemical warfare. The Haber-Bosch process of nitrogen fixation supplied the nitrate explosives the Kaiser used to attack the Allies, and Fritz Haber instituted chemical warfare on a large scale in 1916 when he unleashed chlorine gas at Ypres (26). When America entered the war in 1917, academic chemists went into the Chemical Warfare Service in great numbers. "I have been on the road almost continuously in the government service since the last of April," MIT's Lewis reported to President Richard M. MacLaurin in July, "to organize the chemical research relative to the use of gases in warfare" (27). Colonel William H. Walker took charge of the Edgewood Arsenal, the massive production facility that resulted from that research (28).

Perhaps the most significant aspect of wartime chemical engineering was the production of synthetic organic chemicals previously manufactured in Germany. These "intermediates" not only colored military uniforms but were essential in the manufacture of high explosives. "It should be understood that the equipment and the processes used in making such dyes are very similar to those used in making munitions," DuPont's *Molecules and Man* explained. "It is, therefore, proper to say that a dye plant is a potential munitions factory and, as such, of the first importance to national defense" (29).

The Alien Property Custodian's Office created the Chemical Foundation to make German patents available to the new organic chemical industry spawned by the war. The Foundation survived the attacks of the Harding administration, and succeeded in enacting favorable tariffs that protected the chemical industry in the 1920s. The "Chemists' Crusade" (30), in which the Foundation played a leading role, catalyzed the growth of chemistry and chemical engineering in America in the land-grant colleges, which had been mobilized to train civil, mechanical, electrical and chemical engineers for the war effort (31).

By synthesizing the alliance of chemistry with federal government, military and industrial partners, the Chemical Foundation catalyzed the interwar coalition that saved the Chemical Warfare Service, passed the Fordney-McCumber Tariff that protected the nascent synthetic organic chemical industry and rescued demobilized American chemists from the postwar economic and academic slump (32).

The Spoils of War

Land-grant colleges and universities took the lead in setting up separate chemical engineering departments after the war, when MIT appointed Warren K. Lewis to lead what became the leading chemical engineering department in the nation. Through the AIChE, Little, its president in 1919, rationalized the curricula of the field and provided an incentive for other schools to follow its example. An AIChE curriculum study showed that nearly half of the schools offering chemical engineering courses were land-grant colleges. The AIChE set up an accreditation system for chemical engineering education, the first engineering discipline to do so, and catalyzed the creation of the Engineering Council on Professional Development, which, as ABET, continues to accredit engineering programs today (33).

Land-grant college programs previously had included hundreds of varying courses, not least because each school's service mission to its state seemed to dictate studies of local industry. The new definition of chemical engineering in terms of unit operations transcended the details of most such processes and reduced the curricula to a common focus exemplified, but not defined, by local industrial interests. "Unit operations" became, in effect, a lingua franca for chemical engineers. The first universities to adopt the concept, usually in the form of Walker, Lewis and McAdam's *Principles of Chemical Engineering*, were able to transform their existing facilities into unit operations laboratories. At the University of Minnesota, one chemist wrote, "The underlying philosophy of chemical engineering ... is embodied in the definition of the profession propounded in 1922 by the American Institute of Chemical Engineers"

(34). Within a few years, Iowa State, Michigan, Ohio State and Wisconsin were also accredited by the AIChE.

The historical synthesis of chemical engineering in land-grant colleges and universities required the ingredients of industrial technique, chemical understanding, and government funding, the high pressures and temperatures of World War I, and the catalyst of the unit operations concept, which transformed a heterogeneous field into a profession with a standard curriculum, method and definition. The stability of the synthesis through the depression and World War II testified to the durability of the catalyst, which remained unchanged as chemical engineers developed the petroleum industry, synthetic fibers, plastics and what was, increasingly, an engineered environment where automobiles in coats of many Du Pont colors edged out the legions of black Fords, traversed the nation on roads composed of engineered materials, and carried not wood or metal appointments but plastic seats, dashboards and steering wheels. The efficacy of the refining of industrial chemistry into chemical engineering, like catalytic cracking of crude petroleum and polymerization of simple molecules into resilient nylon, transformed the world of the chemical engineer just as his art limned the nation with synthetic colors and materials.

Engineering Science Crystallizes

Although chemical engineering, like its physical counterpart, electrical engineering, tamed the effluence of American industrial innovation into a comprehensible stream of technology, unit operations, like "Moore's law" in modern computer science, was an artificial rather than a fundamental scientific principle. Since, like computers, industrial processes do evolve incrementally, and since the vitality of both electrical and chemical engineering found both fields inadequate to the challenges posed by such new innovations as radar and transuranic chemistry, the formulation of engineering science in the wake of World War II required a resort to more fundamental scientific discoveries that made it possible not only to deal with scaling up, but also with scaling down to the atomic and subatomic levels encountered in nuclear science and quantum electronics. Since both of these enterprises were inescapably mathematical, this transformed chemical engineering into a discipline that drew from new scientific and mathematical techniques the inspiration for further progress.

The architects of the reformation of chemical engineering were also found in land grant schools, in particular Minnesota and Wisconsin, where transport processes and mathematical analysis of reactions became the new focus in the postwar period. Engineering science emerged as empirical studies were reduced to mathematical formalisms characteristic of advanced analyses of flow, like the Reynolds number, the Prandtl number and other dimensionless quantities, revealing fundamental knowledge that was not derived directly from, nor the result of, the application of preexisting scientific knowledge like chemistry (35). The "Minnesota-Wisconsin Revolution" catalyzed the crystallization of chemical engineering as an engineering science.

Minnesota contained chemical engineering in its school of chemistry until the late 1940s, when saturated enrollments precipitated chemical engineering into a new department. It was blessed with a new building but few other resources (36). A chemical engineer turned mathematician, Neal Amundson, became its head and hired new staff, including mathematical prodigies like Rutherford Aris as well as chemical engineers, biochemists and other scientists who refined graduate education into engineering science. Aris, who had worked for Imperial Chemical Industries (ICI) designing chemical reactors, had already demonstrated the importance of mathematical analysis in chemical engineering. Aris, whose eminence in the study of ancient inscriptions rivaled his fame in chemical engineering wrote (37)

> In the 50's at Minnesota, Neal Amundson began to show the power of ... "thatt supersensuous sublimation of thought, the euristic vision of mathematical trance," (as Bridges calls it) and the triumvirate of Wisconsin were to write that famous book which can be read either by rows or columns. Nuclear engineering was recognized as cousin german to chemical; biochemistry was her wash pot and over biology itself she had cast her shoe.

The famous book was *Transport Phenomena* by R. Byron (Bob) Bird, Warren E. Stewart, and Edwin N. Lightfoot. The Wisconsin engineers provided a new paradigm—flow and transport processes—that transcended unit operations. Olaf Hougen and Bird reduced the heterogeneity of unit operations into material transport processes that were more easily captured in the differential equations computers could solve more effectively than human calculators. Amundson and Aris computerized the calculations of chemical engineering that applied mathematics to these processes making them more accessible to their colleagues, who had relied upon more empirical techniques.

The Minnesota-Wisconsin revolution, with its heavy doses of math and science, spread through the graduate programs in chemical engineering just as unit operations had through chemical engineering programs, with a salutary effect on the accelerated development of nuclear and chemical technology in the postwar era (38). Enrollments continued to increase as federal funding supplemented industrial investment in chemical engineering education (39).

Bhopal and Better Living

The scientific sophistication of chemical engineering at MIT, Minnesota and other land-grant universities overshadowed the traditional concerns of these schools for democracy and social consciousness. While graduates of these programs were better researchers and teachers, they were less concerned with the humanitarian and ethical aspects of engineering than the increasing impact of chemical technology required (40). Academic chemical engineering was increasingly remote from practice, especially in underdeveloped parts of the world. While chemical engineers could rejoice that Norman Borlaug made substantial use of their products in the Green Revolution of the 1960s, and industry reveled in slogans like "Better Living through Chemistry," the environmental movement, beginning with Rachel Carson's *Silent Spring,* challenged the short-sighted application of chemicals like DDT, the engineering of lead into gasoline to provide antiknock protection, and other unintended consequences of 20th-century chemical engineering. This was in part a consequence of the privatization of research in chemical engineering in land-grant universities and colleges, where industrial interest trumped democratic concerns about the effects of chemical technology. While private universities owe nothing to such concerns, the Land-Grant Colleges and Universities do, by virtue of the public support afforded them by federal and state governments (41).

The prestige enjoyed by chemical engineers in industry and academe plunged precipitously in the 1970s, as a series of environmental and industrial disasters called into question the efficacy, if not the ethics, of the profession. The 1976 chemical spill at Serveso, Italy, was a harbinger of these events. "More than a chemical engineering disaster," in the words of a recent analysis, "Serveso is a useful reminder to engineers to be ever mindful of the first canon of their profession ... to hold paramount the health, safety, and welfare of the public" (42).

The Bhopal disaster eight years later reinforced the impact of the Serveso disaster on chemical engineering. Union Carbide chemical engineers who designed the plant were blamed for their evident inability to successfully transfer the methyl-isocyanate (MIC) production technology to a third-world setting, and while the parent company's lawyers minimized the damages, they did not succeed in convincing the world that sabotage was the sole cause of the failure of the plant's safety system (43). The academic-industrial coalition that had launched the profession at MIT chose to support the American multinational's assumption of victimhood in the face of legal and environmental onslaughts (44). Although controversy and litigation continues, public concern about the incident escalated after leaks from the Union Carbide MIC plant in Institute, West Virginia, revealed deficiencies similar to those alleged at Bhopal. Subsequent historical analyses have remained critical of Union Carbide's role, especially after it "lawyered up" to avoid indictments in American courts and extradition of its chief executive to India (45). As a result of the public concern, the National Academy of Engineering prescribed a case study of the accident, ABET instituted new requirements of engineering schools for engineering ethics education (but found them to be poorly received) (46). A National Research Council Study of *Frontiers in Chemical Engineering* chaired by Amundson recommended a modicum of design and safety modifications in response to what they considered an unrealistic desire for "no risk" and focused on the financial risks inherent in such cases (47).

The origins of chemical engineering in the land-grant college system did not insulate the profession from the corporate society that it primarily serves. Although our universities and colleges can do more to inculcate the independence of engineering in corporate settings, it will require a reformulation of the original goal—"to promote the liberal and practical education of the industrial classes"—to ensure chemical engineers "hold paramount the safety, health and welfare of the public and protect the environment in performance of their professional duties" (48).

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The 2014 HIST Award in the History of Chemistry

The History of Chemistry Division of the American Chemical Society is pleased to announce Professor Ernst Homburg as the winner of its 2014 HIST award. This international award for contributions to the history of chemistry has been granted since 1956 under sequential sponsorships by the Dexter Chemical Company, the Edelstein Foundation, the Chemical Heritage Foundation, and the History of Chemistry Division. The event, consisting of a monetary presentation, a plaque, a symposium honoring the work of Professor Homburg, and a lecture by the awardee, will take place on 12 August 2014 at the American Chemical Society's annual meeting in San Francisco, California.

The 2014 winner, Ernst Homburg, was born in 1952 in Venlo, The Netherlands. After studying at the Protestant Lyceum, he studied at the Municipal University, Amsterdam, where he received M.Sc. in chemistry and at the University of Nijmegen where he received a Doctoral degree in History. From 1972 to 1993 he served at various posts in history and technology at the Universities of Amsterdam, Groningen, Nijmegen, and Eindhoven. From 1993 to present he has served as Assistant Professor, then Professor, in the Department of History at the University of Maastricht, The Netherlands. With his broad background, Dr. Homburg is one of the leaders in the history of modern chemical industry and technology. He has been involved as a co-organizer and writer in two multi-volume book series on the history of European technology in the 19th and 20th centuries, as well as a multitude of other books and papers. He has been president of a number of organizations that have promoted the history of technology and science throughout Europe and other parts of the world. As an influential speaker, Dr. Homburg is known for his conciseness and fresh viewpoints, with an ability to change viewpoints without any display of ego or discourtesy.

CHEMISTRY OF COOKING, CHEMISTRY IN WAR: WOMEN IN NINETEENTH AND TWENTIETH-CENTURY LAND-GRANT SCIENCE AND ENGINEERING (1)

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American higher education has a gendered history, true across the board, but often especially evident in the question of who was allowed to study science and engineering, why, and on what terms. Nineteenth-century women's colleges graduated scores of chemistry, biology and other science majors, but female employment and professional advancement in science-related work remained limited. Before World War II, schools such as Princeton, Caltech and Georgia Tech remained primarily all-male. Many in American society considered it inappropriate or odd for women to pursue science seriously. But at land-grant colleges, female faculty developed pioneering "domestic science" programs, where ideals of intelligent femininity justified teaching women chemistry, as well as physics, nutrition and household-technology. As home economics programs incorporated science into women's territory, they set a precedent that gradually opened other doors at land-grant schools for women to become chemistry students, teachers and researchers. It was also no coincidence that in the late 1800s and early 1900s, land-grant colleges such as Purdue, Iowa State, Cornell, Minnesota and California were among the first in the country to grant engineering degrees to a handful of women. For many years and for many reasons, women were discouraged from pursuing science and engineering in the same ways that men did, a debate that still resonates today.

