

BRIAN DOLAN

EMBODIED SKILLS AND TRAVELLING SAVANTS

Experimental Chemistry in Eighteenth-Century Sweden and England

1. ANALYSING THE LANDSCAPE

Blowpipe analysis was pioneered in Sweden in the eighteenth century. The blowpipe has secured a place in chemical hagiography by being an instrument with which Swedish chemists such as Axel Cronstedt and Carl Scheele isolated a number of elements including nickel, manganese, molybdenum, and tungsten. Other chemists, such as Gustaf von Engeström, Torbern Bergman, and Jacob Berzelius, were well-known authors of chemical treatises which espoused the utility of blowpipe analysis. This instrument was valued because of the simplicity of the apparatus and its portability. It was small (capable of fitting into a pencil case) and inexpensive. In design, it was a thin, curved metal tube, through which a practitioner would blow air in order to concentrate a candle flame onto a mineral specimen. The intense reducing flame caused rapid decomposition of the mineral, and, with the use of chemical reagents, the chemical constituents of the specimen could often be determined. Analysis could be performed on small mineral samples to provide instant results in the field.¹ Economic, social, and political conditions in Sweden aided the development of this form of chemical analysis. Training in blowpipe analysis was an important dimension in the education of Swedish civil servants, who conducted on-site analyses to determine the location and nature of metals for the increasingly important mining industry.

Sweden's achievements in chemical and mineralogical analysis were widely recognised in Britain by the late eighteenth century. As early as 1770, an edition of an English text on blowpipe analysis written by Cronstedt and enlarged by Engeström drew attention to these practices.² While scattered references to blowpipe analysis by British authors can be found during the

1

Ana Simões, Ana Carneiro, Maria Paula Diogo (eds.), Travels of Learning. A Geography of Science in Europe, 1—27.

© 2007 Kluwer Academic Publishers. Printed in the Netherlands.

first few years of the nineteenth century, it was not until the 1810s that this form of experimentation became popular among British chemical practitioners. Many articles relating to blowpipe analysis were published in natural philosophical journals, discussing new experimental results, new designs for the blowpipe, and suggesting improved ways of conducting analysis. Blowpipes became widely advertised in the market for philosophical instruments and public lectures incorporated demonstrations of their uses. One enthusiastic reviewer of “chemical achievements” in 1816, who referred to the immense interest in blowpipe analysis and its uses for the application of chemical theory to classification systems, went so far as to claim that these steps led to the reconfiguration of classification systems and effected a “very considerable revolution in the theory of that science.”³

Revolution or no revolution, the blowpipe did appear rather suddenly in significant numbers in Britain’s analytical community with widely discussed and debated results.⁴ Why so sudden—and why in the 1810s? The beginning of the nineteenth century was a critical moment for British chemistry—antiphlogiston debates were settling down, a number of new chemical societies were established, and Humphry Davy had just announced the results of his pioneering electrochemical experiments to the patrons of the new Royal Institution and the Royal Society.⁵ Natural philosophical attention was concentrated on what further chemical revolutions might occur through new developments in instrumentation and experimentation, and in the 1810s blowpipe analysis attracted much attention. But why was such a well-known form of analysis not developed more readily in Britain prior to the 1810s? There exists a curious lacunae, particularly if we take as an “introduction” of blowpipe analysis to chemistry and mineralogy in Britain to be Engeström’s 1770 publication. The familiarity with the accomplishments of, and the debt British practitioners owed to, their eighteenth-century Swedish predecessors in developing blowpipe analysis was widely acknowledged in their contemporary accounts. Theory was known, but practice, save a few isolated examples, delayed. Why?

In the 1810s, London instrument dealers such as John Newman, Friedrich Accum, and John Mawe, sold an array of affordable blowpipe apparatus, while authors, including Mawe and Arthur Aikin, wrote manuals describing the use of the instrument.⁶ In Britain by the 1820s, blowpipe kits were standard equipment for chemists, mineralogists, and geologists. In 1827 the chemist and author of popular textbooks, John Joseph Griffin, collected “scattered intelligence” from the previous decade and published an updated essay on the use of the blowpipe.⁷ Historians of science Brian Gee, William Brock, and Ian Inkster have suggested that the familiarity with blowpipe

analysis among the chemical community was the result of the translations of Swedish texts being introduced to the short-lived Askesian Society (1799) and the British Mineralogical Society (1799-1806).⁸ Yet pointing to the appearance of books translated from Swedish as cause for the development of chemical practices in Britain is inadequate.⁹ The aim of this article is to explore some additional issues involved in understanding the transfer of the practices of blowpipe analysis from Sweden to Britain from Engeström's 1770 publication until the publication of subsequent manuals by British authors in the 1810s and after.

At one level, crossing national boundaries draws attention to the different bureaucratic structures in which scientific practices develop. But more detailed examination reveals further subtle conditions which affected the ways in which scientific knowledge "travelled" from one place to another. To this end it is useful to examine the relationship between scientific knowledge presented in texts and the skills of experimentation that transfer face to face. Publications on blowpipe analysis were descriptions of experimental practices linked to particular contexts. Even when examining the use of an instrument celebrated for its simplicity, it is useful to look beyond textual translations to the activities of travellers who acquired new skills and knowledge which they later used to effect changes in their own local contexts.

As we will see in the following account, blowpipes were simple in design but difficult to use. A significant amount of skill was necessary to conduct analyses correctly. In Sweden, attention was given to, and patronage from the state received for, instituting training regimes which facilitated face-to-face, practical training in blowpipe analysis for chemists and mineralogists. This system was observed by three British travellers to Sweden in the late eighteenth and early nineteenth century: Smithson Tennant, Edward Daniel Clarke, and Thomas Thomson. Upon their return to Britain, these travellers pursued an ambitious programme to reform the educational practices in chemistry and mineralogy, and each carried back to Britain a particular interest in blowpipe analysis. Many acknowledged that the books and articles which discussed the uses of this instrument were inadequate guides for teaching others the practical skills involved in this useful form of chemical analysis. Thus, looking at travellers' moments of "hands-on" training helps us to get a sense of the wider issues involved in the transfer of this form of experimentation from Sweden to Britain.

2. TRAINING AND ANALYSIS IN SWEDEN

Chemists in the eighteenth century worked within a framework which distinguished between “dry” methods of chemical analysis, which focused on reactions to heat, and “wet” (or “solution”) methods of analysis.¹⁰ Fire was the central component in dry methods of analysis, the uses of which were promoted by the development of different kinds of furnaces (often the centrepiece to alchemists’ or chemists’ laboratories) and blowpipes. The ability to intensify and concentrate flames broadened the range of chemical reactions, and created new means to define “chemical elements” which contributed to mineral classification.¹¹ These classification systems distinguished between so-called “species” of minerals.¹² In addition to perceived external characteristics, the practice of melting minerals to determine their chemical composition became essential to classification systems.¹³ The first order of classification was the characteristic of fusibility—determining if the mineral could be melted, a quick test with the blowpipe. If the mineral *was* fusible, a larger sample would typically be placed in a furnace for further tests to determine its chemical composition. Chemical analysis of minerals with furnaces was common practice by the late eighteenth century, yet not without its problems. It was clumsy and time consuming. Precise temperatures were difficult to judge and maintain, hours were needed for the specimen to burn, and only once the furnace was opened—was the end result visible.

Before it was developed as an instrument for the chemical analysis of minerals, the blowpipe was a familiar tool for prospectors, smelters, and artisan glass-blowers. However, William Campbell has noted that seventeenth-century natural philosophers including Robert Boyle and Robert Hooke found a “small crooked pipe of metal or glass, such as tradesmen for its use call a blow-pipe,” useful for assaying purposes.¹⁴ Traces of the use of the instrument in mineralogy also stem back to the seventeenth century, when natural philosophers directed blowpipe flames onto mineral samples to reduce them to their simple metallic constituent. This test was designed to meet the practical demand of estimating the amount of metal which could be obtained from an ore, an important analysis for prospectors tending to the increasingly important mining industry both on the Continent and in Britain. Continental theories of mineralogy and chemistry, especially in Sweden and Germany, gave new meaning to heat analysis, mineral classification, and the value of blowpipe analysis for the mining industry.¹⁵

Compared to the “portable laboratories” (which consisted of small furnaces) designed by London instrument makers and natural philosophers in the eighteenth century, blowpipe equipment used in Sweden proved more efficient.¹⁶ Because of their portability, blowpipes could be conveniently taken to the mines where on-site analyses could take place, thus realising the advantage of *in situ* observations during field experiments. During analysis, a pea-sized mineral sample was used, carefully ground to powder, making experiments on precious metals more economical and instantaneous. Unlike using furnaces, the blowpipe allowed the analyst to see chemical reactions as they occurred, rather than just the end result. Hence, flame and smoke colour and brightness, smell, reactions when cooling, weight, even sound in certain instances all became signs signifying the mineral’s chemical constituents.

