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On pedagogy of a Soil Science Centre for Doctoral Training

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Abstract

Here we describe and evaluate the success of a multi-institutional Centre for Doctoral Training (CDT), which was established to address a UK skills shortage in Soil Science. The government-funded 'STARS' (Soils Training And Research Studentships) CDT was established in 2015 across a range of universities and research institutes in the UK. It recruited 41 PhD students equitably split across the institutions under four core research themes identified as being central to the national need, namely, (1) Understanding the soil–root interface, (2) Soils and the delivery of ecosystem services, (3) Resilience and response of functions in soil systems and (4) Modelling the soil ecosystem at different spatial and temporal scales. In addition, the STARS CDT provided a diverse skills programme, including: Holistic training in soils, the promotion of collegiality and joint working, strategies to promote science and generate impact, internships with end users (e.g., policymakers, industry), personal wellbeing, and ways to generate a lasting soils training legacy. Overall, both supervisors and students have reported a positive experience of the CDT in comparison to the conventional doctoral training programmes, which have less discipline focus and little chance for students to scientifically interact with their cohorts or to undertake joint training activities. The STARS CDT also allowed students to freely access research infrastructure across the partner institutions (e.g., long-term field trials, specialised analytical facilities, high-performance computing), breaking down traditional institutional barriers and thus maximising

the students' potential to undertake high-quality research. The success and legacy of the STARS CDT can be evidenced in many ways; however, it is exemplified by the large number and diversity of journal papers produced, the lasting collaborations, final career destinations, and creation of a web-based legacy portal including new and reflective video material.

Highlights

- Soil science was identified as having a scientific skills shortage in the UK.
- A dedicated soil science Centre for Doctoral Training (CDT) was established to address this skills gap.
- The multi-institutional, discipline-focused CDT proved more successful than conventional generic PhD training programmes.
- The CDT model provides critical mass to provide more effective training of soil scientists.

KEYWORDS
doctoral training, pedagogy, post-graduate learning, soil science, upskilling

1 | CONTEXT AND INTRODUCTION

Soil Science underpins many of the solutions needed to address the multitude of problems that face the planet (Lal et al., 2021). However, a recent training needs analysis carried out by the UK Natural Environment Research Council (NERC) on behalf of the UK government identified a major national skills shortage in Soil Science (NERC, 2012). This led to the recommendation for the establishment of a subject-specific Soil Science Centre for Doctoral Training (CDT) in the UK. This paper focuses on the UK's national CDT in Soil Science, commonly known as 'STARS' (Soils Training And Research Studentships). The STARS CDT was commissioned in 2015 as part of a funding collaboration between the UK NERC and the UK Biotechnology and Biological Science Research Council (BBSRC), collectively UK Research and Innovation (UKRI). The resulting 'college' was formed, after a competitive commissioning process, across eight organisations that spanned England, Wales and Scotland and included four universities (Bangor, Cranfield, Lancaster, Nottingham) and four research institutes (British Geological Survey (BGS), James Hutton Institute, Rothamsted Research, UK Centre for Ecology and Hydrology), recruiting 41 students between 2015 and 2018, each having a nominal 3.5 years of funding and 4 years to complete their PhD. As well as the core funding from the UKRI, additional studentships and management funding were also supplied by the four universities. There were three main cohorts recruited in October 2015 (10 in Cohort 1), October 2016 (12 in Cohort 2), October 2017 (18 in Cohort 3, which included 7 funded by the National Productivity and Investment Fund (NPIF)), plus an additional single student Cohort 4 in October 2018 after receiving additional funding from the NPIF. Therefore, 41 students were recruited in total, of which four have since left the college without completion. In the text that follows, we share our reflections and lessons on this new Soil Science pedagogic experience, written from various perspectives of the diverse team of authors.