The position of women in American chemistry, other sciences and engineering advanced slowly during the early twentieth century, but World War II abruptly transformed the situation. The federal government, industry and universities encouraged, even begged, women to enter non-traditional work. The U.S. Office of Education spent millions of dollars running special wartime programs around the country to train women (as well as men) in science and engineering. Land-grant colleges such as Penn State led the way in offering chemistry classes, designed to prepare women for jobs in explosives manufacturing, petroleum production and other essential defense industries. Although many female trainees did not continue full-time careers in science after peace came, the wartime experience ultimately contributed to a long-term transformation. Over the postwar decades, land-grant colleges and other American institutions created and supported new opportunities to help more women than ever pursue education in chemistry, other sciences and engineering. Gradually, change did come, and over the last 150 years, the nation's land-grant college system has played a key role in that evolution of women's place in the world of science and engineering.

Nineteenth Century Education for Women

Both before and after Europe's Scientific Revolution, a small number of women studied and worked in various fields of science, often thanks to supportive fathers, brothers or husbands. Educational reformers advocated offering young women at least some scientific training, especially in fields such as botany and star-gazing, which seemed linked to feminine talents and interests. Both in Europe and America, however, traditional assumptions about what was and was not appropriate for girls prevailed, favoring an education centered around arts, accomplishments and some areas of basic general knowledge. While applauding the 1826 opening of New York's High School for Females, supporter John Irving said, "I would not wish to be understood as advocating [girls'] attention to any abstract branch of science. Such knowledge is not necessary for them" (2).

Decades before Harvard, Yale, Princeton and many other institutions even considered admitting females, the nineteenth-century establishment of America's women's colleges played a key role in opening up education. In 1837, Mount Holyoke justified women's college education as a vehicle for creating a corps of well-prepared schoolteachers, who would turn into well-prepared mothers, serving to rear new generations of patriotic male citizens. Leaders of women's colleges soon moved toward a broader vision and expanded their curricula to include serious scientific training. Vassar hired noted astronomer Maria Mitchell in the 1860s and required all students to take at least one semester of chemistry, plus botany, zoology, geology and physiology (3).

At Vassar, charismatic chemistry professor Charles Farrar influenced numerous students, including Ellen Swallow, who particularly appreciated Farrar's emphasis on chemistry's practical applications to ordinary life. Unable to secure a job in industrial chemistry after graduating Vassar in 1870, Swallow managed to become the first woman admitted to MIT, a land-grant school since 1863—though MIT accepted Swallow only as an experiment, without granting her status equal to male students. She finished both a second undergraduate degree at MIT and a master's degree from Vassar in chemistry, and married MIT engineering professor Robert Richards. In 1876, Ellen Swallow Richards helped open MIT's Women's Laboratory, which gave dozens of female students a place to study chemistry, in the years before MIT accepted them as true degree candidates. In 1884, MIT appointed Richards as an instructor in its new sanitary chemistry lab, first in the country, where she specialized in pioneering studies of water pollution and public health, helping shape sewage-treatment standards. Meanwhile, Richards extended her interest in showing women how to benefit by applying chemistry to everyday household life. In 1882, she published *The Chemistry of Cooking and Cleaning: A Manual for Housekeepers*, which emphasized the scientific principles behind good sanitation, effective cleaning and nutritious meals. Richards went on to help establish the discipline known as home economics, domestic science or household engineering. She became the first president of the American Home Economics Association, founded in 1908. (4).

Histories of women in American science, both as students and as faculty members, often center around the significance of elite women's colleges such as Vassar. There is very good reason for such a focus; as Margaret Rossiter and others have documented, those schools cultivated some of the most well-trained female scientists of the late 1800s and early 1900s. But it is important to also remember the broader story, that during some of the same decades that prestigious women's colleges were graduating alumnae in physics, biology, math, and chemistry, the American land-grant college system was created and expanded. Not all land-grant schools were automatically coeducational from the start, and certainly those institutions did not treat female and male students equally. Nonetheless, land-grant colleges provided invaluable access to science education for thousands of young women. With regard to the history of chemistry, the role of the land-grants is particularly important, since their leadership in the field of home economics became the basis for requiring and encouraging female students to take a significant number of science classes and conduct scientific research projects.

Starting from the era during and just after the Civil War, land-grant schools that were coeducational, had to decide how to shape college training for young women, in accordance with the mission of promoting economic and social advance by providing accessible, practical training centered around agriculture and mechanical arts. Trustees at Iowa State College, which admitted women from its start in 1869, declared

> If young men are to be educated to fit them for successful, intelligent, and practical farmers and mechanics, is it not as essential that young women should be educated in a manner that will qualify them to properly understand and discharge their duties as wives of farmers and mechanics? We must teach the girls through our Agricultural College to acquire by practice a thorough knowledge of the art of conducting a well-regulated household, practiced in our Farm House, Boarding Hall, garden, dairy, and kitchen.

First president Adonijah Welch commented,

> If to woman has been entrusted, by virtue of her nature, the care of infancy, training of childhood, and… guardianship of public morals, what wonders for the advancement of society might she not

> accomplish if she were properly taught for these duties?... Among her increased facilities for scientific instruction should stand prominent the study of domestic economy.

Iowa State adopted a "ladies' course of study," and its first official class in domestic economy appeared in 1871, under the title, "Chemistry as Applied to Domestic Economy" (5).

During the late 1800s and early 1900s, home economics became a convenient home for female land-grant students, a gender-appropriate and hence respectable academic base to prepare them for marriage and "scientific home-making," and/or employment as teachers, extension workers, "women's page" reporters or other gender-appropriate jobs (6). Land-grant programs served as a vehicle to propagate the field, as early female graduates secured posts to inaugurate home-economics teaching in other colleges and in secondary schools. The field gained academic credibility with formation of the American Home Economics Association in 1909, building on a decade of annual conferences held in Lake Placid, New York, where influential women and men defined the goals of their new discipline and outlined possible directions for teaching, research and social impact (7).

By 1912 at Iowa State, home economics had grown into its own college division, which expanded rapidly. Majors took a considerable range of science courses; beyond basic requirements in chemistry and physics, female students pursued physiological and nutritional chemistry, food analysis, plus classes on research statistics and writing scientific papers. The school boasted (8),

> Courses in domestic economy have been organized on a thoroughly scientific basis.... Instead of merely empirical work, learning how to make a good bread, a lesson which any good mother ought to be able to teach her own daughter, students in this subject should approach it in as thoroughly a scientific manner as students in any field of applied science … and should be as well equipped … as the technically trained agriculturalist or engineer.

Female faculty and graduate students published research connected to broader soc ial and academic themes. Studies of kitchen efficiency connected to scientific-management principles; nutrition research tied into emerging studies of vitamins, while sanitation work linked up with public health and the germ theory of medicine (9).

Domestic science professors at land-grant colleges modeled their philosophy and teaching after (and in cooperation with) science and engineering programs. At the same time, home economics was defined by and for women, explicitly addressing females' presumed sphere of interest, domestic life. In that fashion, these programs created an alternate vision of gendered knowledge, asserting a link between scientific mastery and femininity—at least in the kitchen.

While home economics departments encouraged women to assert interest in science and technology, it is easy to dismiss their existence as a gender-stereotyped trap, a strategy to glorify home-making and conservative gender roles in an era when many women were agitating for the vote, for better professional opportunities and other political, economic, social and political rights. At least in some instances, home economics did seem to serve as an excuse to pigeonhole women with scientific interests and channel them away from men's areas of traditional science and engineering. When ambitious chemistry student Isabel Bevier was considering her options for graduate study in 1889, advisers distinctly told her that "the place for women in chemistry was in work with foods" (10). But home economics provided reassuring gender messages, helping justify coeducation in an era when many experts and parents alike still questioned the wisdom of sending daughters off to college.

Home-economics courses undoubtedly thrived in part because women's knowledge of domestic science didn't threaten men's leadership of pure science and engineering training. Yet on balance, home-economics programs served to subvert the notion of women's scientific ignorance and technical incompetence. Through courses, textbooks, research, extension service and public remarks, faculty women constructed a powerful alternate image of women as scientifically knowledgeable, with an intelligent theoretical understanding applied to practical skills. In decades when female science graduates faced severe difficulties locating rewarding jobs in industry and government, home-economics majors trained in science enjoyed valuable opportunities, including employment with corporations such as General Foods and General Mills, major newspapers and magazines and other businesses.

In part because of the link to home economics, significant numbers of female students at land-grant schools took chemistry, often multiple classes. Photographs at the University of Wisconsin, Iowa State College, and other land-grant schools of the early twentieth-century showed men and women working side by side at laboratory benches. In 1907-08, the

University of Wisconsin made it compulsory for home-economics majors to take at least one chemistry class in each semester of their freshman, sophomore and junior years (11). Chemistry classes served as prerequisites for a wide range of other courses, including food selection and preparation, nutrition and dietetics, textiles, home sanitation, child development and household management. Wisconsin encouraged female students with a concentration in hospital administration to take physiological chemistry and pharmacology; those focusing on applied bacteriology took advanced classes in the chemistry of water analysis (12). As the curriculum in home economics expanded, so did the emphasis on chemistry, especially for those women who conducted original research to earn their master's degrees and doctorates.

The requirement for female home-economics majors to take chemistry and other classes created a precedent for women in the laboratory, which helped a small but number of women secure places as students, faculty and staff in land-grant chemistry departments. Iowa State, for instance, hired Nellie Naylor in 1908 as an Assistant in Chemistry, to set up lab preparations and experimental demonstrations. She remained at Iowa State for 45 years as the second woman on its chemistry faculty, promoted to associate professor after she completed her chemistry doctorate at Columbia. For more than twenty years, Naylor headed the program of chemistry instruction for all first-year women studying home economics (13).

In connection with her home-economics-related teaching, Naylor published a 1933 textbook and lab manual, *Introductory Chemistry With Household Applications,* adopted at numerous other land-grant and other colleges. The book started with fundamental chemistry of atomic structure, characteristics of gases, liquids and solids, properties of solutions and types of reactions, then applied such principles to topics such as the chemistry of yeast and other leavening agents; the chemical principles of antiseptics, disinfectants and preservatives; water hardness and softening agents; properties of different textile fibers and cleaning methods; and the metallurgy of different cookware. Naylor wrote, "A chemistry teacher, before a class of home economics students, needs to bridge the gap between familiar home-like problems which have held the attention of the girls in their own field and the scientific facts which she is intending to disclose to them." Naylor's textbook linked study of saturated and supersaturated solutions to the students' experience with candy-making in their foods-laboratory course, and explained colloid chemistry with references to mayonnaise and jellies. Naylor said she believed that women were as much interested in chemistry as men were, especially when seeing its connections to life in general. She wrote, "A girl can learn to analyze a baking powder as easily as to analyze an ore, and one can appeal to her interest in a baking powder" (14).

In addition to teaching chemistry to home-economics majors, Naylor also served as a counselor for those freshman women who opted to pursue degrees in pure chemistry and a mentor to Iowa State's female graduate students in chemistry. Meanwhile, Naylor published numerous articles in the *Journal of the American Chemical Society*, specializing in the amylase of wheat, rye and other cereal grains. Her research collaborators included a growing number of master's and doctoral students, both male and female, both in chemistry and in the food and nutrition department (15).

Just as land-grant colleges allowed women to gradually insinuate themselves into chemistry and other science departments, they also allowed a handful of female students to enter an even more traditionally masculine field, engineering. It was no accident that the state land-grant schools provided America's first female engineering graduates, at a time when Caltech, Georgia Tech, RPI and other technical schools remained all-male. Just six years after the University of California, Berkeley, opened, Elizabeth Bragg Cumming earned the first woman's civil engineering degree there, in 1876, writing a thesis on a technical issue in surveying (16). In the 1890s, Iowa State College granted civil engineering degrees to sisters Elmina and Alda Wilson. After Elmina earned her engineering master's degree from Iowa State, the school hired her to head its drafting room, then promoted her; as assistant professor of civil engineering, she helped plan a new campus water system (17). Bertha Lamme completed an 1893 mechanical engineering degree at Ohio State, then designed motors at Westinghouse (18).

During the early twentieth century, simply being a woman studying engineering was still unusual enough to get your picture on the front page of campus papers. Media coverage at Cornell, Iowa State and elsewhere treated each woman engineer individually, as if each case were unique—which it was. Under the cute headline, "Beauty Meets Resistance," the *Penn State Engineer* noted in 1934 that Olga Smith had become the first female enrolled in electrical engineering. But slowly, the number of female engineering students at land-grant schools such as Illinois, Ohio State, Penn State and Purdue began to add up, one or two at a time.

At Cornell alone by 1938, more than twenty women had received engineering degrees. Nora Stanton Blatch earned a civil engineering honors degree in 1905, then worked for construction companies and the water-supply board in New York City. Cornell graduate Olive Dennis established a thirty-year career as an engineer and designer at the B&O railroad. Female engineering students such as Blatch and Dennis remained a curiosity. Remarking on the intriguing rarity, a 1920s campus paper ran the headline, "Three Coeds Invade Engineering Courses and Compete With Men at Cornell University: Stand Well in Their Studies." Alongside a photo of mechanical-engineering junior Jeannette Knowles working on a compression-testing machine, the article noted that the three represented "the greatest number of women students ever enrolled here at one time," attending classes alongside over eight hundred men (19).