The first order in mineral classification systems which the blowpipe quickly determined was combustibility. In the eighteenth century, a substance’s ability to burn was thought to be a characteristic marked by the presence of phlogiston in the substance. While phlogiston itself could not be isolated during combustion, weight differences recorded with a precision balance indicated degrees of combustibility, which provided for a two-component theory of classification. Combustible earths could be distinguished experimentally and classified based on measurements of the degree of phlogiston released, as well as different appearances in the reaction of the specimen to heat analysis. Further, the “affinity” which held the component parts together could likewise be measured through degrees of combustibility, which worked by quantifying weight differences in minerals’ constituent ingredients. Blowpipe analysis thus involved skilful qualitative analysis (interpreting empirical signs of the combusting mineral) as well as quantitative measurements (such as using the balance), thus resembling the analytical spirit of precise and disciplined measurement which later became associated with the theory of definite proportions.¹⁷

While the benefits of blowpipe analysis were in its economy, portability, and efficiency, much was demanded of the analyst. Associated equipment ranging from the chemical reagents to the candlewick needed careful preparation. Special training was required in order to link the empirical signs—such as flame coloration—to substances present in the mineral sample. For a number of specimens, however, different chemical fluxes and reagents were used in the analysis which increased the complexity of the visual language of colours displayed.¹⁸ “Reading” the signs of the reaction was not all that was taught. In order to get the expected responses from the mineral, a particular style was necessary in using the instrument. As the

Swedish doyen of late eighteenth-century blowpipe analysis, Jacob Berzelius, wrote, “the variations in the sort of flame required in experiments with the blowpipe, depend on such slight changes in the position of the beak [tip of blowpipe], that it is impossible to accomplish them with precision by the mere action of the mouth.”¹⁹ Successful analyses often hinged on the ability of the practitioner to create a consistent reducing flame when blowing into a candle flame. Thus not only were the reactions of the burning mineral to be observed, but careful control in managing the yellow, orange, or blue parts of the flame was necessary. Nor was it as simple as merely blowing through the pipe. Most experiments could be conducted within a few minutes, but during this time the practitioner was required to maintain a steady flow of air through the instrument—a notoriously difficult task. Advice on how to accomplish this included filling one’s cheeks with air, slowly releasing it, and simultaneously inhaling through the nose. Determined students frequently confessed to light-headedness, muscle aches, and fatigue when conducting experiments.

Skilful operation required specific training in observation and technique; one had to acquire “the knack,” as was reported in Rees’ *Cyclopaedia*.²⁰ It was the “skill in its application” and the “sufficient knowledge of the phenomena presented,” as Berzelius further remarked, that Swedish miners gradually acquired through training at the mining academies, and what university students went on to use for the development of their classification systems. It is significant that all Swedish pioneers of chemical and mineralogical analysis were at some time connected to either the chemical labs at Uppsala University or the Board of Mines.

The chemical laboratory at Uppsala was in operation by 1754 and used by the first professor of chemistry Johan Gottschalk Wallerius.²¹ Wallerius worked with Daniel Tilas, a supervisor at the Board of Mines who worked with Cronstedt, who also studied at Uppsala. Wallerius’ successor, Bergman, extended Cronstedt’s blowpipe experiments and was quickly recognised as a leading blowpipe analyst.²² Engeström learned blowpipe analysis from Cronstedt at the Swedish Mint, and afterwards both of them found employment at the Board of Mines. Two people working with Bergman, Carl Scheele and Johan Gottlieb Gahn, went on to become luminaries in Swedish chemistry and obtained positions elsewhere; in 1775 Scheele became an apothecary in Köping and, in 1784, Gahn became an assessor for the Board of Mines at Falun, the oldest and most productive mine in Sweden. Berzelius studied in Uppsala under Johan Afzelius and was trained in the proper use of the blowpipe by Gahn. In his autobiographical notes, Berzelius drew a vivid picture of his experiences with Gahn. “It was

surprising to see the speed and accuracy with which he could identify minerals and how traces of metals, which otherwise would certainly have escaped the eyes of the analyst, could be detected and identified,” he noted while collecting minerals with Gahn in Falun in 1814.

Gahn, who at this time had attained an age of seventy years, followed the work with youthful vivacity. I learned his method of handling the blowpipe, with which he had acquired unusual skill, enhanced by the microchemical methods he had developed. Henceforth the blowpipe became an altogether indispensable tool for the analytic chemist as well as for the mineralogist. A number of simple chemical instruments, moreover, had been devised by Gahn for his own use but had never been described and therefore were not known.²³

Berzelius’ encounter with Gahn was not unusual. He noted that “Gahn always travelled with his blowpipe, and the continual use which he made of it, led him to make several improvements in its application; ... He most readily and carefully instructed those who were desirous of information on the subject, but he never appears to have thought of publishing an account of his labours, nor has it been done by others.”²⁴ Gahn’s position with the Board of Mines made his abilities at training others in blowpipe analysis important to the Swedish economy, linked as it was to the paleoindustrial exploitation of mines.²⁵ Between the development of laboratory practices, the elaboration of classification systems based on blowpipe analysis, and the training regime instituted under the direction of the Board of Mines and Uppsala University, blowpipe analysis – recognised for both theoretical and practical uses – received heavy patronage.

From Cronstedt and Engeström in the 1760s to Gahn and Bergman in the 1780s to Afzelius and Berzelius in the 1800s, a direct pedagogical heritage is traceable in which the skills of blowpipe analysis, face-to-face demonstrations, and training for dexterity and acute observation, were passed on through generations of analytical chemists and mineralogists.²⁶ The sites of the Swedish laboratory and assaying chamber (spaces with blurred boundaries in Sweden) were regarded as perhaps the most important places in the production of knowledge, for it was here that all miners were obliged to undergo training, including blowpipe analysis, before travelling to mines all over Sweden.

Late eighteenth-century chemical analysis of minerals in Sweden was recognised by natural philosophers elsewhere. Not only did Swedish analysts travel with their blowpipes (at home and abroad), but accounts of their

achievements and their classification schemes were published in foreign journals and books. Nevertheless, the practice remained a particularly Swedish enterprise. This was not because the published accounts of their analytical practices were disguised to protect national secrets, but because the craft skills involved with this form of experimental practice could not be transferred through the textual medium. The development of blowpipe analysis in Britain in the early decades of the nineteenth century – long after textual accounts of blowpipe analysis in Sweden were available in London – can be linked to Sweden via the travels of certain Britons trained there.

3. TRAVELLERS TRAINED

In 1782, the young Smithson Tennant inherited his father's estate in Yorkshire, providing him with enough income to leave his Edinburgh medical studies and migrate to Christ's College, Cambridge, where he entered with the privileged status of Fellow Commoner.²⁷ With very few academic obligations, Tennant took to the casual pursuit of the extra-curricular subjects of botany and chemistry. His interests in chemistry were first sparked by the Professor of Chemistry in Edinburgh, Joseph Black, most well-known for his work on gases in which he isolated "fixed air" (carbon dioxide). Desirous of exploring the wider intellectual geography of chemistry, Tennant took further advantage of his new wealth and embarked on a trip to Sweden, where he hoped to meet the famous Uppsala chemists. When he arrived in Stockholm at the end of July 1784, however, he learned that Bergman had recently died. Further, his meeting with Scheele the following month was hampered by language. The only way they could communicate was through an intermediary: Tennant spoke English or Latin, Scheele Swedish or German.²⁸ Despite these trying circumstances, Tennant's travels through Sweden were not in vain. Carrying Engeström's 1770 edition of Cronstedt's *An Essay Toward a System of Mineralogy*, along with Engeström's *Guide aux Mines*, Tennant went to visit Engeström himself, who was a central administrator at the Board of Mines in Stockholm. Besides touring chemical labs, Tennant also met Gahn, with whom he spent a week learning – in Gahn's preferred "hands on" method – the skills of blowpipe analysis.

