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REVOLUTIONIZING TRAINING IN AEROSOL SCIENCE

Until 2019, researcher training in aerosol science in the UK, and elsewhere, was fragmentary, occurring within the context of individual disciplines (for example inhaled drug delivery, formulation science, emissions, and environmental science). However, in many of the disciplines in which aerosol science is key, the research challenges that must be addressed are, perhaps unsurprisingly, very similar. As examples, the micro-architecture and phase of aerosol particles (e.g. solution, amorphous, crystalline, core-shell)[i] are crucial to health impacts of aerosol (e.g. viability of bacteria, solubility of drugs on inhalation), the function of manufactured particles (e.g. light interactions with pigments, preservation of biologics in spray-dried pharmaceutical products), the impaction of particles on surfaces (e.g. volcanic ash in jet engines, distribution of agrochemical sprays), and air quality and climate change (e.g. mass concentration of particulate matter in urban environments, ice cloud formation). Similar synergies exist between disciplines in areas of aerosol chemistry, transport, deposition, and optical properties, to name just a few further examples. Exploring such interdisciplinary challenges collaboratively, supported by research in the underlying physical science and the development of new measurement technologies, represents an efficient path for achieving innovative step-changes in knowledge, productivity, and capability.

The EPSRC Centre for Doctoral Training in Aerosol Science (CAS)[ii] has addressed the disconnect between typical training paradigms and contemporary research and engineering challenges, and offers an entirely different approach to training the next generation of aerosol scientists. Since autumn 2019, CAS has been busy equipping the first three of five cohorts of doctoral postgraduate researchers (PGRs) with the core competencies required for practitioners in aerosol science, supporting them to develop not only a mastery of fundamental principles, but also an ability to apply their knowledge across disciplinary boundaries and the agility to be at the vanguard of this rapidly-evolving area.

Figure 1 presents the nine PGR competencies which are developed through the CAS training programme. These capture the competencies required by a professional practitioner in aerosol science and were developed through consultation with practicing scientists at a group in-person event in January 2018[iii], an online survey, and individual telephone interviews with CAS partners. To deliver this training CAS brings together around 80 academic teams at seven UK universities and 60 industrial and public-sector partners based in the UK, Europe and North America and drawn from the areas of healthcare, material science, energy and transport, environment, consumer products and agrochemicals.

CAS emphasizes a cohort-based approach and an interdisciplinary training environment. Our PGRs are drawn from diverse backgrounds spanning the physical, environmental and life sciences and engineering and work together throughout the programme.

1. Apply theoretical knowledge of aerosol science across a range of problems of a chemical, physical, biological or technological nature.
2. Undertake independent design and conduct experiments/models with technical mastery, as well as analyse and interpret data.
3. Identify, formulate, critique and solve reearch problems within their specialised context to advance the understanding of aerosols.
4. Develop or adapt advanced methodological approaches to contemporary problems, recognising the complexity and tolerating the ambiguity that arises in real-world systems.
5. Synthesise new approaches to meet an identified outcome within realistic constraints such as economic, environmental, social, political, ethical, safety, manufacturability, and/or sustainability.
6. Act in congruence with professional and ethical values, and manage ethical dilemmas in formulating scientific solutions.
7. Function effectively and confidently in multidisciplinary teams, acting autonomously and taking responsibility for the scientific activity of others.
8. Communicate and share research knowledge to both expert and non-expert audiences, and guide the learning of those from outside their discipline.
9. Manage personal intellectual development as a self-critical, reflective scientist with the agility to respond to new challenges.

Figure 1. The nine PGR competencies.

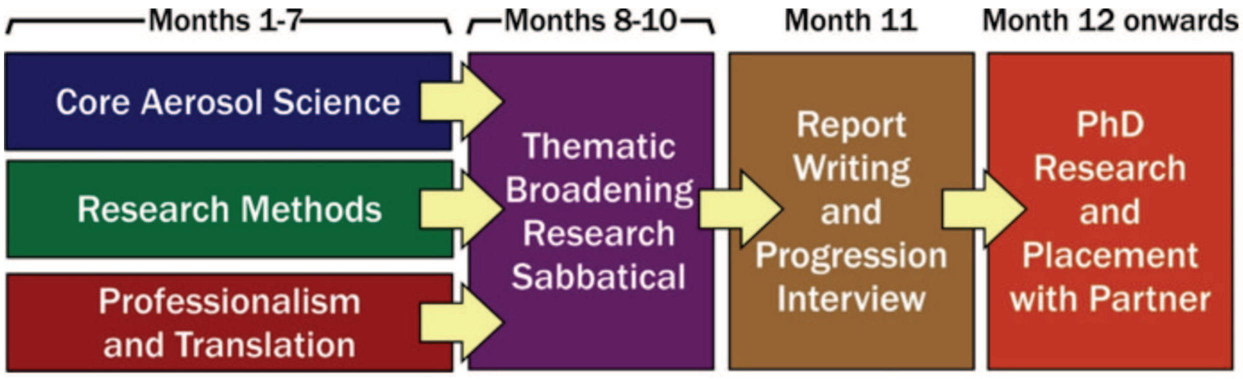

Figure 2. An overview of the structure of the four-year doctoral training programme.

Inverting the paradigm

CAS inverts the previous training paradigm by engaging PGRs in an initial period of comprehensive and broad-based training in the core physical science of aerosols transferable across all areas of aerosol research. This contrasts with the conventional approach in which PGRs identify with a single disciplinary area from the start of a PhD. Enhanced training in areas such as responsible innovation and entrepreneurship is paid significant attention.