Administrators didn't encourage women to enroll in engineering; just the opposite. Gladys Tapman had to cite Cornell's promise of instruction in any subject regardless of sex, before the dean accepted her into civil engineering. Cornell's handful of female engineering students, nicknamed "Sibley Sue" and "Slide Rule Sadie," became the target of jokes. Isolation made their experience hard. One said (20):

> A girl has to want … pretty badly to go through with the course in spite of the unconscious brutality of … [male] classmates …. She must be ready to be misunderstood, as … many … will conclude that she took engineering … to catch a husband. She must do alone lab reports and other work men do in groups—because men who are willing to face the scorn of their peers and … work with her are more interested in flirting than in computations. She must be prepared for a lonely academic career; she cannot approach her classmates to exchange notes without appearing bold ….

Hints of change came at Purdue in the 1930s, where progressive president Edward Elliott supported bold thinking about opportunities for women. Elliott hired respected engineer Lillian Gilbreth to teach industrial management and mentor female students. As another career consultant, Elliott also recruited famed aviator Amelia Earhart. Purdue had recently opened its first residence for women; with Earhart's high-profile appointment, female enrollment jumped fifty percent, and the new dorm overflowed. Both Gilbreth and Earhart encouraged female students to combine marriage with careers in engineering or science. Still, gender crossing in land-grant culture remained limited; as at other schools, few Purdue women chose to enroll in engineering, and among that handful, attrition proved high (21).

It is, of course, impossible to estimate how many land-grant female students before World War II felt interested in science and engineering, only to be sidetracked by self-doubts or steered into more traditionally feminine fields. Women who persisted understood the simple reality that they needed to tolerate the inevitable skepticism, pointed criticism or outright ridicule from some classmates, professors, employers, family and acquaintances.

World War II Encouragement for Women in Science and Engineering

World War II proved a crucial transition. Defense industries complained of crisis manpower shortages, and military leaders feared that the nation lacked enough expert scientists and engineers who could scale up defense production and design new and better weapons. Accordingly, the US Office of Education set up the national "Engineering, Science, and Management War Training" program. Under ESMWT, colleges in every state ran crash courses in math, physics, chemistry and engineering. Those classes aimed to train underutilized workers to fill gaps in essential defense industries and upgrade their skills. Between 1940 and 1945, the ESMWT program taught almost 1.8 *million* students, spread across every state. Enrollment in chemical engineering classes alone topped 52,000 students, and chemistry courses attracted almost 39,000 students. The curriculum included general chemistry, analytical, inorganic, organic, physical chemistry, biochemistry and applications of chemistry to special war problems. Classes in metallurgy and industrial chemistry were in high demand. Other ESMWT chemistry courses included work in pharmaceutical chemistry, photographic chemistry, colloidal and surface chemistry, plus laboratory techniques and glass-blowing (22).

ESMWT chemistry courses were oriented to meet specific and urgent research, development and production needs in the military and defense industries. For example, with production of smokeless powder scheduled to rise to one thousand tons per day, the Army and manufacturers desperately needed inspectors. Few colleges could handle training in explosives, since faculty were not familiar with the details. Accordingly, the Office of Education ran special preparation for organic chemistry professors from thirty-three institutions, who then organized local courses on powder science. "We never get an opportunity to complete a class," one noted; arsenals and munitions companies "take [pupils] away from us before they finish." Toward war's end, changing priorities called for more courses on plastics, synthetic rubber and petroleum refining. Colleges focused on serving regional businesses; Oklahoma and Penn State set up courses in petroleum methodology to prepare technicians for the oil industry. One such class placed four unemployed women, two former secretaries and one ex-salesclerk in Pennzoil laboratories; two female soda-fountain operators retrained as core analysts.

With the military taking away able-bodied men, employers turned to "Rosie the Riveter" on the shop floor, and also sought to hire female scientific and engineering workers. Wartime pressures justified stretching gender boundaries, at least temporarily. Government, schools and industry urged women to serve their country by taking more science and engineering. Women ultimately accounted for about twenty-five percent of ESMWT students. A number of schools taught three-month courses in chemical quantitative analysis for women, placing many in industrial labs. Fifteen colleges offered "Engineering Fundamentals for Women," to help women qualify for junior engineer posts with the Navy, War Department or civil service.

Companies desperate for wartime help began recruiting women who had math and science skills, then gave those women customized crash courses to become engineering aides. In one of the most elaborate programs, in 1942, the Curtiss-Wright airplane company began training what they called "Curtiss-Wright Cadettes," giving over 600 women a ten-month immersion in engineering math and mechanics, theory of flight, airplane materials, drafting, job terminology and aircraft production. It was no coincidence that five out of the seven colleges handling Cadette training were land-grants—Cornell, Iowa State, Minnesota, Penn State and Purdue (the other two were RPI and University of Texas). All but RPI already had women enrolled. Granted, only a few prewar women students had earned degrees in engineering, but at least students and faculty were accustomed to seeing women around campus. At these schools, announcement of the Cadette program elicited some joking about the notion of female engineers. But Cadettes could claim to be doing their part for the war effort and on that patriotic ground, they were welcomed. By contrast, at all-male RPI, the arrival of "engineeresses" created a culture shock. Local newspapers carried giant headlines, "RPI Opens Doors to Women: Institute Breaks 116 Year Old Rule Due To War Need," "Curtiss Wright Women … Invade RPI Campus" (23). The Curtiss-Wright story represented a perfect wartime morale-booster; Cadettes proved temptingly photogenic, and *Life* published a special feature (24).

War provided rationalization for training women in science and engineering. While many Cadettes and other women who entered wartime classes did not continue full-time science or engineering careers once peacetime came, others did. More than that, temporary changes had important lasting effects. Before the war, the one or two women enrolled at any one time at schools such as Cornell or Penn State were an anomaly. By 1945, Purdue alone had eighty-eight women majoring in engineering, where a critical mass made life easier; aeronautics major Helen Hoskinson remarked, "Now that lady engineers are not a novelty on this campus, people no longer stare at the sight of a girl clutching a slide rule" (25). Among other land-grant schools, there were fifty female engineering students at Ohio State, forty-eight at the University of Minnesota, thirty-seven at Cornell, thirty-two at Illinois, twenty-seven at Wisconsin and twenty-six at Iowa State. Overall, in November 1945, colleges and universities reported a total of 48,977 men enrolled in engineering courses and 1801 women (at a time when Caltech, Georgia Tech and some other engineering schools still refused to admit women at all). Numbers validated the notion that women could handle technical subjects. It was no coincidence that wartime brought a number of "firsts" for female students in engineering, with more women initiated into student honor societies and joining engineering clubs (26).

Conclusion

Though peacetime American culture brought strong pressures for a return to traditional gender roles, even during the 1950s, women's place in the scientific and engineering world continued to evolve. Women choosing non-traditional fields often still faced serious problems of discrimination in college classrooms, in hiring and promotion, and in professional life. But increasingly, women mobilized, forming groups to provide mentoring, job networking and other forms of mutual support. The Society of Women Engineers (SWE) was incorporated in 1952; female engineering majors at Purdue formed a student section two years later, followed soon by women students at other land-grants such as Iowa State. College SWE chapters undertook a wide range of activities to provide mentoring, networking and other forms of support; they paired first-year women with "big sisters," hosted talks by industry representatives, organized panel discussions, distributed women's resumes and more (27). Land-grant schools had long contributed to efforts to recognize and support women in science; Iota Sigma Pi, the national honor society for women in chemistry, had been founded in 1902 at Berkeley. The group Graduate Women in Science originated at Cornell in 1921, convened in connection with the American Association for the Advancement of Science. Especially during the 1960s and 1970s, faculty, students and administrators at land-grants and other colleges organized deliberate efforts to encourage more young women to consider studying science and engineering and to help them succeed.

In 2009, women earned just over fifty percent of United States bachelor's degrees in chemistry, up from 2000, when women claimed forty-seven percent of chemistry bachelor's degrees (28). In engineering, physics and other fields and sub-disciplines of science, women remain underrepresented, as undergraduate students, graduate students, postdocs and faculty, for multiple complex reasons. But today, it is virtually impossible to find a land-grant or other campus that does not have multiple programs supporting female students, faculty and researchers in chemistry and other fields of science and engineering. While issues of difficulty and discrimination unquestionably persist for women in science, American education today offers an overall climate of encouragement simply not available to women a few generations before. Especially at land-grant colleges, the history of American higher education tells a dramatic story of change for women seeking degrees in chemistry, in other sciences, and in engineering.

About the Author

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BAKING POWDER AND SELF-RISING FLOUR (1) IN NINETEENTH-CENTURY BRITAIN: THE CARBON DIOXIDE AERATIONS OF HENRY JONES AND ALFRED BIRD

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Introduction

It is not known when or how the first leavened bread occurred. The first records are found in ancient Egyptian hieroglyphics and it is possible that the leavening of dough by a fermentation process was known to ancient civilizations long before recorded history.

Baking powder (hereafter BP) is a chemical raising agent used in baked goods. This article will show that its composition has origins from the early nineteenth century when the reaction of an acid with a base to produce a salt plus water and carbon dioxide was the main basis on which developments centered. While BP can be composed of a number of materials, it was commonly, in its early years, baking soda (sodium bicarbonate, $NaHCO_3$) as the alkaline constituent, and cream of tartar (potassium bitartrate) as the acid, diluted with filler such as corn-starch.

Also considered in this article is the early history of self-rising flour (hereafter SRF) but it should be noted that the chemical development of the aerating materials required in this product had a direct relationship with the early BP history: the two products are therefore intertwined. A full historical treatment of SRF must encompass the invention and development of BP since the former product is nothing more than flour to which BP has been added in correct amount. Indeed it can be supposed that the invention of one or other product would in itself lead to the development of the other. In this account only two years separated two main case studies, one of BP, the other of SRF.

Two important protagonists involved in this account are Alfred Bird (bap. 1811-1878) and Henry J. Jones (1812-1891). Both depended on the principal chemical reaction of BP because SRF, as already stated, is merely flour containing BP. Whichever product is under consideration both involve flour containing sodium bicarbonate and an acidic ingredient able to react when in a moist dough to produce carbon dioxide (hereafter CO_2) as aerating agent. The process does not involve yeast fermentation and early BPs were sometimes termed yeast substitutes.

The American history of BP development is well described in Paul R. Jones's paper of 1993 (2). This author points out that Eben N. Horsford began experiments to find a substitute for tartaric acid in the 1850s. This was a period sometime *after* the discoveries and developments of Bird and Jones in England and other earlier British experimenters. Jones answers his own question as to the inventor of BP, if indeed any one individual holds that distinction, by quoting Justus von Liebig's own words (3):

> …the preparation of baking powder by Professor Horsford in Cambridge in North America, I consider one of the most important and beneficial discoveries that has been made in the last decade.

No comparable assessment of the earlier British development of BP has so far been made and it is hoped that this present article may go some way to remedy this lacuna.

The British story of SRF is not without reliable primary source evidence (4), and it is this that forms the basis of what is known about Jones's endeavors to successfully produce what was the first SRF. Priority of invention will be considered and if this is judged on the basis of who first produced, patented and sold such a product, then Jones will be seen as satisfying these requirements. Nevertheless Alfred Bird produced BP two years earlier in 1843 (5), but apparently without the protection of patenting.

One may ask how these inventors and other early producers of chemical aeration knew about the reaction of fairly innocuous acids such as tartaric and cream of tartar with sodium bicarbonate in order to produce CO_2. An attempt to answer this question is made in this article. To modern eyes, knowledge of BP is in itself sufficient to be able to produce SRF, but perhaps for Jones the idea of a domestic "convenience food" had not occurred, certainly it was not a question addressed by Bird.

The background of Bird and Jones and the chemistry involved in their products will be considered since their success hinged upon the proper working of a chemical reaction dependent upon the correct quantities of materials used. Was it obvious to Jones and Bird that so many ounces of bicarbonate react to neutrality with so many ounces of acid ingredient, whether it is tartaric acid or cream of tartar? The earlier use of dilute hydrochloric acid posed the same question. Unlike the legislative controls regarding bread (6), Jones's and Bird's chemically aerated products continued in production for the following hundred years without serious legislative intervention. Indeed it was not until wartime conditions of the early 1940s that standards were prescribed regarding the available CO_2 content of SRF and BP.

Alkaline and Acidic Constituents

It seems impossible to point to a particular time when sodium carbonate (or bicarbonate) was first found to react with some other acidic ingredient, such as lactic acid in sour milk, as a means of producing CO_2 in a baking process. Such a discovery was very probably accidental as also in the case of potash (or pearl ash) which predated the sodium salts.

Alkaline Constituents

Sodium bicarbonate appears as the most common alkaline substance used in both BP and SRF. Nevertheless, potash (potassium carbonate) played an important part as forerunner to sodium bicarbonate. For example, one early American recipe book of 1796 showed clear evidence of the use of potash, as pearl ash, in domestic baking (7), but ultimately sodium bicarbonate became available from apothecaries and newly developing chemical manufacturers described below. Sodium bicarbonate has retained its position for nearly two centuries perhaps because of its relative cheapness, purity and ability to produce a substantial volume of CO_2. The full chemical nature and understanding arose from the work of Valetin Rose (junior) and S. F. Hermbstädt in the first decade of the nineteenth century (8). Sodium bicarbonate is less alkaline than ordinary carbonate but on a weight-for-weight basis produces more CO_2 when reacted with an acid. Of course, any unreacted bicarbonate in a baking process breaks down thermally from 50° C onwards to produce CO_2, leaving behind undesirable sodium carbonate.

$$2\ NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$$

However, when reacted with a suitable acid the bicarbonate provides not only the desired CO_2 but also innocuous products and is therefore an ideal alkaline component. Consequently, the acid constituent of BP and SRF has received most attention.