Tennant returned to Cambridge in late 1784 with newfound enthusiasm for practical chemistry and blowpipe analysis (Tennant designed his own blowpipe after returning to England; see illustration 1). He was one of the founding members of the short-lived Askesian Society and in 1813 became professor of chemistry at Cambridge. Soon, his experiments and portable chemical apparatus attracted the interest of a number of students, in particular William Hyde Wollaston, who proved keen to take up research in blowpipe analysis. Wollaston had attended the lectures of the Jacksonian Professor of Natural and Experimental Philosophy and Chemistry, Isaac Milner, before Milner was driven from the University for his radical Unitarian beliefs. According to Wollaston, Milner was a “first-rate Showman,” who kept students entertained by staging experimental explosions and dramatic chemical reactions. For professors whose income often depended on the enrolment of students, entertaining often proved more useful than lecturing.²⁹ In 1792 Francis Wollaston, William’s brother, succeeded Milner and seems to have stuck to the syllabus a bit more closely. The syllabus included a description of chemical apparatus, including various types of furnaces, blowpipes, and lenses; it discussed the various degrees of heat necessary for the fusion of substances, processes for separating the ingredients of compound bodies, as well as doctrines of chemical affinity. The course was then further divided into an investigation of the three kingdoms of nature with discussion on the natural history and practical uses of chemical substances.³⁰ Despite being extra-curricular, the activities of even a small group (in a thinly populated university) suggest that experimental practices in chemistry were an increasingly stimulated subject in Cambridge.

As Henry Warburton, a fellow Cantabrigian and Secretary of the Geological Society of London later remarked, when Tennant returned from Sweden he had “strengthened in [William] Wollaston that passion for the science [of chemistry] which Milner had kindled.”³¹ It was from Tennant that Wollaston became interested in small-scale chemical analysis, a method for which Wollaston later went on to champion, and which was a technique which had commonly been associated with blowpipe analysis.³² Even Berzelius, after having travelled to England in 1812, informed Gahn about Wollaston’s “astonishing ability” to work with small quantities of materials. Commenting on Wollaston’s scrupulous detection of nickel in meteoric iron, he noted:

The whole of his apparatus for these experiments in some bottles with stoppers, drawn out to a point so that they reach down into the liquid and collect one drop, which is the quantity he needs to extract. In these he keeps the commonest acids, alkalis and a few reagents. The solutions are made on a narrow glass strip, and he uses a small lamp for his blow-pipe and evaporation experiments on the piece of glass. Everything stands on a small wooden board with a handle, and is taken out or put away all together.³³

Tennant and Wollaston together pursued a line of chemical inquiry using blowpipe analysis. Through researches with Tennant on crude platinum, Wollaston was able to develop platinum crucibles for blowpipe experiments, helping to reduce the risk of contamination of the analysis previously performed with weaker crucibles.³⁴ Wollaston not only pursued his own line of inquiry in chemical mineralogy, but, by 1806, had designed his own portable blowpipe.³⁵ Nor were their researches isolated. After becoming professor of chemistry in 1813, Tennant corresponded with Berzelius, discussing the results of his, Wollaston's, and others' experiments at Cambridge and London.³⁶

Wollaston's and Tennant's collaboration in blowpipe analysis took place within a community experiencing rapid changes in common concepts and practices in chemistry. By the late 1780s, the "new chemistry" of anti-phlogiston was promulgated by many across Europe. Even though blowpipe analysis grew from theoretical principles based on phlogiston chemistry, its usefulness as a methodological practice transferred easily to the chemistry of oxygen. In short, the effects of mineral combustion with the blowpipe flame could be explained either by the old or new chemistry. Many mineral analysts, whether using the blowpipe or the furnace, could have embraced the new chemistry. As Anders Lundgren has pointed out, in Sweden, where concerns over the practical identification of mineral substances were predominate, the signs of the chemical reaction—whether caused by the removal of phlogiston or the addition of oxygen—revealed information about the specimen's constituent ore.³⁷ The theoretical underpinnings of the chemical revolution that separated the "phlogistonists" from the anti-phlogistonists did not necessarily affect the experimental practices in chemical mineralogy and the use of instruments of fire to identify simple substances and construct mineral classification systems. Thus, in Cambridge in the 1790s, the phlogistonist geologist and mineralogist John Hailstone could replicate the anti-phlogistonist Martin Klaproth's experiments on the analysis of Baryta with the central concern being that the furnace was constructed properly.³⁸ By the beginning of the nineteenth century, mineral

analysis with the blowpipe could well embrace Lavoisian chemistry. Lavoisier himself seems to have employed traditional blowpipe experiments to develop his mineral classification scheme, which showed how the blowpipe, the effects of the chemical reaction, and the use of the precision balance could work towards a rational analysis of mineral composition.³⁹

The culture of chemistry in Cambridge in the 1790s grew to encourage new forms of experimental practices and the use of new types of instruments, and to accommodate debates about the nature of chemical reactions. From this atmosphere in 1799, Edward Daniel Clarke, a Fellow from Jesus College and a former student of Milner's, set out on an exploration of Europe as a "travelling tutor" to a young gentleman named John Marten Cripps. Their first destination was Sweden. Clarke was a seasoned traveller by this time, having spent much of the decade supervising other patrician students on fashionable trips to the Continent. This was the first time, however, that Clarke would see Scandinavia, a land little explored by British travellers but of great interest, not least due to Tennant's recent sojourn. Following in Tennant's footsteps, Clarke went well prepared. He read up Linnaeus' *Flora Lapponica*, Pontoppidan's *Natural History of Norway*, and Engeström's *Guide du Voyage*, all purchased specially for the journey.⁴⁰ From the outset, natural history was central to their interests and both eagerly collected mineral, botanical, and insect specimens.⁴¹

Clarke was an indefatigable traveller with an ambitious itinerary. Moving swiftly through Copenhagen and Stockholm, through "land of wood and iron," the travellers headed for Uppsala, having already made arrangements with Adam Afzelius, assistant to the professor of botany at the University and brother of John Afzelius, professor of chemistry. With their horses, servants, translators, and wagons loaded with trunks and specimens, they approached the University.

Its appearance, in approach to it, is really noble: we descended a hill towards it, calling to mind the names of Celsius, Linnaeus, Wallerius, Cronstedt, Bergmann, Hasselquist, Fabricius, Zoega, and a long list of their disciples and successors, which has contributed to render this University illustrious; the many enterprising young travellers it has sent forth to almost every region of the earth; the discoveries they have made, and the works of which they are the authors. For since the days of Aristotle and Theophrastus, the light of Natural History has become dim, until it beamed, like a star, from the North; and this was the point of its emanation.⁴²

Clarke and Cripps remained in Uppsala for about a week, absorbed in the glory of the past. Uppsala was where the “northern star” had shone, reminiscent of the image of *Svecia*, the allegorical guardian of the Board of Mines, sitting on her throne with the north star beaming over her crown.⁴³ The light illuminated the activities of the chemists and natural historians in the eighteenth century whose work was celebrated around the world. Clarke reflected on the history of Uppsala, “once the metropolis of all Sweden,” and commented that comfort was to be found in the thought that the university “may never be without a Wallerius, a Hasselquist, a Thunberg, or a Berzelius.”⁴⁴

With letters of introduction from Hailstone, the vice-chancellor of Cambridge University, and assorted English diplomats, Clarke and Cripps were shown around the famous Botanic Garden. They saw the cottage where Linnaeus had once lived, and visited the chemical laboratories where Wallerius and Bergman had worked. Finally, “having expressed an earnest wish to be present at some of the public lectures,” they joined the students and attended the lectures of Thunberg, who succeeded Linnaeus in the botanical chair, and John Afzelius’s chemical lectures. The latter lectures were particularly impressive, thought Clarke:

Around the chemical lecture room was arranged the Professor’s collection of minerals, - perhaps more worthy of notice than anything else in Uppsala; ... It was classed according to the methodical distribution of Cronstedt, and has been in the possession of the University ever since the middle of the eighteenth century. The celebrated Bergmann added considerably to the collection, which may be considered as one of the most complete in Europe; especially in specimens from the Swedish mines, which have long produced the most remarkable minerals in the world. ... One small cabinet contained models of mining apparatus; pumps, furnaces, &c. There is no country that has afforded better proofs of the importance of mineralogical studies to the welfare of a nation, than Sweden.⁴⁵

Encountering a mineral collection based on Cronstedt’s methods, who, as Clarke went on to note, “laid the true foundation of the science, by making chemical composition of minerals the foundation of the species into which they are divided,” was to have a significant impact on the view that Clarke maintained of the organisation of the mineral kingdom and of mineralogical investigations. But Clarke’s mineralogical training did not stop in Uppsala.