2 | STARTING THE NEW SOIL SCIENCE CDT

When STARS was established, the UK CDT funding model was relatively new, providing an opportunity to shape the UK soils learning experience in new and exciting ways, embracing a multi-organisation, multi-disciplinary approach. While a CDT might seem, on the face of it, a wonderfully collaborative opportunity, it only works for the organisations that are 'in', and for those left on the 'outside' at the time of commissioning it can seem awkward, for all parties. Some of the ways to address this were: (i) Carefully determining the right blend and representation of partners, in terms of institute facilities and local landscape access *a priori* (see also 'Multiple site opportunities and challenges' below), and (ii) for those not 'in' at the outset, working hard to continually develop new external collaborative partnerships, outside of the core team of eight. The latter was achieved through collaborative ('CASE') funding and other academic partners, providing additional training input and collaboration, where required.

Providing governance and administrative support proved to be a finely balanced challenge to complement the structures provided by the core universities, while adding specialist (soil) training and cross-cutting cohort support to the students, without making life unnecessarily complicated, and pulling against the strengths of the established 'home' universities. At times, managing the different protocols, regulations and complexities of relationships between research institutes and registering universities, was challenging. Notwithstanding, with some careful communication and mapping of the strengths offered by different partners, we were able to set up quality management protocols to help govern the best possible CDT soils training and cohort experience, in the best interest of the students. The recruitment of a dedicated and committed Management Board, including one enthusiastic member from each organisation and one student representative for each cohort, has been key to the success of the CDT.

One of the primary objectives of the CDT was to encourage training in all aspects of Soil Science. To facilitate this, we identified four broad soil research themes, which complemented the national skills gaps identified by UK government (NERC, 2012), namely:

1. Understanding the soil–root interface
2. Soils and the delivery of ecosystem services
3. Resilience and response of functions in soil systems
4. Modelling the soil ecosystem at different spatial and temporal scales

These themes provided a framework to ensure a full range of research projects throughout the lifetime of the CDT and gave a 'disciplinary home' to individual students and components of the CDT.

Cohort-building activities were critical in establishing good relationships between the students and supervisors and creating a sense of collegiality. The soil research themes also helped to promote this, creating excellent support networks and keeping students connected with their peers across organisations, despite geographical barriers. These activities took the form of residential training events involving social as well as training aspects; most often based around soil science training, but generic and team building training was also included (Figure 1).

Much of the training has been mandatory, ensuring everyone took part to reinforce the sense of cohesion. Initially, students worked mainly within their annual cohort, but over time more widespread interaction across cohorts has been encouraged with 'summer schools' and an annual conference that was open to all cohorts. The number of activities (induction events, STARS conferences), where the students and supervisors were brought together, also strengthened this development of shared knowledge and equipment, while also developing new networks among researchers of different experience and generations. The students got to visit various research establishments and their facilities (e.g., Bangor University Experimental Station, Rothamsted archive and long-term experiments) through some of the STARS training courses

FIGURE 1 Schematic representation of the main training elements with the STARS Centre for Doctoral Training (CDT). The training encompassed four main themes representing activities targeted at upskilling the PhD students in soil science, those focused at promoting teamworking and building links, those focused on generic life skills and communicating science, and those aimed at maximising their career potential or exposing them to a range of career pathways after completion of the PhD

and events. Gaining knowledge of the national range of data and facilities, as part of the CDT experience, was seen as being essential to the career development of the students. This was further encouraged by each student having supervisors in at least two different institutions, facilitating working at both sites as well as providing access to more resources and academic support.

Empowering students through opportunities, such as planning the annual STARS conference, and providing them with a small training budget to use as a group, has encouraged successful collaborative and multidisciplinary working. With most cohorts having between 11 and 19 students, a cohort was small enough for students to know each other and their research areas quite well, providing a sense of community and peer-support. Nonetheless, ensuring full support from supervisors has been critical to the success of STARS. Supervisors have been strongly encouraged to take part in supervisor-only pedagogic sessions, reflecting on ways to optimise, adjust and continually improve the soil science experience. Supervisors have also joined the larger events, so that they too can build on the relationships and networks forming throughout the CDT. Ensuring supervisor commitment and 'buy-in' to STARS has at times been a challenge, given timetable and geographic separations, but there have been some productive interactions, which were vital to the success of the college.