Acid Constituents

The most commonly used acid ingredient was cream of tartar (known to the early Greeks and Romans as tartar). However, experiments were made using dilute hydrochloric acid, and much earlier, soured milk. The latter found application in early baking recipes though it provided only limited aeration (9).

Cream of tartar was a by-product of fermentation in wine making and in this process the increasing alcohol content caused potassium acid tartrate (cream of tartar), to crystallize out on the side of the fermentation vessel. The hard crust, referred to as argol or lees, when refined, became the principal source of cream of tartar. By heating this deposit with a solution of calcium hydroxide, calcium tartrate forms as a precipitate, which by treatment with sulfuric acid produces a combination of calcium sulfate and tartaric acid (dihydroxy-succinic acid). After separation, the tartaric acid can be purified for commercial use.

Following the discovery and preparation of tartaric acid by C. W. Scheele in 1770, its production was soon taken up by apothecaries and small-scale chemical producers. For example, a company at Ternes near Paris owned by J. A. Chaptal (1756-1832) was producing tartaric acid as early as 1804 (10). Instructions for making this chemical by a simple and cheap process also appeared in 1807 (11). Its production in wine making locations was therefore not unexpected; for example, a company set up by Philippe-Charles Kestner (1776-1846) at Thann in the Alsace region produced tartaric acid on a commercial scale as early as 1809 (12). Evidence of much earlier availability of cream of tartar in Britain appeared in a list of materials sold by Bevan around 1730 (13).

Being chemically related, tartaric acid and cream of tartar found use as acidic ingredients:

$$H_6C_4O_6 \text{ (tartaric acid)} + 2\ NaHCO_3 \rightarrow Na_2H_4C_4O_6 + 2\ H_2O + 2\ CO_2$$

$$KH_5C_4O_6 \text{ (cream of tartar)} + NaHCO_3 \rightarrow NaKH_4C_4O_6 + H_2O + CO_2$$

These modern equations show reactions with sodium bicarbonate in which tartaric acid has over twice the neutralizing strength of cream of tartar per unit mass. Though this may appear an advantage it necessitates accurate weighing of smaller quantities and also has the disadvantage of reacting more quickly than cream of tartar.

Early Experimenters and Bread Making

It can be reasonably supposed that potash, as a very early known alkali, was used in bread making perhaps as a means of countering the sourness of sourdough and other similar baked goods. Its availability during the eighteenth century was well established and its chemical understanding arose from Edinburgh's enlightened natural philosophers such as Cullen, Black and Francis Home, the latter having given quantitative credence to its use and as a source of fixed air (CO_2). Indeed, Home's method of quantitative analysis, by its effervescence against a standard acid, while hardly of significance to a baker of the time, would nevertheless have given some degree of tacit authority to the use of potash in baking.

Without any form of artificial aeration, whether produced chemically or by fermentation, a baker would hand knead the dough for long periods of time in order to incorporate air. But it was Thomas Henry (1734-1816), in 1785, who attempted to find a theory about the use of yeast. He believed that during fermentation there is a loss of nutritive gluten and sugar, and therefore his experiments might offer an effective substitute for yeast.

He also thought that the gas liberated in fermentation "was the exciting cause, as well as the product of fermentation" (14). Being fully aware of the use of yeast or barm (the frothy substance collected from an already fermenting liquor) in fermentation, he made an experiment in which he introduced CO_2 from an external source into an already fermenting medium. He suspected (15)

> …that fixed air is the efficient cause of fermentation; or, in other words, that the properties of yeast, as a ferment, depend on the fixed air it contains; and that yeast is little else than fixed air, enveloped in the mucilaginous parts of the fermenting liquor.

Whilst this belief is in error it nevertheless reinforced the close connection between fermentation, fixed air, and the aeration of baked goods. Henry described his experiment thus (16):

> I therefore determined to attempt the making of artificial yeast.
>
> For this purpose, I boiled wheat flour and water to the consistence of a thin jelly, and, putting the mixture into the middle part of Nooth's machine, impregnated it with fixed air, of which it imbibed a considerable quantity. The mixture was then put into a bottle, loosely stopped, and placed in a moderate heat.
>
> The next day the mixture was in a state of fermentation, and, by the third day, had acquired so much of the appearance of yeast, that I added to it a proper quantity of flour, kneaded the paste, and after suffering it to stand, during five or six hours, baked it, and the product was bread, tolerably well fermented

However one views Henry's erroneous conclusion, it was nevertheless, commonly held. Indeed, not until the work of Pasteur in 1857 was it realized that fermentation is a biological process, and a further twenty years elapsed before the microorganisms were identified in detail (17).

Henry's 1785 experiments were fully endorsed twenty years later by Abraham Edlin, a physician and surgeon of Uxbridge, who repeated the process and recorded his observations in detail. Edlin took matters further by advocating the use of aerated water in the form of "one pint bottle of the artificial Seltzer water, prepared by Mr. Schweppe, …" (18). He then listed various foreign natural spring waters equally capable of use in fermentation. A note of interest resulting from Henry's and Edlin's suggestion for an external source of CO_2 lies in a later process devised by Dauglish—see below—whose industrial-scale bread making depended entirely on injecting the gas into bread dough.

Edlin's work, and to a lesser extent Henry's, is frequently referred to by Thomas Thomson, MD (1773-1852), in his *System of Chemistry* of 1810. In the chapter "Of the Panary Fermentation," for example, Thomson repeats Edlin's recommendation for the use of potash where otherwise sourness in dough might occur (19):

> It consists in adding a sufficient quantity of carbonate of potash to neutralize the acetic acid, and to knead the alkali rapidly into the dough, so as to prevent, as much as possible, the carbonic acid disengaged, from escaping.

There is no mention however of using sodium carbonate with hydrochloric acid as an alternative to yeast-raised dough.

By 1838 Thomson had slightly revised this section of his *System* and this appeared in *Chemistry of Organic Bodies* (20). Here he reports the use of the sesqui-carbonate of ammonia "to render their bread porous" by the addition of a quarter of an ounce to every pound of flour and that any residual ammonia after baking should be insufficient to cause concern. Somewhat earlier in 1820, Frederick Accum had suggested the use of ammonium bicarbonate in bread making, but there is no evidence of its commercial use (21). Thomson also mentions Colquhoun's method (see below) of using sodium bicarbonate or magnesium carbonate with a solution of tartaric acid. And again, like Colquhoun he noted the difficulty in getting successfully raised ginger bread; a result which could be achieved by incorporating potash. Thomson repeated Colquhoun's suggestion to use "the requisite quantity of sulfuric acid to saturate the alkali" in gingerbread making, but the result often being "a taste decidedly bitter" (22).

Interestingly in 1817, the *Gentleman's Magazine* reported on a substitute for yeast in bread making, quoting from a letter from a reader of *The Monthly Gazette of Health* and the response of its editor (23). The letter, regarding the difficulty of getting bread to rise, asked if "using alum or potass, this desideratum may be accomplished; …"

The editor replied by stating his own practical success in this endeavor by using:

> … four drachms of carbonate of soda … with six pounds of flour … mix three drachms of muriatic acid, diluted with a pint of water … The acid and soda, uniting in the mass, form the culinary salt, and during the union a considerable quantity of fixed air is disengaged …
>
> Salt of tartar and soda, which have been recommended to the public prints to improve bread, render it darker, and so far as the Editor's experience goes, more heavy.

Henry's and Edlin's work was summarized in an essay of 1826 by Hugh Colquhoun (1802-1878) (24). But first he pointed out that the acidity sometimes found in bread by "over-fermentation" (allowing the fermentation by yeast to proceed too far) results in an "acetous" taste which can be easily remedied (25):

> The use of a little of the carbonate of soda, or of the carbonate of magnesia, is all that is required in order to secure to the baker a dough which he may always have sweet and pleasant during the entire progress of fermentation; …

Recognizing that the evolution of CO_2 from added carbonates "materially promote the vesicularity of the bread," he mentions that the use of sesqui-carbonate of ammonia in his own baking tests always resulted in residual ammonia in the bread and poorer texture compared with yeast-raised bread. Whilst acknowledging Edlin as the first to impregnate dough with CO_2, he nevertheless questions his theory that this gas affects the yeast fermentation where (26)

> …the activity of yeast in exciting the saccharine fermentation of dough, resides exclusively in the carbonic acid gas with which that liquid is always nearly saturated, when kept properly excluded from the open air.

In support, Colquhoun quoted M. Vogel as having found only negative results in similar trials. However, convinced by his own tests, Coulquhoun claimed CO_2 as being "incapable of exciting the panary fermentation," having experimented with both sodium carbonate and magnesium carbonate "in those proportions in which they pretty exactly saturated each other, with the requisite quantity of water holding the acid solution" (27). He also tested the use of tartaric acid and magnesium carbonate; in one recipe he quoted "4 ounces flour; 20 grains sesquicarbonate of soda; 19 grains of tartaric acid" and in using magnesium carbonate he quoted "4 ounces flour; 30 grains carbonate of magnesia; 15 grains tartaric acid." In both recipes there was an excess of bicarbonate and thus an insufficient quantity of tartaric acid to generate the full potential amount of CO_2 (28).

But from these and other formulations, he noted the early loss of CO_2, this being more than in standard yeast-raised bread (29):

> … that no loaf-bread can be well made by any of the extemporaneous systems above considered, because they are all inconsistent with the thorough kneading of the dough. It is this process which is found to render dough at once elastic enough to expand when

> carbonic acid gas is generated within it, and cohesive enough to confine this gas after it is generated.

Such observations show Colquhoun's very forward thinking on this subject much of which arose from his baking experiments. He also found the use of a mixture of sodium carbonate and tartaric acid proved most acceptable in taste and aeration, particularly in the difficult making of ginger bread. In an interesting footnote Colquhoun pointed out that "tartaric acid may now be purchased at 4s. 6d., and carbonate of magnesia at 1s. 4d. per pound" (30).

It might be reasonably assumed from Colquhoun's reporting that the use of solid aerating ingredients was poised to become accepted practice. Oddly this was not the case, and experimentation in the use of dilute hydrochloric acid continued. Before assessing one particular case that of Whiting, whose approach resulted in his taking a patent based on the use of hydrochloric acid and bicarbonate, we note that other experimenters continued on similar lines.

For example, though somewhat later, in 1846, there appeared an anonymously published pamphlet in which the author, probably George Darling, gave instructions for aeration by using sodium carbonate and muriatic acid (31). The author of this pamphlet claimed that Thomas Thomson wrote an essay on baking for the supplement to the *Encyclopaedia Britannica*, published in 1816, 2nd volume (32). This was said to contain the suggestion to use carbonate of soda with muriatic acid to obtain a better performance than that given by yeast in bread making (33):

> … the dough so formed will rise immediately, fully as much, if not more, than dough mixed with yeast; and when baked, will constitute a very light and excellent bread.

The writer also claimed to having tested out Thomson's instructions using this recipe (34):

> Flour, 3 lbs. avoirdupois, Bicarbonate of Soda, in powder, 9 drachms apoth. weight and Hydro-Chloric acid (Muriatic) 11 ¼ fluid ounces. Sp. Gravity 1.16.

He then pointed out that:

> … the proportion of soda and acid are those which make common culinary salt, when united chemically … If either soda or the acid be in excess, the bread will taste of one or the other accordingly …

The pamphleteer claimed, "It always appeared to us [Darling] that the proportion of hydrochloric acid recommended by Dr. Thomson was too great …" in that 7 oz of hydrochloric acid is too large a quantity for 2 oz of carbonate of soda. Darling proposed therefore a better bread recipe of 3 lb avoirdupois flour, half an oz bicarbonate, 5 fluid drachms of hydrochloric acid of specific gravity 1.17 and 26 fluid oz of water. Nevertheless, this recipe would give a very slight acid result and 0.5% (by weight) available CO_2.

In the same year (1846), the editor of the *Edinburgh Medical and Surgical Journal* reviewed and excerpted this pamphlet under "Materia Medica and Therapeutics" (35), pointing to the tract's support of "unyeasted bread" as being "more salubrious and more safe for the dyspeptic." Also advocating the consumption of unfermented brown bread to "obviate constipation and to diminish the violence of dyspeptic symptoms, … (36)."

The idea of using an external CO_2 source however did not end with Henry or Edlin, for somewhat later (in 1860) the physician and bread maker, John Dauglish, MD (1824-1866) (37), perfected the use of a solution of carbonic acid but in which the kneading process was carried out in a pressurized vessel thus restricting premature loss of CO_2 from the dough (38). According to Burnett, Dauglish's work ultimately led to the formation of The Aerated Bread Company (39), and mechanization of the baking industry.

Nevertheless, the internal chemical generation of CO_2 remained a desirable objective and so, even without knowledge of the work of Henry, Thomson, Colquhoun *et al.* it remained possible that early bakers found by accident that addition of potash altered the taste and aided aeration of the dough—by its reaction with natural acids of the dough or other acidic ingredients to evolve CO_2. And so from these early steps in the development of chemically and physically generated CO_2 significant changes in baking practices became possible.