With Engeström’s *Guide aux Mines* in hand, Clarke and Cripps journeyed up to the Great Copper mine in Falun to meet (the now anti-

phlogistonist) Gahn, who was head of the research school. Gahn was occupied in extending the experimental research into the chemical composition of minerals begun by his mentor Cronstedt, as well as training students in blowpipe analysis, including Berzelius, who was still working with Gahn at that time. During his few weeks with Gahn, Clarke also received training in the use of the blowpipe. Soon he was an enthusiast not only for mineral collecting, but mineral analysis. Throughout the remainder of their journey, Clarke was equipped with a blowpipe and conducted a number of on-the-spot experiments. Appropriately, as a vignette to a chapter in his *Travels*, Clarke reproduced a picture of his travelling “mineralogical apparatus,” including a blowpipe, hammer, and phials for fluxes and reagents.⁴⁶

Clarke returned to Cambridge after his three-year journey with Cripps in 1802. Shortly after, Clarke was granted permission from the vice-chancellor of the university to unpack his collection (which totalled seventy-six boxes) and advertise “lectures” which related to his travelling experiences. Clarke occupied one of the lecture rooms next to the chemical laboratories in the Cambridge Botanic Garden. This became Clarke’s “museum.” The room was set up as a dazzling display of artefacts from exotic locations, a successful allurements to undergraduates. Clarke’s “delivery was a masterpiece of didactic eloquence,” recollected one student. “From every stone, as he handled it and described its qualities—from the diamond, through a world of crystals, quartz, lime-stones, granites, &c. down to the common pebble which the boys pelt with in the streets, would spring some pieces of pleasantry.”⁴⁷ Clarke presented a unique natural history of each mineral, combining narration of where he had collected the specimen, an account of how various natural philosophers classified the mineral, as well as reflections on how ancient authors had described it. Included was his own classification scheme, based on blowpipe analysis.⁴⁸ So popular were Clarke’s lectures that in 1808 the University Senate awarded him a specially-created position of Professor of Mineralogy.

A few years after Clarke settled down into his new professorial position in Cambridge, another British traveller visited Sweden, the Edinburgh-trained historian and chemist Thomas Thomson. From the beginning of the nineteenth century, Thomson, also a student of Joseph Black, was active in promoting chemistry. In 1802 the first edition of his popular *System of Chemistry* appeared and, between 1800-1811, he was a private chemistry tutor for Edinburgh students, to whom he offered unique training in practical laboratory classes.⁴⁹ In 1812, having just finished teaching, as well as

writing his *History of the Royal Society*, Thomson decided to visit Sweden with the ostensible aim to “take a mineralogical survey of that Country ...to view as nearly as possible the state of chemistry in Sweden, and to make myself acquainted with the discoveries made in that science by the Swedes during the last ten years.”⁵⁰

It had been ten years since Clarke visited Sweden, but Clarke’s account of his experiences there would not be published until 1819. Thomson was familiar with late eighteenth-century “guide-books” to Sweden and had similar natural philosophical interests as Clarke. Indeed, the account of his journey looks almost as if the two travelled together.⁵¹ Like Clarke, Thomson had included hagiographic accounts of the great eighteenth-century chemists: Scheele, Cronstedt, and Bergman, praising their achievements in the chemical analysis of minerals. These chemists, reflected Thomson, “contributed prodigiously to the great revolution which chemistry underwent; invented many new methods of analysis, and left admirable models of research to their successors,” such as Berzelius, who Thomson described as pushing ahead the frontiers of chemistry.⁵²

In Stockholm, Thomson spent several days visiting various mineralogical collections and touring the Royal Academy of Sciences. When he arrived in Uppsala, Thomson met John Afzelius, the professor of chemistry, who showed him Bergman’s laboratory and the mineral collection of the University. Continuing further north, collecting specimens along the way, Thomson visited Falun, where he met the sixty-eight year old Gahn, “an excellent mechanic, who has supplied himself with accurate philosophical instruments of every kind.”⁵³ With Gahn, Thomson examined an admirable cabinet of minerals in Falun’s “Mining Company,” performed blowpipe analysis, and discussed recent experiments by Gahn and Berzelius.⁵⁴

The trip was profitable for Thomson. Shortly after returning from Sweden – even before his mineral collection arrived back in Britain – Thomson wrote his *Travels*, which were published in 1813. That same year he became the editor of *Annals of Philosophy*. As editor of the journal, Thomson aimed to reform the image that British science was parochial and inferior compared to the rest of Europe; the articles, reviews, and summaries of annual achievements were meant to acknowledge and embrace European methods of inquiry and work to synthesise British and continental developments in natural philosophy.⁵⁵ Throughout the 1810s, Thomson’s reputation as a successful textbook writer grew with successive, improved editions of his *System of Chemistry*. The decade of his achievements was crowned with his election to the position of Regius Professor of Chemistry at the University of Glasgow in 1818.

The 1810s also became the decade of the popularisation of the blowpipe in Britain. One of the most enthusiastic proponents of blowpipe analysis and ardent experimentalists was Clarke. From his lecture-room demonstrations to late-night laboratory experiments, the blowpipe was the core of Clarke's concentration. Nothing escaped the intense heat of the blowpipe, and with virtually every analysis he claimed a remarkable discovery. He was outspoken about the uses and benefits of blowpipe analysis, spreading the word in the local Cambridge newspaper which reported on his more spectacular experiments and in the many articles he wrote in the *Annals of Philosophy*.

In fact, Thomson's *Annals* – one of the main natural philosophical journals of the period – became the vehicle for a profusion of articles relating to blowpipe analysis. In general, this reflected the desire of a number of practitioners to try blowpipe analysis, to relate the results of their experiments, and often to draw attention to particular difficulties they encountered in their investigations. The activities of natural philosophical instrument makers, who redesigned and marketed a variety of blowpipe kits and “manuals” for their use, reveal a similar story. For chemists such as Friedrich Accum or Arthur Aikin, mineralogists like John Mawe, or instrument makers such as John Newman, the market in the 1810s for “portable labs” and travelling blowpipe kits could provide a lucrative source of income.⁵⁶ The relevance of Tennant's, Clarke's, and Thomson's travels to Sweden, and their explicit commitment to learning local practices for chemical analysis, is that their efforts to promote that method of experimental inquiry upon their return to Britain make them central to increased interest in their own local communities. The three travellers, who each endorsed blowpipe analysis through their teaching programmes and subsequent publications, were clearly linked to the propagation of this form of experimental practice. The transfer of blowpipe analysis from Sweden to Britain (as marked by the developments in Britain in the 1810s) is understood better through an examination of the activities of these travellers than the distribution of texts. As the following section suggests, the degree of skill involved in the practices of blowpipe analysis complicated its acceptance.