3 | A STUDENT PERSPECTIVE

In this section, the written narrative is provided directly from the perspective of one of the students:

'For each STARS cohort, our first experience of the CDT was an intense 3 days of introductions, talks and activities, which introduced us to our fellow students and the wider STARS consortium. While the setting for this induction differed for each cohort, all set the tone for 'our time' in the CDT, welcoming us and starting to build cohorts of students who would undergo their PhD journeys together. From our first presentations on our research plans, through our training, to watching one another present our findings at STARS or other conferences, it has been clear how much we have developed and grown as researchers. Much of this has been down to the outstanding training and support provided by the STARS CDT.

3.1 | Training

Initial training provided by STARS included scientific writing, peer reviewing of soil science literature, and statistics. While this overlapped with training provided by our own institutions, it was often both substantially more in-depth and better suited for soil scientists. Furthermore, membership of a CDT brought training opportunities beyond those provided by STARS itself, as partnering with other doctoral training bodies allowed STARS to facilitate additional training, such as writing retreats or explorations of innovation and how to engage with governmental policy.

Perhaps the most important training for inspiring our interest in soil science, however, took us out of meeting rooms and into the field. In our first year, we visited field sites at two of the consortium's partner institutions, Lancaster and Bangor, receiving training which first introduced us to the fundamentals of soil science, before moving into an exploration of landscape-scale pedogenesis, soil health, soil quality indicators and soil-related ecosystem service delivery down a catena sequence in the Welsh mountains. These training courses mainly focused on young soils developed since the last glacial period which ended ca. 10,000 years ago (e.g., Entisols, Inceptisols, Spodosols, Alfisols, Histsols). Coming from a diverse range of academic backgrounds and previous experience, for many students this was our first real experience of hands-on soil science and allowed us to fully experience the diversity of soil types present in the UK. Given that soil science is now rarely taught at undergraduate or MSc level in the UK, the STARS training courses played an important role in providing a strong grounding in soil science, going beyond our own areas of PhD research.

In our second year, we visited the subtropical islands of Tenerife and La Gomera, investigating World Soil Orders not found in the UK (Figure 2). This was an invaluable opportunity to explore the many factors—temporal, geological, topographical, climatic and biological—controlling soil formation and development. The soils we worked with ranged from young Entisols and Inceptisols still forming in magma fields, to those that had subsequently developed into Aridisols and Andisols, leading on to highly weathered Oxisols, Vertisols and Ultisols on the hills of La Gomera. To spend a week investigating soil development under a truly diverse set of conditions thoroughly enriched our understanding and appreciation of soils.

A further training opportunity was to organise, convene, and present in a session at the European Geosciences Union (EGU) General Assembly. STARS support thus enabled us to plan and host a soil science session at a major international conference at an early stage in our careers. Subsequently, it has also given STARS students the confidence to convene further sessions at the EGU and other conferences. In many areas, the training provided by STARS has not been to simply improve our capabilities and proficiencies as soil scientists, but to expand our horizons and inspire our interest in soils.