John Whiting: An Early Patent for Unfermented Bread

Firm evidence of an acid alkali reaction being used as a means of creating satisfactory dough is seen in the patent of John Whiting of Kennington in 1836 (40). In this Dr. Whiting chose to use hydrochloric acid as the acid ingredient but its use was not original as is evident by the earlier work described above. Also, a somewhat later comment by Andrew Ure is noteworthy (41):

> … when a dough containing sesqui-carbonate of soda is mixed with one containing muriatic acid, in due proportions to form the just dose of culinary salt [neutrality], the gas escapes during the necessary

> incorporation of the two, and the bread formed from it is dense and hard. Dr. Whiting has, however, made this old chemical process the subject of a new patent for baking bread.

Indeed, Ure's criticism also included the work of Colquhoun and Edlin by stating that chemically raised bread (including the use of ammonium bicarbonate) remained inferior to that raised by conventional yeast fermentation:

> … a proper spongy bread cannot be made by the agency of either carbonic acid water, or of mixtures of sesqui-carbonate of soda, and tartaric acid.

Nevertheless, the use of muriatic acid proved of value in baking and is strikingly given in Whiting's patent of 1836.

The Patent

The main body of the patent claims (42):

> … to consist in preparing such food by means of an acid and an alkali (such alkali being in union with carbonic acid), whereby the same is rendered cellular light (spongy), without the aid of fermentation. The acid I employ in the manufacture of bread is the muriatic acid (called also hydrochloric acid, and spirits of salt), and the alkali is the carbonate of soda, or what is considered to be by chemists a sesquicarbonate or bicarbonate. When these two articles, namely, the muriatic acid and carbonate of soda, are mixed together in proper proportions, the following changes take place: namely, two of the ingredients which they contain, combine to form common salt, two other ingredients combine to form water, while the carbonic acid is separated in the form of gas, and accomplishes all the duties performed by the carbonic acid extricated during the common fermentative process of making bread (which fermentative process I consider to be prejudicial), whether produced by permitting the dough, by standing and heat, to rise by fermentation, the result of spontaneous decomposition, or by aiding such fermentation by yeast, as is the common practice, or by any other ferment.

Here follows the composition or recipe for Whiting's bread:

> To form seven pounds of wheaten flour or meal into bread, mix from 350 to 500 grains of carbonate of soda above mentioned with about two pints and three quarters of pure water (the quantity of the alkali may be made to vary within the limits above mentioned, as the baker finds it suit best, and depending on the degree of lightness required). Mix with three quarters of a pint of water in a separate vessel so much of pure muriatic acid as will neutralize the quantity of the carbonate of soda employed, the quantity of the acid varying according to the known specific gravity of the acid, and the quantity of the soda in the carbonate, which are subjects familiar to chemists, from about 420 to 560 grains of the acid, as met with in commerce, I have found in practice to be required for 350 grains of carbonate of soda; and I would remark as bakers are not usually acquainted with chemistry, in order to their adjusting the proportions of the muriatic acid and the alkali, they must depend on someone who is possessed of chemical knowledge …
>
> … Let the flour be divided into two equal portions; to one portion thrown into a wide earthenware pan or trough, add the solution of soda gradually, well stirring and beating the mixture with a large wooden spoon, … so as to form a uniform batter … Upon this batter throw the other portion of flour, and while briskly stirring them together from the bottom, pour in gradually the diluted acid, then let the dough be formed, ..."

After further kneading the dough is shaped and baked. On the subject of reaching a chemically neutral baked product, Whiting remarks:

> … care being taken to obtain the extrication of a sufficient quantity of gas, and to form a neutral mixture of the acid and alkali that is to produce common salt, as above explained.

The patent ends:

> ... But what I do claim, as my improvement or improvements, is the preparing such food by means of an acid and an alkali (such alkali being in union with carbonic acid) whereby the foods are rendered cellular light (spongy), without the aid of fermentation, as above described. —In witness, &c.
>
> Enrolled November 3, 1836.

Because of the practical dangers of using hydrochloric acid in this manner one might assume that the idea had a short life; nevertheless, the method remained noteworthy and appeared thirty-six years later in *Chemistry and Chemical Analysis*. This author considered such bread as wholesome as that made with yeast and in order to achieve neutrality in the baked goods (43):

> The amount of dilute acid, required to liberate the gas, may be ascertained, by adding it gradually until effervescence is no longer produced; …

In 1860 Muspratt also reported on the use of bicarbonate of soda with hydrochloric acid (44).

Commentary on Whiting's Method

The first patented method of producing CO_2 in baked goods by reacting an acid with sodium bicarbonate therefore lies with Whiting. The actual chemical reaction was known before 1836 and is today represented thus:

$$NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2$$

This shows neutral residue products of common salt, water and evolved CO_2 provided the reactants are in proper stoichiometric proportion. The patent suggests Whiting's appreciation of the immediate reaction that would take place with an aqueous acid by his attempt to retain the maximum amount of CO_2 in the dough by a well-judged mixing procedure. Indeed the fast reaction of this acid may have been the motive to find slower alternatives such as given by solid and less soluble acids. His more serious problem probably lay in gauging the correct amounts of chemical components. Whiting's lower figure of 350 grains of bicarbonate when added to 7 lb of flour would generate only 0.34% of CO_2 while his upper bicarbonate addition to the same amount of flour would produce 0.48% CO_2. Both results are low compared with present day expectations (0.6%).

On the matter of reaching neutrality in the reaction Whiting is vague and though he suggests that between 420 and 560 grains of acid "of commerce" will react with 350 grains of bicarbonate to reach neutrality. This tells us nothing without additional information regarding acid strength. However, he wisely suggests that "they [bakers] must depend on someone possessed of chemical knowledge, ..." (45).

Any small error in measuring the acid for example could have disastrous results both in monetary value and reputation. Laboratory quality controls to guarantee the strength of the acid or to determine the amounts for exact neutrality (a neutral pH in the final baked goods) had yet to come into being. No evidence has been located to suggest that Whiting's method found commercial application although seven years were to pass before the entry of a practical BP by Alfred Bird. It seems unlikely that the method would have appealed to bakers of bread whose reliance upon established yeast fermentation has remained to present times. Unfermented aerated bread has, even to the present, never been the natural home of chemicals although both Jones and Bird foresaw what we would now call a niche market in naval and military situations. The need for chemical aeration may have arisen in small part due to the increasing sophistication of baked goods other than bread. For example, those with generous amounts of eggs, sugar and milk; here, normal fermentation may be completely inhibited. Also the availability of yeast may have been a factor. But Whiting was quite clearly motivated by a medical or health aspect regarding bread (42). Furthermore, his patent's claim lies not so much in the use of an acid with an alkali, "but that the foods are rendered cellular light (spongy), *without* the aid of fermentation."

One disadvantage of Whiting's method may have been the rapid evolution of CO_2 on adding the acid. Indeed, later development of BPs took into account the importance of the solubility of the acid component, its granularity and the strong influence of a protective flour coating—against premature reaction. These, together with the chemistry of the reaction "to go," greatly influenced the later choice of acidic ingredient.

That the acid component received attention elsewhere is shown in an unusual approach made by Thomas Sewell in 1848. Perhaps unaware of Whiting's method he suggested "acidic flour" in a patent of that year; the "acidified flour" being thus made ready for the customer's own incorporation of bicarbonate of soda (46). By using dilute hydrochloric acid in the form of a fine spray added to mechanically agitated flour this inventor proposed to add (47):

> … forty-five ounces avoirdupois weight of hydrochloric acid of sp. Grav. 1.14, which contains about twenty-eight per cent of real acid, are incorporated with each 280 lbs. of flour … and is ready for sale. Thus a preparation of flour is produced ready to be combined with other ingredients mentioned, which will render it suitable to be made into bread without the use of yeast.

The customer was recommended to add 63 grains of sodium bicarbonate to every pound of flour (within five weeks of production) plus sufficient water to make dough (48). A second "self-rising" product by Sewell proposed flour acidification as above and addition of thirty-nine ounces of sodium bicarbonate to 280 lb of prepared flour (49). After mixing and sieving, the mixture was ready for packaging and sale—with a suggested use within four weeks of production. Nowhere does Sewell mention the likely premature loss of CO_2 during storage but nevertheless recognizes the necessity for a short shelf-life. No evidence has been found that the invention gained commercial interest.

Mr. Jones and Mr. Bird

On the 3rd September 1845, Queen Victoria acknowledged a specification for a new food product developed by Mr. Henry Jones, baker, of Broadmead, Bristol (50). In this document Jones described his development as a true invention in the form of "A new preparation of flour for certain purposes."

Two years earlier, in 1843, Alfred Bird of Birmingham had invented (but without the proof given by patenting) "Fermenting Powder," later to be known as BP. Both Jones's and Bird's products contained two reacting chemicals, sodium bicarbonate and tartaric acid, intermixed with a filler such as corn starch, or as in Jones's case ordinary flour. From these two developments arose the potential to produce leavened or raised dough conveniently without the need of yeast.

With this comparison in mind one may conclude that baker Jones's specification was not a true invention although his patented "prepared flour" led to the first commercial production and sale of what later became known as SRF (51).

The need for exact neutrality of the active ingredients was recognized by Jones and perhaps indicated some knowledge of acid-alkali neutralization. The leavening or rising of baked goods was a desideratum usually answered by fermentation but in instances where yeast was not available or was ineffective, a chemical means must also have been desirable. There is ample evidence of Bird's and Jones's early identification of the potential markets for their products in both military and more so in naval outlets. (See below.)

However, the first patented use of tartaric acid and sodium bicarbonate as aerating agents remains with Jones (in 1845), but as already pointed out this can hardly stand as a true invention in the light of the earlier "fermenting powder" of Bird in 1843. Jones's specification merely described the application of the above reacting substances when mixed into excess flour. This is little different from Bird's fermenting powder, only inasmuch as the "new invention" by Jones contained extra filler.

As though aware of Bird's product Jones carefully worded his patent application by explaining that his invention was merely … (52)

> the preparation of the flour itself, in manner aforesaid, whereby it will keep for a long time and be always ready to be made into bread, biscuit, and other like food, without the addition of any fermenting matter…

In other words he did not claim "the invention of making bread, biscuit, or other the like food" but only that of the preparation of the flour. Such were perhaps the meanderings of patents at that time. By preparation of the flour he meant of course the introduction of measured amounts of sodium bicarbonate and tartaric acid in order to generate the aerating CO_2 gas. The term self-raising (or -rising) flour does not appear in Jones's patent and its careful wording may seem unnecessary in that Alfred Bird appears not to have sought similar patent protection. The account given by Turner (5) suggests that Bird's developments arose from his wife's allergy to yeast-raised bread and so "chemically raised" bread seemed a natural step. The *raison d'etre* for the now still famous Bird's Custard seems to have arisen from another allergy of Mrs. Bird, that of eggs in traditional egg custard. It may be that at this time Bird did not see his developments of these products as mere commercial moves—and therefore the value of patenting was not in mind. Nevertheless, advertising became a part of his business strategy as shown in his Worcester Street shop, Birmingham. There he displayed the motto: "Early to bed, Early to rise, Stick to your work, and Advertise."

Although having first formulated his fermenting powder in 1843 it was not until more than ten years later that his public advertising occurred. By this time competitors were beginning to appear as the notices below prove. Jones also gained recognition through local advertising in the *Bristol Evening Post* around 1849 (53). A notice regarding Bird's appreciation of wider markets appeared in the *Illustrated London News* (54):

> Mr. Alfred Bird, chemist, Birmingham, communicated with the Duke of Newcastle, as head of the War Department, offering to supply the troops in the East with his baking and fermenting powder, which would admit of their being regularly supplied with fresh bread, as well as prove invaluable in the hospitals for the supply of the sick and wounded with bread, light cakes, light puddings, and other articles of food suited to their condition.

In due course Bird became successful in supplying BP to Her Majesty's Forces. He appears to have made inroads into naval outlets inasmuch as the following notice appeared in *The Bristol Mercury* (55):

> Alfred Bird's Fermenting and Baking Powder, as approved of by the Lords of the Admiralty, The Secretary of State for War, and the Hon. East-India Company.