4. SKILL TRANSFER: DISCIPLINE OR DESIGN?

Many of the manuals relating to blowpipe practice, stemming back to Engeström's 1770 publication, confessed to the difficulties in rendering through text the subtleties involved in conducting accurate analyses, such as describing changes in flame colour, adjustments in breathing patterns, or other signs involved in the chemical reaction. In many accounts on the use of the blowpipe, authors included a disclaimer regarding the efficacy of their descriptions, and appealed to the necessity of direct training. Such was the appeal made by Berzelius, who was a tough critic of experimental practice: "As in other practical sciences, books alone are "weak masters" to make adepts in this; but they who had seen Cronstedt or Von Engeström at work, learned to work like them, and transmitted their skill to their successors."⁵⁷ For Berzelius, face-to-face transfer of skill could not be replaced by textual guides. In Berzelius' account of the history of the chemical and mineralogical sciences, people without contact to the masters were unlikely to advance in the field. Berzelius suggested that this was an important reason why Engeström's book was not well received in England:

The work attracted the general attention of chemists and mineralogists to the use of the instrument, who, however, derived at first little other advantage from it, than as a means of ascertaining the fusibility of bodies, and occasionally their solubility in glass borax; for the want of that skill in its application, which can only be derived from patients [sic] and practice, together with a sufficient knowledge of the phenomena presented by the various fluxes for the bodies experimented on, prevented a just estimate being formed of its value, whilst the difficulties attending its use were abundantly evident; and hence, everywhere but in Sweden, the art of the blowpipe made but little progress.⁵⁸

For some natural philosophers, the attempt to provide a widely accessible and reliable method of analysis, which would ideally provide an unproblematic classification scheme with the use of the blowpipe, could not rely upon textual guides. As an alternative to the problem of providing textual instructions, craftsmen and instrument makers worked to remove such complications altogether by designing an instrument that embodied analytical skills in its design. For example, in the 1780s Bergman experimented with a spirit lamp, slowly heated to release a constant flow of air. Another attempt was made by Bengt Geijer, also in the 1780s, who used displacement of water in two tanks to force air through the blowpipe. Such

attempts, however, met with critical responses from some blowpipe practitioners who argued that, just as attempting to replace face-to-face training with texts, these designs reduced the effectiveness of analysis. Results were less subtle and more prone to error. Similar attempts to transfer the skill from the practitioner to the instrument were made in Britain.

Two articles appeared in the first few years of the 1800s suggesting how the blowpipe could be adapted and attached to a “gasometer” in order to produce intense heat for fusion.⁵⁹ Both devices were mechanically operated with bellows or pumps; the double barrel blowpipes were designed neither for subtle variations in air-flow nor portability. Two additional attempts to design a refined instrument with controlled flame appeared shortly after in *Nicholson’s Journal*. A correspondent who signed as “N .N .” noted that the blowpipe could prove useful to the chemist and mineralogist, but lamented the difficulties involved in attempting to follow the instructions for its use by Bergman or Engeström. Furthermore, he noted the inconvenience of having only one hand free while the other held the instrument. He proposed a device similar in design to one of Bergman’s, where a heated container filled with alcohol forced vapour through the small pipe. He claimed, however, that the instrument was useful for fusion or soldering, and that “glass-blowers have long sold a little implement” similar in purpose.⁶⁰ Shortly afterwards, George Bellas Greenough described a blowpipe which operated on the principle of water displacement which was in use at the Royal Mineralogical Collection in Naples. In neither instance was the instrument’s uses for mineralogical *analysis* referred to, just its convenience for fusion or soldering. It was clear that despite its versatile uses in Sweden for mineral classification, little had changed from Boyle’s observation that blowpipes were “tradesmen’s tools” in England. Blowpipes were devices useful for an artisan’s craft of glass-blowing; if part of laboratory apparatus, they were more likely used for sealing flasks than as instruments of analysis.

In Britain, the transformation from a craft tool to a philosophical instrument – a status reached by the 1810s – was clearly not easy.⁶¹ The “knack” one needed in order to perform successful blowpipe analysis made it difficult to train others, particularly with the lack of institutionalised positions for practical training in science. While mining in Britain had, throughout the eighteenth century, transmitted complex craft skills through generations by means of apprenticeships, a School of Mines was not opened up until 1851, in London.⁶² As opposed to Sweden, where such institutional and government patronage promoted the union between practical mining and scientific theory, the uses of chemistry in mineralogy and the mining

industry were not promoted in Britain until well into the nineteenth century.⁶³ Nevertheless, various attempts were made to legitimise blowpipe analysis which involved trying to replicate and standardise new experimental results reached using the blowpipe. It is interesting to observe who proffered suggestions for ways of making the use of the instrument easier.

In 1813 a letter appeared in the *Transactions for the Society for the Encouragement of Arts* by John Tilley, a craftsman sensitive to the subtle manners of using a blowpipe. “Being a travelling fancy glass-blower,” he wrote, “I work with a machine which I have contrived for my own use, and which I have been advised, by a great number of respectable gentlemen, to lay before the Society of Arts, &C.”⁶⁴ His “Hydro-pneumatic” blowpipe consisted of a tin box, approximately one square foot, fitted with handles. The box was internally separated into two compartments, each partially filled with water. Tilley claimed he could control the airflow by blowing through tube which caused a displacement of water, which in turn forced a controlled and steady stream of air through the pipe. “The whole apparatus,” he went on to note, “including lamp and case, weighs only three pounds and a half.”⁶⁵

The benefits of this blowpipe were conveyed in an appended note to Tilley’s letter, which was reprinted in the *Philosophical Magazine* in 1814:

The usual manner of producing a stream of air for blowing glass, is by means of a small pair of double-acting bellows, fixed beneath a table, and worked by the operator’s foot; ...The defect of the bellows are [*sic*], that the stream of air is not perfectly regular, which causes a wavering of the flame, so that it does not fall steadily upon the object which is heated.⁶⁶

Tilley’s blowpipe corrected this problem, and he deemed it suitable for artists and natural philosophers alike. The important feature of portability was retained with Tilley’s blowpipe, and the emphasis on a continual, controlled flame acknowledged a central concern in its use. The instrument attracted immediate attention and the Society of Arts awarded it a Gold Medal for its unique design.⁶⁷

Another structural change to the blowpipe came with the suggestion in 1816 from Henry Brooke, in a letter published in Thomson’s *Annals of Philosophy*. Brooke was the first to replace the mouth tube with an air pump.⁶⁸ His design retained the metal box (he used copper) but removed the principle of water displacement. Instead, air was pumped and compressed into the sealed copper box. Extending from the front of the box was the air

pipe, through which air was released; the flow was controlled by a stop-cock. This design rendered the instrument completely mechanical.

In the same year, John Newman, the instrument maker for the Royal Institution, published an article in their journal describing his structural change to the blowpipe. Newman modified Brooke's blowpipe by attaching a bladder to the air pump. Aware of Humphry Davy's researches on electrical decomposition of water and the combustibility of hydrogen, Newman filled the bladder with a mixture of oxygen and hydrogen gas, which was then pumped into the copper box. The mixed gases were burned, thus creating a flame without requiring an external source (candle, spirit lamp, etc.). Burning the oxy-hydrogen gas created a flame of greater intensity and higher temperature than previously produced, which effectively eliminated the characteristic of "infusibility" as the first order of a mineralogical classification system. This development had major implications for experimental results produced with Newman's blowpipe, also known as the "gas blowpipe."

By this time, changes in the design of the blowpipe produced new kinds of results one obtained when different quantities of gases were used in the experiment, thus re configuring the criteria of experiment. The use of very powerful flames eliminated the subtleties of experiment and important details about the chemical constituents of minerals. It had also altered what were originally considered the virtues of the instrument, including its portability, simplicity, and low cost. Some, like Berzelius, rejected changes in the design of the blowpipe, arguing the impracticality of trying to transfer human skill to a mechanical device. As Berzelius reminded his readers, correct use of the traditional, hand-held blowpipe involved a great deal of sensitivity in controlling air flow. The inventors of "pretended improvements" such as bellows, he complained, "have demonstrated by their very contrivances that they did not know how to use the blowpipe."⁶⁹

While the heat from the new gas blowpipe pushed back the frontiers of analysis, an element of skill involved with the analysis was not lost. After the development of the gas blowpipe, Clarke quickly became known as *the* fervent analyst with this new instrument – so much so that philosophical shops began to advertise "Clarke's blowpipe" rather than "gas blowpipes" (illustration 7). With it, Clarke started a research programme which involved analysing everything from diamonds to rose petals, work which culminated in the publication of his *The Gas Blow-Pipe*, where he argued that the instrument was essential for every chemist and mineralogist.⁷⁰

Some remained sceptical, such as Davy, who resisted Clarke's claim that with the blowpipe he was able to reduce refractory earths to their metallic constituents, something Davy claimed only he was able to do with his esteemed Galvanic battery.⁷¹ Clarke supposed that the reason for resistance was because others found difficulty in performing analyses and replicating his experiments in attempting to verify his results. In any sort of blowpipe analysis, varying the intensity of the flame, adjusting the proportion of the oxygen and hydrogen mixture, interpreting the colours involved in the reaction correctly, and knowing when to stop the analysis continued to be difficulties for even the most skilled of analysts. Clarke's persistence, combined with crucial support and patronage he gained from Thomas Thomson (who encouraged Clarke to publish the results of his work in *Annals of Philosophy*), convinced many others of the benefits of blowpipe analysis.