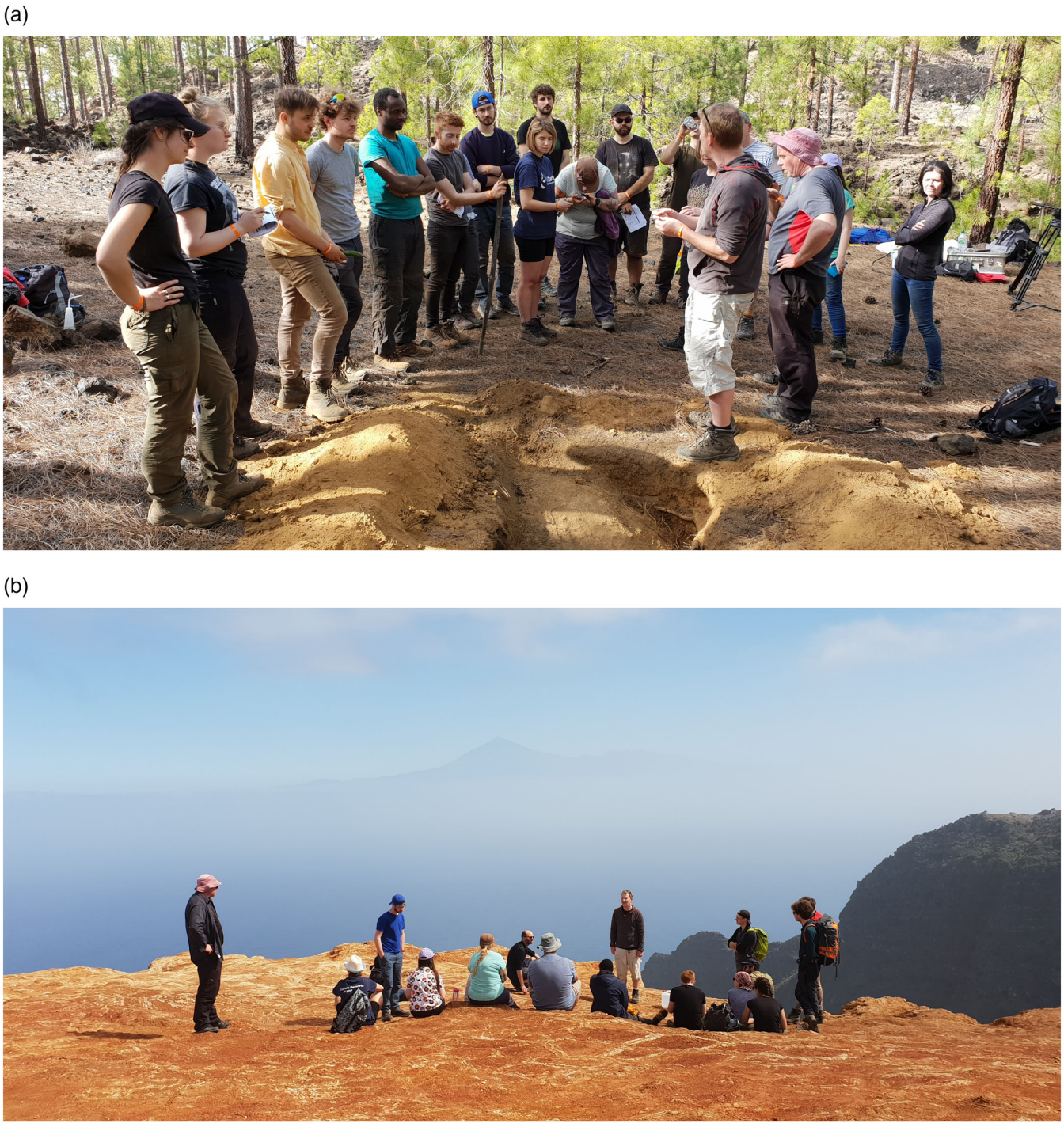

FIGURE 2 Students and staff from the STARS Centre for Doctoral Training (CDT) studying soil formation in the Canary Islands, 2019, part of a 2nd year compulsory training event for all STARS cohorts. (a) Studying a young Andisol in a pine forest on southern Tenerife. (b) Studying an eroded Oxisol on La Gomera (February 2019, photos P. M. Haygarth)

3.2 | The STARS network

A particular strength of STARS has been developing connections among students at different institutions, and across a wide range of soil research areas. Most of the training took place within our annual cohorts, bringing together students from all universities and institutions within the STARS consortium and fostering strong connections throughout, and beyond, our PhD studies. A review of other Doctoral Training Centres (DTCs: a generic term within which CDTs are a discipline-specific type) funded by the Economic and Social Research Council has indicated that non-discipline-specific DTCs did little to promote collaboration between academics (Budd et al., 2018). By contrast, STARS,

which is technically not a DTC, but a deep discipline-based CDT, has undoubtedly promoted inter-institutional collaboration among students that would otherwise not have existed. The annual STARS conferences and workshops served to link the whole CDT together and provided engaging and stimulating opportunities to share our research, helping to develop a sense of a research community in the CDT. The inter-institutional connections that STARS enabled among PhD students created avenues for research collaboration, leading to outputs such as Cimpoiasu et al. (2021; published in this *Special Issue*). These connections among the STARS alumni will likely enhance the potential for future research collaborations. More broadly, the STARS network has connected students to researchers at institutions across the UK. Many of us found that having a supervisor at, and affiliation with, a partner intuition enhanced our research capabilities, providing expertise and access to facilities not available in our home institutions.