Nevertheless, Bird was not without competition in domestic markets, perhaps as a result of the absence

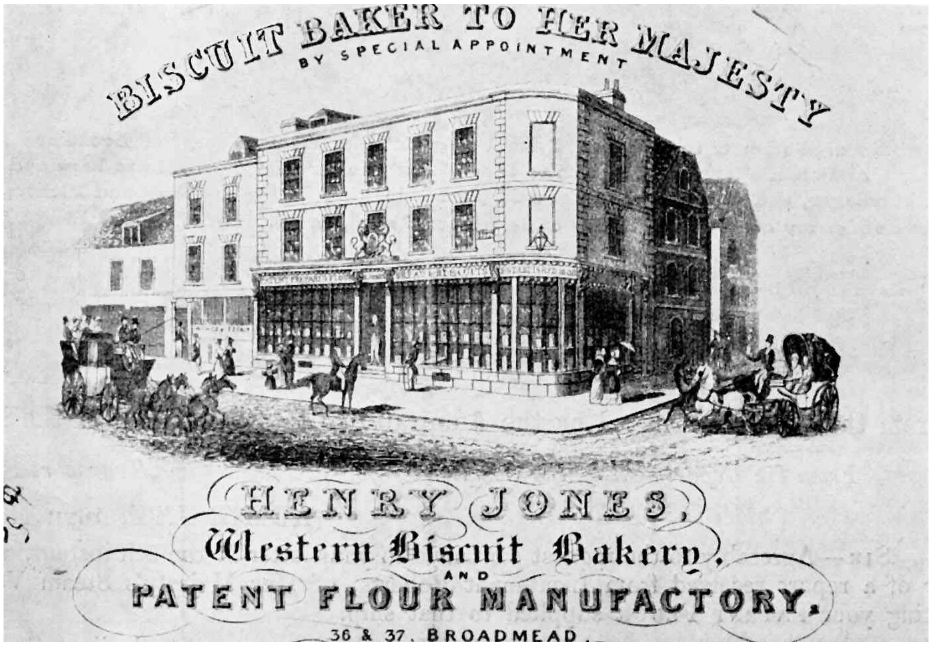

Figure 1*. The bakery and patent flour factory of Henry Jones, "Biscuit Baker to Her Majesty," in Bristol. Courtesy of Peter Townsend, www.bristolpast.co.uk .*

of patenting. Several new suppliers came into being as shown by newspaper advertising:

- The Bristol Mercury, Saturday, June 6, 1846; Issue 2933 Matthew's Baking Powder "as prepared by E H Matthews of Bristol."
- The Leeds Mercury, Saturday, August 28, 1847; Issue 5934 "Bread Without Yeast—BORWICK'S German Baking Powders On sales at London druggists etc."
- The Times, Thursday, May 3, 1855; issue 22044 "Barm Superseded, by using Bird's Baking and Fermenting Powder" Lists suppliers, e.g., Fortnum & Mason, et al. and Ray, chymist, George street, Dublin ... and of the inventor, Alfred Bird, experimental chymist, 5, Worcester Street, Birmingham.

There is strong evidence pointing to Jones's immediate commercial success. Royal patronage had been granted in 1846, only one year after his invention, by being appointed purveyor of patent flour and biscuits to Queen Victoria. This success and that of the protracted saga with the admiralty is well described by Chivers (56), who provided a generous narrative and ample evidence of Jones's efforts over many years to gain recognition by naval authorities. Such slow progress with these authorities occurred in the face of overwhelming support from individual ships' captains and one important writer to *The Lancet*. An extensive letter by the son of the eminent analytical chemist, W. Herapath, commended Jones's patented flour to mariners and described the product as having "perfectly succeeded in its object" (57). This journal published another correspondent's opinion, "We agree with Dr. Herapath, in considering that Jones's Patent Flour is one of the most valuable inventions of the age; …" (58).

Whatever problems Jones found in his earlier negotiations with the Admiralty there could be no doubt of the efficacy and value of his new product. According to an earlier notice in *The Lancet* (59):

> Approved by the Lords of the Admiralty and eminent Medical and Naval Authorities—By Royal Letters Patent.
>
> Prepared Flour, for making bread at Sea, &c., by the addition of water only. Manufactured by the patentee, Henry Jones, 36 and 37, Broadmead, Bristol. By the use of this flour, captains, passengers to India, &c. may have fresh bread daily through the longest voyage; it is made in two or three minutes, and will be found far superior to that by the ordinary mode. Sold in cases, (containing 14 lb.) 4s 6d …

In the same edition, and others, the following notice appeared:

> Sir, _ With reference to your letter of the 27th ult., relative to your Patent Prepared Flour, from the use of which nautical men may have fresh bread, daily, during long voyages, I have to acquaint you, that

> their Lordships have tried the flour made into bread, which they find to be perfectly good, and wish to know whether your patent can be applied to the flour manufactured in the victualing establishments. I am, sir, your obedient servant, William Leyburn. For Controller of Victualling.

Clearly, not only was Jones an inventor but also a very active business man. By 1846 he had appointed an agent in the West Indies and patents in several other European countries soon followed. Chivers claimed he had "granted licenses to make the flour to seventy-eight persons in Britain, ..." (60). Furthermore, an American patent of 1849 points to Jones's continued commercial success (61).

The question of how an artisan baker became aware of chemical neutrality is not easy to answer, but his patent demonstrates such awareness (62):

> The quantities of acids and alkalies may have to be slightly varied according to their quality, but the point to be attained is the neutralization of both;…

His recipe consisted of 10½ oz tartaric acid, 12 oz sodium bicarbonate, 24 oz salt and 8 oz of loaf sugar, into one hundredweight of flour—these amounts of reactants would give an alkaline result and some yellowing of baked goods, and more importantly, by modern standards a low volume of CO_2 (63).

He gave no indication how he determined the total amount of reactants needed although a later reference to the high cost of using alternative raising agents (potassium bicarbonate, citric acid) suggested he had somehow worked out the minimum quantity to give an acceptable degree of "rise"—if but low by modern standards. To one hundredweight of flour he added the carefully weighed tartaric acid (62):

> I mix it well with the flour, and pass both through a flour dressing machine, and allow it to remain untouched for two or three days that the water of crystallization always more or less present in the tartaric acid may be absorbed by the flour, and so form around the particles of acid a coating of flour that will prevent its immediate contact with the particles of alkali.

Then follows Jones's remarks on two chemical aspects—neutrality and water of crystallization, and perhaps a commercial awareness of sell-by-date aspects of his new food product. Premature loss of CO_2 remained a problem not entirely removed until the introduction of "two stage" reactants based on cream of tartar and later on by acid phosphates. There is no clear indication from where Jones's chemical information came. Chivers mentioned that W. B. Herapath was a personal friend of Jones but sadly gave no direct evidence for this opinion. One indirect pointer to a possible friendship shows in Herapath's letter to the *Lancet* (64):

> Some time ago he [Jones] kindly permitted me to inspect his apparatus and the whole process of preparing the flour, making the dough, and baking the bread … A few minutes suffice to mix the necessary ingredients with the flour, and then, simply by stirring up a little water with this mixture, and kneading the mass for a short time, it becomes a dough, as spongy and elastic as if twelve hours had been consumed in its manufacture by the old method; ...

The writer makes no mention of the nature of the raising ingredients but admits to having eaten a loaf eight months ago and testified "to its sweetness and perfect flavour." Obviously Jones was successfully making unfermented bread long before Herapath's bakery visit mentioned above.

In the absence of appropriate chemical knowledge it seems possible that Jones or indeed Bird, could have based their recipes on simple empirical observation. It should be noted, however, that Jones's home town of Bristol supported a renowned philosophical institution (65) and a Society of Enquirers from 1823 (66). One can reasonably assume these provided areas of active chemical discussion and exchange.

Jones comments on the water of crystallization of tartaric acid but this is not easily understood. His patent implies that the acid would give up its water of crystallization to the flour and so reduce the risk of premature reaction, and also that the flour would provide a protective coating to the acid particles. If he was indeed using a hydrated tartaric acid of say one molecule of water of crystallization, then his final CO_2 evolution would have been further reduced to about 0.31% (by weight). But there is no certainty that a hydrated tartaric acid was in use other than his strange reference to the transfer of water of crystallization to the flour. Muspratt (1860) described Jones's invention without mentioning him by name, and pointed out that the flour mixture should "remain untouched for two or three days, that the constitutional as well as the mechanical water present in the tartaric acid may be absorbed by the flour, …" (67). Water held in hydrated tartaric acid would not tranfer to flour granules. In either case the recipe contains unused bicarbonate due to insufficient tartaric acid which would result in an alkaline baked product. Perhaps his suggestion that the reactants "may have to be slightly

***Figure 2**. The patent flour factory of Henry Jones in the 1950s. Courtesy of Peter Townsend, www.bristolpast.co.uk .*

varied according to their quality" was thought sufficient information in a published patent.

Much of Bird's chemical knowledge may have originated from his early apprenticeship with the Birmingham druggists and chemists company of Philip Harris. He became a member of the Pharmaceutical Society of Great Britain in 1842, having set up his own shop in Bell Street, Birmingham in 1837 (68). His life's chemical abilities show in his gaining Fellowship of the Chemical Society on 20th January 1870 (5).

The formulation of a chemical reaction as an alternative to fermentation demanded some moderate chemical knowledge. This would have been well within Bird's capabilities but the expertise of Liebig's more scientific work on the reaction of sodium bicarbonate with an acid to liberate CO_2 in baked goods, did not occur until well after the successes of Jones and Bird in England. Furthermore Liebig should not be entirely credited with the invention of BP as reported by Partington (69). Nevertheless in his *Familiar Letters* Liebig pointed out that during fermentation there is a loss of nutritive value of flour and therefore supported aeration "by means of substances [hydrochloric acid and sodium carbonate] which, when brought into contact, yield carbonic acid." Earlier he had argued differently insofar as (70)

> … chemical preparations ought never, as a general rule, to be recommended by chemists for culinary purposes; since they hardly ever are found pure in ordinary commerce. For example, the commercial crude muriatic acid, which it is recommended to add to the dough along with bicarbonate of soda, ...

Liebig was writing in 1851, but Bird, Jones and others had long before established the better use of solid aerating agents. Whatever uncertainties Liebig's comments suggest, the period of using aqueous mineral acid must have been drawing to a close.

The success of Bird's BP and related products, in parallel with Jones's "prepared flour," later to become known as SRF, is well recorded. Their use of trademarks and packaging gave immediate recognition and show little change to this day. The chemical basis of their products continued to receive investigation—particularly because of the inherent chemical inclination to produce CO_2 prematurely.

While cream of tartar (potassium hydrogen tartrate) was generally the acid ingredient of choice, the investigation of acid calcium phosphate in one form or another soon followed. It was probably Horsford in America, through collaboration with Liebig in Germany who first experimented with phosphoric acid and phosphate salts (71). To this day BPs and SRFs employ acid phosphates offering a two-stage reaction. Tartaric acid, which is very water soluble, is rarely used although cream of tartar remains popular. This, like the acid phosphates, offers slow release of CO_2 in the cold, the main evolution being at oven temperatures (72). Some degree of aeration during initial dough making is desirable followed by further release of CO_2 during proving and final baking. It is in these requirement where acid phosphates (particularly acid sodium pyrophosphate, $Na_2H_2P_2O_7$) prove more favorably but their consideration is outside this present article.

Conclusion

The history of BP and SRF has origins from the early use of pearl ash in baking (for reasons not entirely clear) to the incorporation of a balanced chemical reaction to provide aeration without harmful effect on human digestion. It is perhaps unique inasmuch as it represents a very early employment of a chemical reaction so well known to chemists, i.e. acid plus base gives salt plus water—but in this instance an additional aerating gas, CO_2. From whatever compound an innocuous gas might be easily and cheaply obtained, it was to sodium bicarbonate that early pioneers soon turned, having dismissed potashes, sodium carbonate and ammonium carbonate.

The history therefore turns on the acid rather than the alkaline component. To modern eyes the sheer impracticality and danger of using mineral acids (particularly hydrochloric acid) rules out their use and it is surprising that this means received serious consideration. That such a method continued to be reported in academic journals for such a long period may seem surprising particularly, Muspratt's reporting in1860 of the continuing use of hydrochloric acid in unfermented bread.

In whatever way we now view Whiting's patent and those of others considered in this article, such efforts provided the initial turning point that expanded baking processes.

It is reasonable to assume that the interest in bread by early chemical philosophers, such as Henry in 1785 arose from their medical standing and this article has shown their concerns about yeast-raised baked products. From Henry's early work there appears to have been an idea that in the fermentation process there is a loss of nutritive gluten and sugar. This posed the question whether a more strictly chemical process might overcome this drawback. The possible inconvenience and slowness of yeast fermentation and the market availability of yeast are factors now difficult to determine. If a judgment is on the basis of the number of medical persons investigating this topic, then a perspective embracing nutrition and health seems inescapable. Dyspepsia has been frequently noted as a factor arising from yeast-raised bread and though, to modern eyes, this appears of minor importance it is difficult to judge its contemporary significance. Darling had no hesitation in claiming his process as offering anti-dyspeptic properties and as a means to obviate constipation, but nevertheless the question of taste remained uppermost. Colquhoun had observed the acidity found in bread by over-fermentation resulting in an acetous taste—this being answered by a chemical additive—magnesium carbonate, (a substance frequently prescribed for dyspepsia). But it was his work on chemical aeration which drew Darling's support based on the belief that chemical aeration provided a more "salubrious product ideal for the dyspeptic."

Overlaying these perspectives there nevertheless remained the almost tacit belief that fermentation had some deeper meaning bordering on the mysterious. Oddly, no evidence has been found that the temperance movement (73) ever feared residual alcohol in yeast fermented bread. Nevertheless, according to Harrison (37), Dauglish's competitors were quick to adopt a new selling point for yeast-raised bread "by placarding the neighbourhood of the aërated bread factory with 'Buy the bread with the gin in it.'" But it was also this entrepreneur who firmly believed in the wholesomeness of unfermented bread as against the implicit degradation through "decay and corruption" in fermented bread. However we might now interpret these personal comments it seems clear that medical reasoning provided a motivating force for chemical aeration—perhaps no better illustrated than by Bird's endeavors to remedy his wife's allergies. McGee, in 1984 (74), pointed to an American health movement of the mid-nineteenth century that "raised breads were likely to be harmful," a conclusion apparently reached from certain religious concerns arising from sacrificial ceremonies in which leavening was somehow related to "spoilage and decay."