I have drawn attention to the various means of mechanising blowpipe practice and the difficulties in replicating the experiments to point out the contemporaneous concern over the skill involved in using the instrument. Once a sense of the amount of labour and training that was demanded of the analyst is obtained, one realises the difficulties involved in providing textual accounts of experimental practices. This helps broaden our conception of what contexts are necessary to consider when thinking about how scientific practices (and subsequent experimental results) "travel" to other places – particularly to places, such as Britain, with different bureaucratic, institutional, and pedagogical structures to support such activities.

5. CONCLUSION

The development of blowpipe analysis in the 1810s – changes in the structural designs of the instrument and the dissemination of the results obtained with it – was boosted by the interests and enthusiasm of certain individuals with special knowledge and training in the correct use of the instrument. If we consider the local community of Cambridge University, we see that two travellers – Tennant and Clarke – who acquired certain experimental skills while visiting Sweden, were crucial to the promotion of this form of chemical analysis. It is possible to trace others, like Wollaston, who then carried their skills elsewhere, and helped inform and perhaps influence the work of people around them. Clarke's enduring commitment to blowpipe analysis affected a number of practitioners, among them John

Kidd, the professor of chemistry at Oxford. Kidd watched Clarke perform blowpipe experiments in Cambridge and later, in defence of science teaching at the ancient universities, cited the development of blowpipe analysis in Cambridge as a significant improvement in chemistry. After Clarke died, the excitement over accessibility and practice in chemical instrumentation at Cambridge was expressed by Erasmus Darwin, when he first arrived as a student in 1822. An early letter he wrote to his brother, Charles, offers an insight into what many of Clarke's students would no doubt have felt:

There is a shop here with every sort of thing, it quite made my mouth water to *see* all the jars & stopcocks & all sorts of things, graduated tubes, blow pipes, cubic inch measures, test tubes & ye Lord knows what besides. ...I have also found out another very nice little man. He was 14 years assistant to ye late Dr Clarke, ye great mineralogist. I have bought 2 or 3 little stones from him; ... He sells things very cheap & so if you will mention any stones I can probably get them.⁷²

By the 1820s, blowpipe analysis was part and parcel of chemical, mineralogical, and geological practice. The blowpipe was no longer constrained by disciplinary boundaries. It also continued to travel; Charles Darwin conducted blowpipe analyses while on the voyage of the *Beagle*, and Charles Lyell purchased a blowpipe in London in preparation for his travels in 1822.⁷³

Thomson's support of Clarke and the coverage of blowpipe analysis in the pages of his *Annals* further propagated interest in this form of instrumentation. With the further development of blowpipe kits, such as those popularised by John Joseph Griffin in the 1820s, and the integration of blowpipe instruction at places such as the Surrey Institution, blowpipe analysis gradually became a routine part of chemical and mineralogical education. Although blowpipe analysis was significantly displaced by the invention of the Bunsen Burner and spectral analysis in the 1850s, blowpipe practices continued to be taught in many chemistry classes into the twentieth century. Despite the existence of a number of texts on blowpipe analysis, including at least one reprint in 1984, few people can claim to have the skill necessary to perform blowpipe experiments properly.⁷⁴

What is clear is that the transfer of blowpipe analysis from Sweden to Britain involved complicated steps. This article has examined certain conditions which made the development of practices of blowpipe analysis not just acceptable but popular. This account suggests ways that historians of

science can refine conceptions of the diffusion of scientific knowledge. What we have traditionally called “science” does not travel, people who practice science do. All that is involved with experimental practices can not always be bound between hard covers and forwarded to different areas of the world. The production of scientific knowledge took place within a complex culture of communication and support which affected the way people behaved—the way natural philosophers worked to make sense of the world in which they lived and travelled.

University of California San Francisco

NOTES

- ¹ For a survey of the literature on the history of the blowpipe, see Brian Dolan, “Blowpipe,” in A. Hessenbruch, ed. *Reader’s Guide to the History of Science* (London: Fitzroy Dearborn, 2001), 87-88, useful studies which should be mentioned include U. Burchard, “The History and Apparatus of Blowpipe Analysis,” *The Mineralogical Record* 25 (1994) 251-277; W.B. Jensen, “The Development of Blowpipe Analysis,” in J.T. Stock and M.V. Orna, eds., *The History and Preservation of Chemical Instrumentation* (D. Reidell Publishing Company, 1986), pp. 123-149; and W.A. Campbell, “The Development of Qualitative Analysis 1750-1850: The Use of the Blowpipe,” *The University of Newcastle Upon Tyne Philosophical Society* 2 (1971-2), 17-24.
- ² G. von Engeström, *Description and Use of a Mineralogical Pocket Laboratory, and especially the use of the Blowpipe in Mineralogy* (London, 1770), added as an addendum to his translation of A.F. Cronstedt, *Försök till Mineralogie eller Mineral-Rikets uppställning* (1758).
- ³ [Thomas Thomson] “Improvements in Physical Science during the Year 1816,” *Annals of Philosophy* 9 (1817), 6-13, p. 8.
- ⁴ Jan Golinski, *Science as Public Culture: Chemistry and Enlightenment in Britain, 1760-1820* (Cambridge: Cambridge University Press, 1992), particularly chap. 6, for good discussion of analytical community, although he simplifies debates over blowpipe results.
- ⁵ Ian Inkster, “Science and Society in the Metropolis: A Preliminary Examination of the Social and Institutional Context of the Askesian Society of London, 1796-1807,” *Annals of Science*, 34 (1977), 1-32; G. Averley, G. The “Social Chemists”: English Chemical Societies in the Eighteenth and Early Nineteenth Century,” *Ambix*, 33 (1986), 99-128.
- ⁶ For an account of the market for chemical apparatus and attempts to write chemical textbooks in the early nineteenth century, see Brian Dolan, “The Language of Experiment in Chemical Textbooks: Some examples from early-nineteenth-century Britain,” in A. Lundgren and B. Bensaude-Vincent, eds., *Communicating Chemistry: Textbooks and their Audiences, 1789-1939* (Canton, MA: Science History Publications, 2000), 141-64.
- ⁷ J.J. Griffin, *Practical Treatise on the Use of the Blowpipe in Chemical and Mineral Analysis* (Glasgow, 1827), p. iii.

-
- ⁸ B. Gee and W. Brock, "The Case of John Joseph Griffin: From Artisan- Chemist and Author-Instructor to Business-Leader," *Ambix* 38 (1991), 29-62, p. 39; Inskster, *op.cit.* (5).
- ⁹ It is worth noting, as Gee and Brock also pointed out, that Griffin's interests in blowpipe analysis probably grew from his personal acquaintance with Aikin, who was one of the original members of the Askesian Society. In this respect it is significant that Smithson Tennant was also one of the founding members of the Askesian Society; Gee and Brock, *op. cit.* (8) p. 39.
- ¹⁰ For distinctions between dry and wet analysis, see W.A. Campbell, "Analytical Chemistry," in C.A. Russell, ed., *Recent Developments in the History of Chemistry* (London: Royal Society of Chemistry, 1985), pp. 176-190, pp. 178-179; A.G. Debus, "Fire Analysis and the Elements in the Sixteenth and the Seventeenth Centuries," *Annals of Science* 23 (1967), 127-147; Debus, A.G. "Solution Analyses prior to Robert Boyle," *Chymia* 8 (1962), 41-61.
- ¹¹ F.L. Holmes, "Analysis by fire and solvent extractions: the metamorphosis of a tradition," *Isis* 62 (1971), 129-148; R. Siegfried and B.J. Dobbs, "Composition: A neglected aspect of the chemical revolution," *Annals of Science* 24 (1968), 275-293; H. Cassebaum and G.B. Kauffman, "The Analytical Concept of a Chemical Element in the Work of Bergman and Scheele," *Annals of Science* 33 (1976), 447-456.
- ¹² R. Hooykaas, "The species concept in 18th century mineralogy", *Archives Internationales d'Histoire des Sciences*, 5th year (1952), 45-55; D.R. Oldroyd, "Mineralogy and the "Chemical Revolution," *Centaureus* 19 (1975), 54-71.
- ¹³ R. Laudan, *From Mineralogy to Geology: The Foundations of a Science, 1650-1830* (Chicago: University of Chicago Press, 1987), for discussion of external characteristics and crystallography.
- ¹⁴ Hooke quoted in Campbell, *op. cit.* (1), p. 17; also F. Greenaway, *Chemistry: 1: Chemical Laboratories and Apparatus to 1850* (London, 1966); G. Turner, *Nineteenth-Century Scientific Instruments* (London: Philip Wilson Publishers Ltd., 1983); M. Dumas, *Scientific Instruments of the 17th and 18th Centuries* (New York: Praeger, 1972), for chronological catalogue of blowpipes.
- ¹⁵ T.M. Porter, "The Promotion of Mining and the Advancement of Science: the Chemical Revolution of Mineralogy," *Annals of Science* 38 (1981), 543-570; B. Earl, *Cornish Mining: The Techniques of Metal Mining in the West of England, Past and Present* (Cornwall: D. Bradford Barton Ltd., 1968), for examples in Britain; Frangsmyr, "Science in Sweden;" see Gee and Brock, *op. cit.* (8) for discussion of later significance of continental theory for British chemistry and mineralogy, pp. 39-41.
- ¹⁶ For example, in 1731 two well-known London natural philosophers published a book describing a "portable laboratory" for various chemical analyses. They described small, portable furnaces, the uses of which extended from testing mineral composition of minerals at mines to providing a means for families to brew their own alcohol. See P. Shaw and F. Hauksbee, *An Essay for Introducing a Portable Laboratory: By Means where all of the Chemical Operations are Commodiously Perform'd, for the Purpose of Philosophy, Medicine, Metallurgy, and a Family* (London, 1731) for broader conception of portable labs, which include blowpipe kits, see W.A. Smeaton, "The Portable Chemical Laboratories of Guyton de Morveau, Cronstedt and Gottling," *Ambix* 13 (1966), 84-91.
- ¹⁷ D.R. Oldroyd, "Some Phlogistic Mineralogical Schemes, Illustrative of the Evolution of the Concept of "Earth" in the 17th and 18th Centuries," *Annals of Science* 31 (1974), 269-