3.3 | Opportunities within and beyond STARS

A key benefit of being part of STARS was the wealth of opportunities made available beyond the CDT itself. International research placements allowed some students to undertake work in outstanding labs outside the UK (e.g., Brazil, Germany), enabling students to perform research that would otherwise not have been possible within their PhDs, and to forge links with the wider soil science community. While STARS set out to train the next generation of soil scientists, the CDT nonetheless endeavoured to help us explore potential non-academic post-PhD career pathways. Placements in industry and (in particular) policy have proved popular. These included influential institutions such as the UK Government's Department for Environment, Food and Rural Affairs (Defra), the Welsh Government and Kew Gardens. Students who undertook such placements found them rewarding and highly valuable experiences, and several who did so are now working in governmental departments, helping to shape UK environmental policy.

Throughout our PhDs, the difference between the opportunities and support provided by the STARS CDT, compared to those offered to students who were not part of the CDT, has been striking. The fact that STARS was a soil science-focused CDT rather than one with a much broader remit has allowed the targeted delivery of training that is more relevant to us and our future career pathways. The opportunities available during our PhDs have added a great amount of additional value to our student experiences and development and set us up for our future careers, whether in soil science, policy, industry or elsewhere.'

4 | MULTIPLE SITES: OPPORTUNITIES AND CHALLENGES

A major benefit of the STARS college has been bringing people together across a wide range of university and research institute departments. This has facilitated easy access to many datasets, resources and equipment for students and supervisors that would otherwise not have been available to students based at a single institution. The complement of the universities with the research institutes has been valuable. Research institutes are custodians of a wide range of valuable national datasets including soil and geology maps, national ecological and soil surveys (e.g., Welsh Environment surveys [Glastir Monitoring & Evaluation Programme (GMEP) and Environmental and Rural Affairs Monitoring and Modelling Programme (ERAMMP)]). Importantly, while these datasets are often freely available, the CDT provides easier access to the very people who have often spent a lifetime collecting the data, so issues and opportunities can be discussed and shared. Long-term experiments are maintained by both institutes and universities and as aforementioned, this has included the Classical Experiments at Rothamsted, which have been used to benefit the student. Thanks to the institutional breadth of the college, members have also generated or brought with them numerous industrial links, which have provided valuable industry experience or practical insights to students.

The involvement of multiple institutions around a central research area also offered opportunities for equipment sharing. In one example, a student based at Lancaster University was researching soil formation rates using cosmogenic radionuclides and was able to accompany the BGS drilling team to obtain soil/regolith samples in sandstones from several metres deep. As PhD research projects progress, new challenges and often unforeseen questions emerge along the twists and turns of the learning experience, which may require accessing equipment previously not considered at the time the project was conceived. For example, having access to the BGS scanning electron microscope facility allowed a student to compare rock matrices as a control on the rate of soil formation from sandstones (Evans et al., 2021), a topic not envisaged until late in the PhD journey. Finally, while statistical courses were part of the students' training, many experiments are designed with a complexity beyond what is taught on a basic statistics course. STARS students had the great advantage of being able to access several excellent statisticians and bioinformaticians at different institutions, who could help develop experimental designs and correct statistical approaches, again highlighting the diverse advantages the national college provides.

Students also had opportunities to reside at either a research institute, a university or to move between both

during their PhD journeys. Some students got to experience the slightly more regular 'work-based' day if sited at a research institute, compared to the academic atmosphere of the universities. Most thrived on the opportunity to experience different working environments, but the choice of blending home research institute with university setting was not always to a student's liking, and some preferred to remain in a single principal place of work, sometimes because of family needs or domestic pull to live in one location. Having the larger CDT 'family' to provide these options for relocation is an advantage to ensuring student retention and wellbeing.

The STARS CDT was all about sharing experiences. Social media has enabled the CDT to share and celebrate the student's victories, allowing the students to keep in touch, and provide updates to the wider soil community, although the degree to which students were happy to use and be involved with social media varied considerably.