Although Henry attempted to formulate a theory of yeast fermentation its absence did not apparently hinder his experiments or those of others in finding a chemical alternative to yeast aeration, and by the time of Pasteur's full explanation in about 1857, both BP and SRF were established domestic and commercial products as shown by Bird and Jones.

Priority of invention, whilst of little value in itself, is clearly shown in these two entrepreneurs. Their efforts concerning the aeration of baked goods took different paths, the dates of which preceded developments in America and certainly those of Liebig in Germany to whom credit has sometimes been wrongly directed. The 1840s was a time when industrial revolution in Britain was well under way, population had increased greatly, and bread was needed. It is no surprise therefore that efforts to find an alternative to yeast in bread-making had beginnings before the work of Bird and Jones. The philosophers mentioned earlier devoted their time and text book writings (which often included extensive sections on bread-making), to aeration by chemical means. Concerns were expressed about the quality of chemically raised baked goods (for example, Ure, as shown earlier, made such criticism), but nevertheless Jones and Bird saw beyond this in foreseeing a product ideally suited to the needs of military and naval outlets, almost before similar insight of their commanders (75). To what extent these outlets promoted a domestic demand is impossible to determine. The commercial success of both Bird and Jones, beginning in the 1840s is without question, and SRF has remained to this day a standard domestic product. The fact that baking powder can be used to obtain the same result does not seem to have influenced demand one way or the other. Both products had different origins of motivation—Bird's arose from his wife's allergies and Jones's by mere business drive. Whatever markets these products find in modern day application it should be noted that BP and SRF have retained their role as efficient substitutes to fermentation by yeast.

Acknowledgment

I would like to thank Professor W. H. Brock for his reading of an early draft of this article and the considerable services of the Radcliffe Science Library, Oxford.

References and Notes

1. The term self-rising appears to be more common in US English, self-raising in UK English. —Editor
2. P. R. Jones, "Justus von Liebig, Eben Horsford and the Development of the Baking Powder Industry," *Ambix*, **1993**, *40* (pt. 2, July), 65-74.
3. Ref. 2, p 73, quoting from J. Liebig, "Eine neue Methode der Brodbereitung," *Ann. Chem. Pharm.*, **1869**, *149*, 49-61.
4. Although much of this article draws on patent record information, there is a considerable archive originating from Henry Jones of Bristol, consisting mainly of Letters Patent, licences, and related correspondence held by Bristol Record Office, ref. 29932.
5. J. R. Turner, "Alfred Bird (Bap. 1811, d. 1878)," *Oxford DNB,* Oxford University Press, Oxford, 2004. [http://www.oxforddnb.com/view/article/38977, accessed March 31, 2012]. This author is a great-great grandson of Alfred Bird and the entry is taken from family records and other published confirmatory material.
6. See J. Burnett, "The Baking Industry in the Nineteenth Century," *Bus. Hist.*, **1962-3**, *5*, 98-108.
7. A. Simmons, American Cookery, Hudson & Goodwin, Hartford, CT, 1796, contains four baking recipes where pearl ash is incorporated into milk, cream or water, but no reasons given for its use. Also cited in H. McGee, *On Food and Cooking; the Science and Lore of the Kitchen,* Allen & Unwin, London, 1986 (© 1984), 519. This author claims potash as the first chemical leavening agent, p 533.
8. J. R. Partington, *A History of Chemistry*, Macmillan, London, 1962, Vol. 3, 659 and 579.
9. Though often claimed to be commonly used, the maximum lactic acid content in fully soured milk is rarely much above 1%. On the basis that half a pint (237 mL) of sour milk is needed to produce a dough from 1 lb (454 g) of flour, and assuming all the lactic acid reacted to produce CO_2 from added sodium bicarbonate, the amount of gas produced would be small (0.26%).
10. M. P. Crosland, "Jean Antoine Chaptal," *Complete Dictionary of Scientific Biography*, 2008. [http://www.encyclopedia.com/topic/Jean_Antoine_Chaptal.aspx, accessed Feb. 16, 2013]. See also J. A. Chaptal, *Chemistry Applied to the Arts and Manufactures*, R. Phillips, London, 1807, Vol. 4, 207-209. The author describes a method of preparing cream of tartar from argol or lees which had appeared in *Memoires of the Academy of Paris* as early as 1725.
11. H. Benninga, *A History of Lactic Acid Making*, Kluwer, Dordrecht, Netherlands, 1990, 7, describes a method as given in the first *Dutch Pharmacopoeia,* Bataafse Apotheek, 1807.
12. Ref. 11, p 34, quoting Société industrielle de Mulhouse, *Histoire documentaire de l'industrie de Mulhouse…*, vol. 2, Veuve Bader & Cie, Mulhouse, 1902**.**
13. D. Chapman-Huston and E. C. Cripps, *Through a City Archway: The Story of Allen and Hanburys 1715-1954*, J. Murray, London, 1954, 18.
14. T. Henry, "Experiments and Observations on Ferments and Fermentation; by which a Mode of Exciting Fermentation in Malt Liquors, without the Aid of Yeast, is Pointed out; with an Attempt to Form a New Theory of that Process," *Mem. Lit. Phil. Soc. Manchester,* **1785**, *2*, 257-277 (259).
15. Ref. 14, pp 262-263.
16. Ref. 14, p 263. This is a very early example of impregnating water with CO_2 which, when later released, aids aeration. See also W. V. and K. R. Farrar and E. L Scott, "Thomas Henry (1734-1816)," *Ambix*, **1974**, *20*, 183-208, 204.
17. See K. E. Golden, "Fermentation of Bread," *Bot. Gaz.*, **1890**, *15* (no. 8 August), 204-209. Little was understood of the chemistry involved until the 1880s. It was generally assumed that yeast caused carbon dioxide and alcohol to be generated from sugar: the liberated gas caused the dough to rise and the alcohol was volatilized without residue.

18. A. Edlin, *A Treatise on the Art of Bread-making* …, Wright for Vernor & Hood, London, 1805, 149-151.
19. T. Thomson, *A System of Chemistry*, Bell & Bradfute, Edinburgh, Murray, London, 1810, Vol. 5, 392.
20. T. Thomson, *Chemistry of Organic Bodies: Vegetables*, Bailliére, London, 1838, "Of the Panary Fermentation," 1028-1032.
21. F. Accum, *A Treatise on Adulterations of Food, and Culinary Poisons*… Longman, Hurst, London, 1820, 2nd ed., 125-142, on 133.
22. Ref. 20, p 1032.
23. Quoted in *The Gentleman's Magazine*, 1817, (London), pt. 1, 149 from R. Reece, Ed., *The Monthly Gazette of Health*: a letter from J. O. R., York, Dec. 16, 1816 and the Editor's response.
24. H. Colquhoun, "A Chemical Essay on the Art of Baking Bread," *Ann. Philos.*, **1826**, *12* (New Series), articles I and IV, 161-182, 263-281. The essay was written at the time of his graduation as MD from University of Glasgow. W. Innes Addison, *The Matriculation Albums University of Glasgow from 1728 to 1858*, Maclehose, Glasgow, 1913, 293, shows, "M.D. 1826; never practiced medicine; was partner for many years of firm of Colquhoun & Balloch."
25. Ref. 24 (Colquhoun), p 177.
26. Ref. 24 (Colquhoun), p 265.
27. Ref. 24 (Colquhoun), p 268.
28. Assuming the tartaric acid to be anhydrous in both recipes, the sodium bicarbonate/tartaric acid content would have given about 0.4% CO_2, whilst the magnesium carbonate/tartaric acid about 0.5% CO_2. If neutrality had been reached in these recipes, as the author claimed, the available CO_2 would have been about 0.6% and 0.9% respectively.
29. Ref. 24 (Colquhoun), p 269.
30. Ref. 24 (Colquhoun), p 276.
31. *Instructions for Making Unfermented Bread…by a Physician*, Taylor & Walton, London, 1846. A 15-page brochure, thought to be by George Darling, was issued in several later editions until 1851. A pamphlet is held by Worcester College Library, Oxford. See also J. Dixon, *"George Darling, (1779/80–1862)," Oxford DNB*, Oxford University Press, Oxford, 2004, rev. P. Wallis. [http://www.oxforddnb.com/view/article/7154, accessed Apr. 20, 2012].
32. No such edition exists, the nearest next being 1817. No entries regarding the use of muriatic acid with an alkali for aeration purposes have been found in sections on baking, bread, fermentation or in the large chemistry section.
33. Ref. 31 (*Instructions*). This appears on p 4 of the pamphlet, but as stated above no similar instructions by Thomson can be found in the 1817 edition of *Encyclopaedia Britannica* or in Thomson's earlier 1810 edition of A *System of Chemistry*, or in his later 1838 *Chemistry of Organic Bodies: Vegetables*, "Panary Fermentation."
34. Ref. 31 (*Instructions*), p 4. This recipe would result in very acidic baked goods. There is up to seven times more acid present than is needed and the bicarbonate present would give more CO_2 (about 1.3%) than is needed.
35. "Instructions for Making Unfermented Bread, with Observations by a Physician," *Edin. Med. Surg. J.*, **1846**, *66* (pt. 3), 248-250.
36. Ref. 35, p 250.
37. W. J. Harrison, "Dauglish, John, (1824–1866)," *Oxford DNB*, Oxford University Press, Oxford, 2004, rev. C. Clark, [http://www.oxforddnb.com/view/article/7189, accessed Feb. 29, 2012].
38. J. Dauglish, "On a New System of Bread Manufacture," *J. Soc. Arts*, **1860**, *8* (April 27), 414-425.
39. Ref. 6, p 101-102. See also Ref. 37.
40. British Patent no. 7076, 3. Specification of the Patent granted to John Whiting, late of Rodney Buildings, New Kent Road, in the County of Surrey, but now of Kennington, in the said County of Surrey, M. D., for an Improvement or Improvements in preparing certain Farinaceous Food.—Sealed May 3, 1836.
41. A. Ure, *A Dictionary of Arts, Manufactures, and Mines*, Longman, London, 1840, 175.
42. *Repertory of Patent Inventions and other Discoveries and Improvements in Arts, Manufactures and Agriculture. New Series*, **1837**, *8*, J. S. Hodson, London, 1837, 267-271.
43. Commissioners of National Education Ireland, *Chemistry and Chemical Analysis*, A. Tom, Dublin, 1861, 319.
44. J. S. Muspratt, *Chemistry, Theoretical, Practical, and Analytical*, Mackenzie, Glasgow, 1860, Vol. 1, 379, "Unfermented Bread."
45. Ref. 42, p 268.
46. *Repertory of Patent Inventions* … **1848**, *11*, T. R. Sewell, of Carrington, in the Parish of Basford, Nottingham, Chemist, for Improvements in preparing flour. —Sealed January 18, 1848.
47. "On Chemical Substitutes for the Fermentation of Bread," *Pharm. J. Trans.*, **1853-4**, *13* (no.4), 172-174, 173.
48. In baked goods this recipe would result in an alkaline product, there being an excess of added bicarbonate. The quantity of acid in the flour would only neutralize a portion of the added bicarbonate to generate about 0.3-0.4% CO_2.
49. These amounts are similar to those already given and again show an excess of bicarbonate resulting in an alkaline product of poor aeration.
50. British Patent A.D. 1845. No. 10,555, Preparation of Flour. Jones's Specification, 1-3.
51. See D. E. Powell, "Jones, Henry James (1812–1891)," *Oxford DNB*, Oxford University Press, Oxford, 2004. The author describes Jones as the inventor of self-raising flour. [http://www.oxforddnb.com/view/article/74330, accessed Feb. 29 2012]
52. Ref. 50, p 2.
53. See Bristol Record Office, ref. 29932/28/a-b c.1849.
54. *Illustrated London News*, Apr. 24, 1855.
55. *Bristol Mercury*, Feb. 23, 1856, issue 3440.