305; A. Lundgren, "The Changing Role of Numbers in 18th-Century Chemistry," in T. Frangmyr, J. Heilbron, and R. Rider, eds., *The Quantifying Spirit in the 18th Century* (Berkeley and Oxford: University of California Press, 1990), 245-266, for suggestive comments about bringing the quantifying spirit to blowpipe analysis.

- ¹⁸ See Campbell, *op. cit.* (1) for chart of simple colour scheme in blowpipe analysis, p. 23.
- ¹⁹ J.J. Berzelius, *The Use of the Blowpipe in Chemical Analysis, and in the Examination of Minerals* trans. J.G. Children (London, 1822), p. 13.
- ²⁰ A. Rees, *The Cyclopaedia; or, Universal Dictionary of Arts, Sciences, and Literature*, 39 vols (London, 1819), "Blow-pipe" (probably written by Arthur Aikin, vol. IV, no pagination, published in 1805).
- ²¹ S. Lindroth, *A History of Uppsala University, 1477-1977* (Stockholm: Almqvist & Wiksell, 1976).
- ²² M. Beretta, "T.O. Bergman and the Definition of Chemistry," *Lychnos* (1988), 37-67, pp. 37-38.
- ²³ Qtd. in J. Jorpes, *Jac. Berzelius: His Life and Work*, trans. B. Steele (Stockholm: Almqvist & Wiksell, 1966), pp.87-88.
- ²⁴ Berzelius, *op. cit.* (19), p. 5; a translation of a paper penned by Gahn did appear: see [J.G. Gahn], "On the Blow-pipe;" for more information on Gahn, see Jan Trofast, *Johan Gottlieb Gahn* (Lund: Wallin & Dalholm, 1994).
- ²⁵ S. Lindqvist, *Technology on Trial: The Introduction of Steam Power Technology into Sweden, 1715-1736* (Uppsala: Almqvist & Wiksell, 1984), pp. 95-107 for discussion of the work of the Board of Mines.
- ²⁶ Some might wonder why Anton von Svab, who was assessor to the Mining Academy at Stockholm in the 1730s, is not added to this list; Gee and Brock *op. cit.* (8), for example, cite Svab as the first in Sweden to use the blowpipe in chemical mineralogy, but Campbell *op. cit.* (1) suggests that this was a mistaken claim which originated with a reference by Linnaeus; Burchard *op. cit.* (1) observed that a reference by Bergman to "Swab" as the first to use the blowpipe was not to Anton, but to Andreas, who died before alleged blowpipe experiments took place, which may have further confused the point. It should also be noted that Jensen *op. cit.* (1) recognised the importance of examining communities of chemists amongst whom skilled techniques could be transmitted, but preferred to trace a chronology of blowpipe literature.
- ²⁷ D. McDonald, "Smithson Tennant, F.R.S. (1761-1815)," *Notes and Records of the Royal Society of London* 17 (1962), 77-94.
- ²⁸ S. Tennant, "Journey to Stockholm 1784," diary transcribed by Henry Warburton, Cambridge University Library, MSS ADD 7736, entries for 28 July and 26 August.
- ²⁹ William Wollaston's account of Milner in Cambridge University Library, MSS ADD 7736, Box 2, Envelope B, ff. 2-3; for income and entertainment, see J. Golinski, "Utility and Audience in Eighteenth-Century Chemistry: Case Studies of William Cullen and Joseph Priestley," *British Journal for the History of Science* 21 (1988), 1-31.
- ³⁰ I. Milner, *A Plan of a Course of Chemical Lectures* (Cambridge, 1788); F.J.H. Wollaston, *A Plan of a Course of Chemical Lectures* (Cambridge, 1794); Cambridge University Library has an annotated copy of Wollaston's syllabus: class- mark 7360.d.11.
- ³¹ Cambridge University Library, MSS ADD 7736, Box 2, Envelope B, f. 2, "Biographical Sketch of Tennant."
- ³² B. Gee, "Amusement Chests and Portable Laboratories: Practical Alternatives to the Regular Laboratory" in F.A.J.L. James, *The Development of the Laboratory: Essays on the Place of Experiment in Industrial Civilization* (London: Macmillan Press, 1989), 37-

- 58, mistakenly claims that Wollaston travelled to Sweden, whereas Tennant was the traveller; p. 46.
- ³³ Berzelius qtd. in D. Goodman, "William Hyde Wollaston and His Influence on Early Nineteenth-Century Science" (Ph.D. Thesis, Oxford University, 1965), p. 129.
- ³⁴ Goodman, *ibid.*, pp. 128-132.
- ³⁵ Wollaston's experiments in his notebook, Cambridge University Library, MSS ADD 7736, Box 2; Wollaston, "Description of a Portable Blow-Pipe."
- ³⁶ For Tennant-Berzelius correspondence, see manuscripts in Royal Academy of Sciences, Stockholm, Saml. 3, ff. 96-101.
- ³⁷ A. Lundgren, "The New Chemistry in Sweden: The Debate that Wasn't," *Osiris*, 2nd series, 4 (1988), 146-168, p. 165; E.M. Melhado, *Jacob Berzelius: The Emergence of His Chemical System* (Stockholm: Almqvist & Wiksell, 1980), p. 130.
- ³⁸ For brief discussion about Hailstone's experiments, see B. Dolan, *Governing Matters: The Values of an English Education in the Earth Sciences* (Cambridge University, unpublished PhD thesis, 1995), pp. 165-166; Hailstone's experiments described in correspondence at West Sussex Record Office, Hawkins Papers.
- ³⁹ A.L. Lavoisier, "De l'action du feu animé par l'air vital sur les substances minérales les plus réfractaires," *Œuvres de Lavoisier*, 6 vols (Paris, 1864-1893), Vol. III, pp. 451-502; Oldroyd, *op. cit.* (12), pp. 60-61; E.L. Gonzalez, "Bochard de Saron and the Oxyhydrogen Blowpipe," *Bulletin for the History of Chemistry* 4 (1989), 11-15, T. Levere, "Lavoisier: Language, Instruments, and the Chemical Revolution," in T. Levere and W. Shea, eds., *Nature, Experiment, and the Sciences* (Dordrecht & London: Kluwer Academic Publishers, 1990), 207-223; Jan Golinski, "The Nicety of Experiment: Precision of Measurement and Precision of Reasoning in Late Eighteenth-Century Chemistry," in M. Norton Wise, ed., *The Values of Precision* (Princeton: Princeton University Press, 1994), for the processes of persuasion used by the anti-phlogistonists to argue the accuracy of the instruments used to "prove" the new chemistry.
- ⁴⁰ E.D. Clarke, *Travels in Various Countries of Europe, Asia, and Africa*, 6 vols (London: Cadell and Davies, 1810-1823), references in Vol. V.
- ⁴¹ For more thorough discussion of Clarke's travels, within the context of the cultures of scientific travel in the late eighteenth-century, see B. Dolan, *Exploring European Frontiers: British Travellers in the Age of Enlightenment* (Basingstoke: Macmillan, 2000).
- ⁴² Clarke, *op. cit.* (40), Vol. V, p. 171; see also H. Sandblad, "Edward D. Clarke och Giuseppe Acerbi, upptacktsresande i Norden 1798-1800," *Lychnos* (1979-80), 155-205.
- ⁴³ For Svecia, see Lindqvist *op. cit.* (25), p. 104.
- ⁴⁴ Clarke, *op. cit.* (40) Vol. V, p. 88.
- ⁴⁵ Clarke, *ibid.*, Vol. V, pp. 178-179.
- ⁴⁶ Clarke, *ibid.*, Vol. IV, p. 594.
- ⁴⁷ J.M.F. Wright, *Alma Mater: or, Seven Years at the University of Cambridge*, 2 vols (London: Black, Young & Young, 1827), Vol. II, pp. 30-31.
- ⁴⁸ E.D. Clarke, *A Methodical Distribution of the Mineral Kingdom* (Lewes, 1806); E.D. Clarke, *A Syllabus of Lectures in Mineralogy* (Cambridge, 1807).
- ⁴⁹ J.B. Morrell, "Thomas Thomson: Professor of Chemistry and University Reformer," *British Journal for the History of Science* 4 (1969), 245-265, p. 246.
- ⁵⁰ T. Thomson, *Travels through Sweden, during the autumn of 1812* (London, 1813), p. 1.