5 | WIDER BENEFITS OF THE SHARED STARS TRAINING

The unified soils training programme was one of the great things about STARS. Not only were the group soil training activities instrumental for building a cohort of students, but they also provided opportunities for the students to interact with multiple supervisors and management board members, and they freed up valuable supervision time that would otherwise be spent on individual training.

Certainly, the broadest and most popular training event was the aforementioned one-week residential course in Tenerife in the students' second year, which was taught by Management Board members with different areas of expertise (Figure 3). The course focused largely on soil development and introduced several of the major soil orders of the world. The choice of location was inspired; thanks to its long history of regular volcanic activity, Tenerife is an ideal place to witness first-hand the five factors of soil formation and see soil types that do not occur in the UK (with the additional bonus of a week of sunshine in late January). The unique natural history of the Canary Islands also gave the students a broader perspective of soils and soil development, as well as a sense of adventure and discovery. Importantly, thanks to the evenings spent having a leisurely chat as a group, the instructors got to know the individuals within each cohort of students, which provided valuable insights into the students' strengths and highlighted potential support needs, while making the instructors more approachable to students throughout their journey towards a PhD.

Although the STARS training programme may seem quite labour- and time-intensive, it is worth noting that

FIGURE 3 Delegates at the first STARS conference hosted in the Lake District, UK, co-organised by students and staff (January 2019, photo. R. Appleton)

such a targeted, collective training programme benefits both students and supervisors. Much less of the training burden falls on individual supervisors when PhD students can learn important and relevant research skills as a group, and cohort training also promotes peer-to-peer learning (Hutchings, 2017). The STARS training course in scientific writing skills is a great example of how cohort-based activities benefit students and supervisors alike. The principle was simple: interactive workshops covered different aspects of the scientific writing and publishing process, from the basic building blocks of a scientific paper to specific techniques for creating a strong narrative, to the essentials of peer-review. The workshops were interspersed with focused writing sessions, in which everyone worked on their own texts, and group discussions around broader considerations such as authorship and journal choice. This format gave the students the opportunity to put theory into practice while progressing with their own thesis chapters or manuscripts, receiving support from experienced authors, and discussing strategies or experiences with their peers. Up to 20 students attended each session, which means that up to 20 supervisors saved considerable time explaining principles or dealing with writing issues. Hence, by investing in doctoral training as a group, the STARS CDT alleviated one of the main pressures on supervision time (Carter & Kumar, 2017), while providing structured support to students, and increasing the likelihood of their thesis chapters being published in peer-reviewed journals.

6 | CREATING MEANINGFUL LEGACY OF THE STARS CDT

A key characteristic of the CDTs in the UK is that they are focused, targeted, discipline-based training centres, which only exist for a fixed time and are designed to give a strategically placed 'boost' to a discipline; this boost should have legacy effects that outlast the CDT. The flip side of this is that when the 'boost' funding ends, there is a need for an impactful 'legacy', which needs careful planning and thought. Funding was provided by the research councils to help deliver such a legacy. Collectively, the STARS consortium has amassed a vast range of soil data and experience, but it is essential to make sure the impact has longevity beyond the end of the individual PhDs. The purpose of STARS legacy was thus to continue the development of a community of PhD students within the focus areas of STARS and ensure maximum impact of the investment. Here is a walk-through of some of the aspects of the legacy so far.

The STARS CDT has (as of October 2021) trained 19 new soil science doctorates with a further 18 expected to graduate in the next 18 months. Of these graduates, 10 have gone-on to research posts, 2 have taken policy posts and one has entered industry. Thirty-six first author publications have been accepted into peer-reviewed journals, of which 13 feature in this special issue of *European Journal of Soil Science*, and a further 35 have at least one STARS student as co-author. Two STARS alumni have published five manuscripts (George et al., 2017, 2020, 2021; George, Creer, et al., 2019; George, Lallias, et al., 2019; Greenfield et al., 2018; Greenfield, Hill, Paterson, et al., 2020; Greenfield, Hill, Seaton, et al., 2020; Greenfield, Puissant, & Jones, 2021; Greenfield, Razavi, et al., 2021), there have been two in the high-impact, broad-appeal journal *Nature Communications* (Cooper et al., 2020; George et al., 2020) and five in the currently highest-ranking soil journal, *Soil Biology & Biochemistry*, including one *Perspectives* article (examples include George et al., 2017; Greenfield, Hill, Paterson, et al., 2020; Greenfield, Hill, Seaton, et al., 2020; Greenfield, Puissant, & Jones, 2021; Greenfield, Razavi, et al., 2021; Mezeli et al., 2020; Seaton et al., 2020). These significant scientific contributions highlight the impact that UKRI's investment has had for the discipline.