56. K. Chivers, "Henry Jones Versus the Admiralty," *History Today*, **1960**, *10*, 247–254.
57. W. B. Herapath, "On the Making of Bread without Fermentation," The *Lancet*, **1846,** May 2, 508. See also K. D. Watson, "William Herapath**,** (1796–1868), Analytical Chemist*," Oxford DNB*, Oxford University Press, Oxford, 2004. [http://www.oxforddnb.com/view/article/13011, accessed Feb. 9, 2013.]
58. X., *The Lancet,* **1846,** June 13, 642.
59. Advertisement, *The Lancet*, **1845**, Sept. 13, "Important Inventions," 304. Copy of a Letter from the Board of Admiralty, London: —Admiralty, July 5, 1845.
60. Ref. 56, p 248.
61. H. Jones, "Improvement in the Preparation of Flour for Bread-Making," US Patent 6,418, issued May 1, 1849.
62. Ref. 50, p 2.
63. According to D. W. Kent-Jones and A. J. Amos, *Modern Cereal Chemistry*, Northern Publishing, Liverpool, 1947, (4th ed.), 369, about 3 lb 4 oz of sodium bicarbonate added to 280 lb of flour (1.16%) generates approximately, 0.60% total CO_2 and is regarded as an acceptable amount. Jones used 12 oz of bicarbonate to 112 lb of flour which, by calculation, would only produce 0.35% CO_2, about half of that required by modern standards. In practice the available CO_2 would have been even lower (0.34%) because of insufficient tartaric acid for complete neutralization. He could have safely increased his bicarbonate to 2 1oz, and tartaric acid to 18.8 oz, to give 0.6% CO_2 and a neutral reaction.
64. Ref. 57 (Herapath).
65. Bristol Institution for the Advancement of Science, Literature and the Arts, founded in 1823, and located in Park Street. See M. Neve, "Science in a Commercial City: Bristol, 1820-60," in I. Inkster and J. Morrell, Eds., *Metropolis and Province: Science in British Culture 1780-1850*, Hutchinson, London, 1983, 179-204.
66. Ref. 65, p 192. This Society dates from 1823 and held weekly meetings in the Masonic Hall, Broad Street with William Herapath as a known activist. Frequently reported in the *Bristol Mercury*; no known archives.
67. Ref. 44, vol. 1, 380.
68. Ten years later, in 1852, he passed the Society's major examination and qualified as a pharmaceutical chemist. Registration with the society became a legal requirement to anyone setting up as dispensing chemist from 1868.
69. Ref. 8, vol. 4, (1964), p 316.
70. J. Liebig, *Familiar Letters on Chemistry*, Taylor, Walton & Maberly, London, 1851, Letter XXIX , 443-445.
71. E. N. Horsford, *The Theory and Art of Breadmaking. A New Process Without the Use of Ferment*, Welch, Bigelow, Cambridge, MA, 1861, a 30 page pamphlet. On p 30, the author uses the term self-raising flour.
72. For a full account of this topic see ref. 2, p 67. The use of acid calcium phosphate in England was reported by Horsford in 1868, p 70.
73. A. McAllister to F. G. Page, personal communication, Jan. 17, 2013. The UK temperance movement is generally regarded as having begun in the 1830s and reached its zenith 1870-1900.
74. Ref. 7 (McGee), p 281.
75. Ref. 18. Such outlets had already been identified by Edlin in 1805: "To captains of ships, to military men, and such who travel into unfrequented regions … such plain and easy instructions are laid down for making good bread, …" viii.

About the Author

After retiring from the chemical industry in 1989, the author gained a M.Sc. degree at the Oliver Lodge Laboratory of the University of Liverpool. His studies of early analytical chemistry under the supervision of Professor W. H. Brock resulted in his earning a doctorate from the University of Leicester in 1999. The article above relates from his early employment with Albright & Wilson and involvement with the development of food phosphates.

BOOK REVIEWS

The Periodic Table and a Missed Nobel Prize, Ulf Lagerkvist (Erling Norrby, Ed.), World Scientific, Singapore, 2012, xii + 122 pp, ISBN 978-981-4295-95-6, $22.

The cover of this small volume proffers a juxtaposition of tantalizing topics. The periodic table is an area of evergreen interest to chemists, and the appeal of Nobel Prizes extends well beyond chemists. The title promises a tale of Nobel glory denied and the cover shows that Mendeleev was the person so denied. Unfortunately, however, much of the book is peripheral to what the title portends—although much of it is interesting in its own right. The disconnect between the book's title and its contents may leave readers disappointed, though; it left me disappointed.

Having led with an assessment that is hardly a ringing endorsement, I feel a bit churlish in criticizing the work of a posthumous author; after all, Prof. Lagerkvist (1926-2010) cannot defend his work. Indeed, it is difficult to fault the author, the editor, or the publisher for the book's deficiencies. After all, the editor and the publisher acted to make sure that Lagerkvist's last work came to fruition. At the same time, Lagerkvist cannot be faulted for a work that may not have been ready for publication or that may have changed in focus over the course of writing.

The story of the book and a brief biography of the author are recounted in editor Erling Norrby's foreword. Lagerkvist was a biochemist, a member of the Royal Swedish Academy, and a reviewer for Nobel committees in chemistry. After his retirement, he turned to writing, including memoir, popular science, and history of science. Shortly before his death in 2010, he was awarded a grant to publish a book with World Scientific entitled *The Bewildered Nobel Committee*—a book that turned into the one reviewed here. Norrby's foreword got the book off to a good start, presenting interesting material unlikely to be already familiar to it readers. And if the foreword was not strictly on the topic defined by the book's title, it was certainly relevant to the circumstances surrounding the very publication of the book.

The main text comprises three sections titled "Elements, Atoms and Molecules," "Atomic Weights and their Relation to Chemical Properties of the Elements," and "The Elusive Nobel Prize." One might expect from the book's title that these sections correspond to a pre-history of the periodic law, the development of the periodic law, and the Nobel prize not awarded to Mendeleev. Certainly the middle section fits such a scheme, but the first and last sections include much trekking far afield.

The first section gets the main text off to a somewhat inauspicious beginning. Its brief treatments of Giordano Bruno, alchemy, and the phlogiston theory are rather distant from the title topics, even as background for the development of the periodic table. Furthermore, these topics are treated more as symbols than with the contemporary historical sensibility of trying to understand the past in its own context. Bruno, for instance, "has become a symbol of the free and independent scientist" even though, as the next sentence notes, "he was a mystic and a poet rather than a scientist." The phlogiston theory is said to have warped chemistry until Lavoisier overturned this "Alice-in-Wonderland kind of chemical thinking."

The latter portion of the first section and the whole of the second have the virtue of treating one of the book's major topics, the development of the periodic table. That material is undermined somewhat by a number of errors and by the fact that most of the information is widely available from other sources (and likely, therefore, to be already familiar to many readers). The errors are mostly minor, such as persistent misspelling of Avogadro and a misidentification of Mendeleev's second (improved) published periodic table as his original. There is also a significant misstatement that Mendeleev predicted three noble gases to fill atomic weight gaps. The fact that later in the book the author states that noble gases were unsuspected by Mendeleev leads me to believe that this error—and perhaps others—would have been caught by the author in the course of revisions and proofs if he had had the opportunity.

The third section, comprising about half of the book's main text, contains much material that is both interesting and likely to be unfamiliar to its readers. Most of this final section describes the Royal Swedish Academy of Sciences from its founding through the early days of the Nobel Prizes. I enjoyed reading this material, focused on the heroes of early Swedish science and their successors, some of whom (Linnaeus, Scheele, Berzelius, and Arrhenius) became leading figures in European science even though they operated on its periphery.

The last ten pages of the section tell the story of the failure of the Swedish Academy's Nobel committee to make Mendeleev a Nobel laureate. Much is made in this section of the provision under which the Nobel Prizes were to recognize recent achievements as a reason why Mendeleev was not even nominated in the very first years of the prize: the periodic table was too old and well established for his accomplishment to be considered recent. Then the Nobel Prize awarded to William Ramsay in 1904 cited both the discovery of the "inert" gases and their placement in the periodic system. This apparently put the periodic system back into the minds of the Nobel committee and provided grounds for recognizing one of its principal inventors—recent research (namely Ramsay's) having shed new light on the significance of Mendeleev's work. Mendeleev was nominated for both the 1905 and 1906 prizes, and indeed was initially the favorite of most of the committee for the 1906 award. How that award came to be bestowed upon Henri Moissan is described in some detail. Mendeleev died early in 1907, making him thenceforth ineligible for consideration.

In sum, readers informed about the contents of the book will find that there is much to like in this slim volume. Readers who judge the book by its cover, however, may well be disappointed.

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A Tale of 7 Elements, Eric Scerri, Oxford University Press, Oxford, 2013, xxxiii + 270 pp, ISBN 978-0-19-539131-2, $19.95.

This book concerns the seven of the 92 naturally-occurring elements which had not been discovered by 1913, when Moseley showed that atomic numbers are an integral part of elemental properties and lie at the heart of the periodic table. These seven elements are treated in Scerri's book in separate chapters arranged by the chronology of their discovery: protactinium (91), hafnium (72), rhenium (75), technetium (43), francium (87), astatine (85) and promethium (61). There are two introductory chapters on Periodicity, and the last, chapter 10, briefly discusses elements 93 to 118.

In a long introduction Scerri discusses the criteria which constitute the discovery of an element, and the often complex matter of priority of discovery; each of these seven elements was claimed by a number of people. Scerri's first chapter, "From Dalton to the Discovery of the Periodic System," recounts the history of periodicity from Dalton to Mendeleev. (A curious conceit here is that it is all in the present tense except for the few pages on Mendeleev, which are in the more conventional past tense.) The second, "The Invasion of the Periodic Table by Physics," takes the story from Thomson's discovery of the electron to the Bohr atom and the four quantum numbers. Werner's astonishingly prescient suggestion of 1905, that thorium and uranium might occupy a lanthanide-like series rather than being transition elements is unfortunately not mentioned, though it is relevant to this book because elements 91 and 93-103 are what we now call the actinides. For each of the next seven chapters in which the tale is woven there is usually an introduction, a modern Periodic table showing the position of the element, a history of its discovery, the names of the generally accepted discoverers, and a short account of its chemistry and applications.

Protactinium (element 91, Mendeleev's *eka*-tantalum) is the first to be considered. Many names are associated with its recognition, for example, Göring, Crookes, Fajans, Soddy and Cranston, but it is generally agreed that Lise Meitner and Otto Hahn discovered it. The deplorable omission of Meitner from the Nobel prize for chemistry awarded to Hahn in 1944 for his work on fission is discussed: rightly, Scerri emphasizes the considerable role that women have played in the story of his seven elements. Hafnium (element 72) is one of the only two non-radioactive elements in this series, and the story of its discovery is complex. In 1911 Urbain (who had discovered ytterbium and lutetium, numbers 70 and 71) thought he had isolated another rare-earth, element 72, and called it celtium; Bohr, however, cast doubt on this, and the Dutch chemist Dirk Coster and the Hungarian George de Hevesy are the accepted discoverers of hafnium in 1923: they named it after the city of Copenhagen (Latin *Hafnia*). Rhenium (number 75, Mendeleev's *tri*-manganese) is likewise not radioactive. It was finally discovered by Walter Noddack and Ida Tacke (who later married Noddack) in 1925, and was named after *Rhenus,* the Latin name for the Rhine. Scerri recounts in some detail an earlier Japanese claim to have discovered the element as Nipponium in 1908 but there is little evidence that this was rhenium. Technetium (number 43, Mendeleev's *eka*-manganese) is the first man-made element (though there is some evidence now of traces of it in nature). The Noddacks, who had discovered rhenium, believed they had discovered element 43 in 1925 and called it masurium; many other "discoveries" were made by others (for example, ilmenium, neptunium, davyum, uralium, canadium, neo-molybdenum, moseleyum and others), but it was Emilio Segrè and Carlo Perrier who obtained it from molybdenum plates bombarded with deuterons in the Berkeley cyclotron in 1937. Francium (number 87, Mendeleev's *dvi*-caesium), was finally discovered by Marguerite Perey, who had been a laboratory assistant of Marie Curie, in 1939. Although Scerri does not mention this, it was Perey who in 1962 was the first woman to be elected to the Académie des Sciences in Paris, which had shamefully refused to elect Marie Curie, and her daughter Irène, many years earlier. Element 85 (astatine) has a very complex history. Unsuccessful claims were made from 1931 for it as alabamium, dakin, helvetium and anglohelvetium, but it was finally discovered in 1940 by Corson, MacKenzie and Segrè, by α-bombardment of bismuth. Scerri points out that it is one of the very few elements never to have been isolated in sufficient quantities to be visible to the naked eye: only about an ounce is thought to be present at any one time in the entire outer crust of the Earth (a similar abundance, or lack of it, is suggested for francium). Finally, element 61 (promethium), claimed in 1926 as illinium, was obtained in 1947 by Marinsky, Glendenin and Coryell at MIT from ion-exchange separations on material from the Manhattan project. It is well-named after Prometheus in view of its birth from a fiery source. A final short chapter, "From Missing Elements to Synthetic Elements," gives a very brief resumé of the discovery of elements 94 to 118.

The classic work in this area is of course *Discovery of the Elements* by M. E. Weeks and H. M. Leicester (7th ed., Journal of Chemical Education, 1968); there are also many books on the periodic table, including Scerri's own earlier book on the subject. This new book breaks no substantial new ground, but I liked it on its own terms. It is compact and well-presented, researched and referenced; and it has an excellent index. At its relatively modest price it makes for rewarding reading.

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Articles of 4-20 pages, double-spaced (excluding references) should be submitted electronically by email attachment to the Editor, giunta@lemoyne.edu, at Le Moyne College. The title of the article should be of reasonable length (up to 15 words); a subtitle may be included if appropriate. Authors should strive to make the title descriptive of the specific scope and content of the paper. Preferred file formats for submissions are .doc, .docx, and .rtf.

Subheadings within the paper are often appropriate to enhance clarity. Authors should bear in mind, however, that the format of an article in history of chemistry (order and content of sections) is not the same as the format of an article in chemistry. Recent issues of the *Bulletin* should serve as a guide. Detailed text formatting (paragraph justification, for example) need not be imitated, however; such text formatting will be applied at the layout stage. *The ACS Style Guide*, (3rd ed., Anne M. Coghill and Lorrin R. Garson, Eds., American Chemical Society and Oxford University Press, 2006) is also a useful resource for names, terms, and abbreviations appropriate for writing about chemistry.

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