-
- ⁵¹ Historians interested in travellers must exercise caution when using published accounts of journeys as if they were field-notes. Published accounts, sometimes written years after the journey took place, were often embellished to meet the demands of an audience eager for new information or exciting narratives. Also, authors often swapped travel-notes and letters in order to reconstruct the journey. What may appear a spontaneous quip about local customs in the published narrative, for example, may have been thought of when relaying stories of the journey at dinner parties back home. The case of Thomson and Clarke is an example. Much of Thomson's observations of Swedish mines and reflections on the "state of chemistry," published in 1813, appear verbatim in Clarke's account, published in 1819. In fact, this was not unusual, and for this reason consulting as many contemporary accounts as possible helps capture the spirit of the genre of travel literature published in a particular era. Many travel writers "borrowed" text from other authors, but usually claimed the uniqueness of their books lay in their *additional* observations. Published travel accounts can generally be relied on as records of where people went, when they arrived, and who they met. Particulars, such as what they thought about individuals or what they gathered along the way, are best cross-referenced with correspondence (often published in *Life and Letters*, as in Clarke's case) or manuscript diaries, when extant.
- ⁵² Thomson, *op. cit.* (50), p. 173.
- ⁵³ Thomson, *ibid.*, p.222.
- ⁵⁴ Thomson, *ibid.*, pp. 224-227.
- ⁵⁵ Morrell, *op. cit.* (49), p. 247.
- ⁵⁶ For more on the "pedagogical market place," Dolan, *op. cit.* (6).
- ⁵⁷ Berzelius, *op. cit.* (19), p.3; for another discussion of skill in laboratory practice compared to textual accounts, see H.O. Sibum, "Reworking the Mechanical Value of Heat: Instruments of Precision and Gestures of Accuracy in Early Victorian England," *Studies in History and Philosophy of Science* 26 (1995), 73-96.
- ⁵⁸ Berzelius, *op. cit.* (19), p.3.
- ⁵⁹ A. Tilloch, "Account of some interesting Experiments, performed at the London Philosophical Society," *Philosophical Magazine* 8 (1800), 21-29, 262-266, 322-326; R. Hare, "Memoir on the Supply and Application of the Blowpipe," *Philosophical Magazine* 14 (1802), 238-245, 298-306.
- ⁶⁰ "N.N.," "Description of a cheap and simple Apparatus or Blow-pipe, in which the flame of Oil or Tallow is impelled by Vapour of Alcohol," *Journal of Natural Philosophy, Chemistry, and the Arts* 3 (1802), 1-3, p. 2.
- ⁶¹ For the wider transition in the discipline of chemistry as a whole, see L. Roberts, "Filling the Space of Possibilities: Eighteenth-Century Chemistry's Transition from Art to Science," *Science in Context* 6 (1993), 511-533.
- ⁶² J.R. Harris, "Skills, Coal and British Industry in the Eighteenth Century," *History* 61 (1976), 167-82; H. Torrens, "Some Thoughts on the Complex and Forgotten History of Mineral Exploration," *DUGS Journal* 17 (1996), 1-12, although Torrens does mention that in 1818 a short-lived "School of Mines" was run by James Ryan in Montgomeryshire: p. 5; Ross, a late-eighteenth-century writer on blowpipe analysis, expressed his dissatisfaction with The City Guilds of London Institute and the Royal School of Mines, for their lack of interest in teaching blowpipe analysis earlier in the century; W.A. Ross, *The Blowpipe in Chemistry, Mineralogy and Geology* (London, 1889), p. x; as a side-note, however, by the 1840s Durham University was training engineers in blowpipe analysis;

see Durham chemistry papers (I would like to thank Professor David Knight for this reference).

⁶³ Porter, *op. cit.* (15).

⁶⁴ J. Tilley, "Description of a Hydro-pneumatic Blow-pipe for the Use of Chemists, Enamellers, Assayers, and Glass-Blowers," *Philosophical Magazine* 43 (1814), 280-284, p. 280; this article is a reprint of the letter in the *Transactions*.

⁶⁵ Tilley, *ibid.*, p. 281.

⁶⁶ Tilley, *ibid.*, p. 284.

⁶⁷ For the Society of Arts award system and its role in the promotion of scientific instrumentation in the early nineteenth century, see J.A. Bennett, "Instrument Makers and the "Decline of Science in England": the effects of institutional change on the elite makers of the early nineteenth century," in P.R. de Clercq, ed., *Nineteenth-Century Scientific Instruments and their Makers* (Amsterdam: Rodopi, 1985), 13-27, pp. 21-22.

⁶⁸ H. Brooke, "Description of a new Blow-Pipe," *Annals of Philosophy* 7 (1816), p. 367.

⁶⁹ Qtd. in Campbell, *op. cit.* (1), p. 21.

⁷⁰ E.D. Clarke, *The Gas Blow-Pipe, or Art of Fusion by Burning Gaseous Constituents of Water* (London: Cadell and Davies, 1819), a catalogue of the results of his experiments, together with brief history and discussion of the use of the instrument.

⁷¹ For more on this debate and a comparison of the development of analysis with blowpipes and galvanic batteries in early nineteenth-century England, see B. Dolan, "Blowpipes & Batteries: Humphry Davy, Edward Daniel Clarke, and Experimental Chemistry in Georgian Britain," *Ambix*, 45 (1998), 137-162.

⁷² E. Darwin to C. Darwin, 25 October 1822, printed in F. Burkhardt and S. Smith, eds, *The Correspondence of Charles Darwin*, 10 vols (Cambridge: Cambridge University Press, 1985-present), Vol. I, pp. 1-2.

⁷³ J.A. Secord, "The Discovery of a Vocation: Darwin's early geology," *British Journal for the History of Science*, 24 (1991), 133-157; L. Wilson, *Charles Lyell: the years to 1841: the revolution in geology* (New Haven and London: Yale University Press, 1972), p. 111.

⁷⁴ The 1984 publication is J. Landauer, *Blowpipe Analysis*, trans. James Taylor (London, 189; reprint, New York, 1984); for a more thorough bibliography of texts relating to blowpipe analysis, mainly from the period covered in this article, see the appendix to B. Dolan, "Transferring Skill: Blowpipe Analysis in Sweden and England, 1750-1850", in B. Dolan, ed., *Science Unbound: Geography, Space & Discipline* (Umeå: Umeå Universitet Skrifter, 1998), 92-125.