Building and maintaining collaborative partnerships with stakeholders beyond academia has been a key component of STARS and stakeholder engagement will thus form part of the legacy. One great example of the CDT's input to stakeholders is cohort 1's collaborative contribution of evidence to national policy on soil health. In addition, 16 students have completed industrial and policy placements, and two of the STARS conferences have been attended by stakeholders from key sectors. The STARS CDT has hosted four conferences: Two student-led events at the Low-wood Hotel, Cumbria, UK (Figure 3) and two online: A one-day meeting in spring 2021 and the STARS four-day Autumn Soil Science Conference 2021—*Soils in Context*. As part of our commitment to broadening the reach of our work and Soil Science in general, we commissioned a visual science communicator to raise the profile of STARS.

We have also commissioned a range of over 40 professional films that are hosted on the (STARS YouTube Channel, https://www.youtube.com/channel/UCQF4JwyJuUGDP_dsi34Epag) that include insights into student research projects, presented by the PhD researchers themselves, as well as a variety of collected 'playlists' around the areas of 'soil phosphorus', and 'soil innovation', with one example being *Innovation and Collaboration across the Academia-Industry-Policy Boundary*. Without doubt, however, one of our most ambitious outputs is the 40-min film celebrating the (*World Soil Orders around the Canary Islands,*https://youtu.be/mENIZtbvnrE*),* made by STARS staff and students. Our aim is that eventually such resources including research talks, presentations and posters will be hosted in the

future on our 'legacy portal' website. This will help us continue our contribution to soil science training, recruitment and awareness by ensuring our resources remain accessible to all. The website will also host a Soil Science 'curriculum' aimed at graduate and post-graduate scientists and the committed hobbyist, structured around our four research themes and proliferated with up-to-date knowledge from our consortium and associated relevant materials. Alumni and partner content will reflect the unique relationship in which they exist within the STARS consortium, highlighting the significant cultural component in establishing a successful CDT and its legacy.

The STARS legacy work is very much an exciting work-in-progress, and we continue to think and plan for the future, for example, we are already planning a STARS legacy half-day session at the World Congress of Soil Science in Glasgow, 2022. STARS legacy represents a long-lasting investment to continue delivering on one of the CDT's central aims: Training and inspiring future generations of soil scientists.

7 | REFLECTIONS

The STARS CDT project was commissioned in part to help alleviate the decline in soil science expertise in UK industry, policy, academia and regulatory organisations. A CDT such as STARS, and celebrated in this *Special Issue* of the *European Journal of Soil Science*, has not only provided soils-based discipline value to students, but also represents a worthwhile foundation of investment to the UK and perhaps wider international soil science. Having fast-track access to the national range of data and facilities held among partners has been a major advantage of the students' CDT experience. Investment in a CDT-like STARS has alleviated one of the main pressures on supervision time (Carter & Kumar, 2017), while providing structured support to students, and perhaps increasing the likelihood of their thesis chapters being published in highly ranked peer-reviewed journals. However, it is not without challenges, especially for those working across multiple institutions and the tensions between different student governance procedures in different organisations. These aspects need to be carefully navigated, to ensure the benefits of the CDT remain positive addition, on top of the more traditional research home of the student. Exposure of the STARS students to industry, policy and regulatory organisations via invited speaker sessions at STARS conferences, work placements and dedicated funding support has provided students with an essential link to the world outside of their PhDs. Delivering a lasting 'legacy' of the CDT is something that needs careful consideration and investment, but given the strength and breadth of the research showcased in this *Special Issue*, we believe we are well on the way to creating an impact that will outlast STARS for many years to come.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

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DATA AVAILABILITY STATEMENT

The data from the STARS CDT are going to be made available on the Legacy portal

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