Co-created with our partners, the four-year programme includes training in core aerosol science, research methods, and professionalism and translation. The structure of the programme is summarized in Figure 2. PGRs spend the first seven months of the first year as a cohort hosted by the University of Bristol (UK), with taught elements delivered by CAS members from all seven participating universities. This is followed by a three-month thematic broadening sabbatical intended to foster transdisciplinary competencies, with PGRs undertaking a project in an academic laboratory in an area of aerosol science complementary to their PhD research. A progression interview is held in month 11, after which they begin their PhD research.

A placement with an industrial or public-sector partner provides an opportunity for PGRs to contextualise their learning in either the second or third year. Cohort training events, CAS conferences and virtual events continue in years two to four, equivalent to around 20 days each year spent reinforcing and deepening the training provided during the initial cohort-based phase. Throughout the four years, each PGR is supported by a mentoring team consisting of two academic supervisors and at least one industrial or public-sector partner.

The core aerosol science training encompasses four thematic contexts (Aerosols and Health, Aerosol Technology, Measurement Techniques and Environmental Aerosol), building mobility and interdisciplinarity irrespective of the research focus of each PGR, and providing opportunities for peer-to-peer learning and inter-cohort training. The core aerosol science unit titles are shown in Figure 3.

Core aerosol science unit titles
Size distributions, shape and concentrations
Aerosol mechanics
Deposition, filtration and sampling
Nucleation and new particle formation
Electrical properties
Aerosol phase and thermodynamics
Optical properties
Analysis: Size, concentration, shape and mass
Particle coalescence and adhesion
Aerosol evaporation and condensation
Inhaled aerosols and health
Particle sources and materials synthesis
Analysis: Composition, phase and volatility
Introduction to biological aerosol
Heterogeneous chemical reactions
Collective motion and transport of aerosols

Figure 3. The core aerosol science unit titles.

Applying evidence-based pedagogies

The design of the training environment has been informed by research on how learning works and research-based instructional strategies. The core training in aerosol science is provided using evidenced-based approaches including Team-Based Learning[iv], an ideal format for training multidisciplinary teams. Using a "flipped-classroom" approach, PGRs access mini-lectures, worked problems, bespoke 'Smart Worksheets'[v] and additional reading materials through an electronic training portal. A two-day training session for each topic then uses application problems to reinforce learning through team-based activity facilitated by experts. Learning is assessed via so-called 'two-stage' examinations involving both individual and collaborative components[vi].

We continue to make use of evidence-based approaches throughout the four years that each PGR trains with CAS. We draw upon educational research and best practice in the development of aspects of professionalism, for example by establishing cooperative learning groups[vii] which PGRs join from month 11. We draw upon research on work-integrated learning[viii] to support our PGRs to relate learning during placements with their PhD projects. Years 2-4 involve PGRs revisiting learning relating to the nine core competencies.

Building connections

CAS operates an innovative tiered model for engaging public-sector and industry partners, with the capacity to welcome further partners. Partners can choose from three modes of engagement depending on their organizational needs. Tier 1 partnership involves in-kind support and has a focus on mentoring. Partners contribute time to provide elements of training and mentoring and access to equipment and other resources. They act as a professional mentor for PGRs, providing a non-academic perspective on science and career development, and host PGR placements. They are invited to attend our annual conferences, thereby raising their profile amongst all cohorts of PGRs, and receive a monthly e-newsletter. Tier 2 support involves a financial contribution and has a focus on building national capability. Contributions are used to expand the electronic training portal and support training of PGRs. Tier 2 partners have access to regular webinars, providing access to the latest research in academia and industry from around the world. They can offer continuing professional development to their employees via CAS training events. Tier 3 partners have the opportunity to be involved in research activities as a co-sponsor of PGRs. The CDT has ongoing opportunities for Tier 2 and Tier 3 partners to directly meet the needs of aerosol-related organizations. Partners have a commensurate role in supervision, host placements in partner organisations with longer duration than those at Tier 1, and have access to IP rights (subject to institutional agreements).

As well as building connections with public-sector and industry bodies, we have partnered with the Center for Aerosol Science and Engineering at University of Washington St. Louis (USA)[ix] to share educational and research resources and practices.

Furthering issues of equality, diversity and inclusion

CAS is strongly committed to furthering issues of equality, diversity and inclusion (ED&I), both for the benefit of individuals and to accelerate the advancement of the field of aerosol science. We are working to improve both cultural aspects and practices relating to ED&I in doctoral training. Challenges particularly relevant to CAS include the representation of women, those from BME backgrounds, those with disabilities and those with caring responsibilities. We consider issues of ED&I as they relate to all dimensions of the training journey (from recruitment and selection, to study, post-graduation destinations and career trajectory) and environment (to include teaching, learning, assessment and offered opportunities). We have established an ED&I committee, including representatives from the PGR cohorts, providing oversight, promotion, and monitoring of ED&I issues. Relevant practices include staff training, signposting for PGRs, considering representation amongst educators, mentors and speakers, and outreach activities.

Looking to the future

By creating a networked community of more than 80 doctoral aerosol science researchers able to work at the boundaries between the conventional disciplines spanning the physical, environmental and life sciences and engineering, and by connecting upwards of 80 academics and 60 public-sector practitioners and industrialists, we anticipate that CAS will drive an invigoration of the aerosol science research base in the UK and beyond, with opportunities to extend the programme past the initial five cohorts.

The training resources we are developing are ideal for upskilling and building existing research capacity through continuing professional development and will be presented as a suite of online materials made available indefinitely through the member portal of the UK and Ireland Aerosol Society[x] website. Public engagement activities and the nurturing of additional strategic research and teaching alliances will further build capability.

In summary, CAS is delivering a paradigm shift in the training of future aerosol scientists through a cohesive cohort-based approach, laying the foundations for enhanced research capacity, and redefining and strengthening the interdisciplinary and multifaceted community of aerosol science.

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