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Article

Developing Key Skills as a Science Communicator: Case Studies of Two Scientist-Led Outreach Programmes

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Abstract: Outreach by scientific researchers in school classrooms often results in widespread benefit for learners, classroom teachers and researchers. This paper presents a consideration of these benefits using two case studies in the Geography, Earth and Environmental Sciences (GEES). In each case, different school classroom-based activities were designed by scientists, but were improved by input from educational professionals, which helped to maximize the mutual learning experiences and to ensure the quality of the content and its delivery. Each case study suggests an improvement in scientist's working knowledge of best practices for classroom-based outreach activities, which can translate to improved practices for University-level teaching, among other tangible career-relevant benefits. Despite these benefits, these projects highlight the well-established need for improved training for researchers in effective outreach practices, increased value on programme evaluation, and the growing need for meaningful professional recognition for researchers involved in these important, and ever-growing, outreach activities.

Keywords: education; outreach; classroom; scientific training; learning experience

1. Introduction

Science outreach is a term that is becoming more commonplace in the parlance of academia; with many grant proposals requiring some form of outreach, broader impacts or knowledge exchange [1]. Outreach in this context is defined here as activities that are designed to educate the public about aspects of scientific research. The UK's Engineering and Physical Sciences Research Council (EPSRC) state in their guidance for preparing a proposal that, "Outreach is a valid and important route to impact and EPSRC encourages researchers to include outreach activities within their Pathways to Impact plans" [2].

There is widespread demand on Geography, Earth and Environmental Sciences (GEES) researchers to double as science communicators, yet of the 95 GEES researchers surveyed in a recent (2013) pilot study, 60% indicated that they have never had any formal public engagement or communication training; this despite the fact that 90% of them "frequently" engage in outreach activities [3]. Despite this lack of formal training, 53% "strongly agreed" that engaging in outreach activities is part of their jobs as scientists, but that this work was often conducted outside of their contracted hours. Similar outcomes are documented in other studies [1,4].

One of the most common forms of outreach is by visiting schools (the term school is used here to refer to pre-University places of education), to teach students and teachers about an aspect of science in an engaging manner that both stimulates the interest of the learners, and also reminds them of the possibilities of what can be achieved with science. The term outreach can include activities such as mentoring, tutoring, giving presentations, supporting teachers and involvement with after-school clubs and summer schools [1,5]. The benefits that such activities can have on the students are well documented, with a well-designed outreach activity presenting them with an opportunity to become engaged in an authentic experience. It also provides the opportunity to deliver hands-on activities that generate interest in science, promoting new perceptions on what it is to be a scientist [6], and providing better context for the science that they learn in the classroom [7].

Outreach activities can also have a significant effect on the teachers' professional development, classroom practice, and students' overall levels of achievement [8]. It can also generate interest early in a student's education, so that by the time they enter university they have a clearer sense of science as a rewarding career [9]. Ultimately, effective outreach work that is carried out in the classrooms of today can inspire the scientists of tomorrow.

Further, the benefits that such outreach activities can provide to the scientists are just as varied and consequential as those offered to the learners, with the knowledge transfer between the educator and the expert a bidirectional process. This means that as well as the key skills that are developed as part of the outreach activity itself, scientists can learn from the teachers' communication, presentational, and interpersonal skills [6,10]. Despite these positives, a lack of official recognition (both externally and within the University or research institute), as well as scientists' perceptions of their own skills, can often have a negative impact on the quality and outcome of such scientist-led outreach activities [11,12].

The aim of this paper is to discuss, from the perspective of GEES researchers, the benefits that are afforded to scientific researchers that partake in school outreach activities. Section 2 presents case studies outlining successful scientist-led activities that have resulted in the development of key transferable skills for researchers. Section 3 discusses these skills, and how they are beneficial to the role of a scientific researcher. Finally, Section 4 offers suggestions for improvements that could offset some of the negativity and lack of professional recognition that is associated with outreach activities, specifically within the university environment [1]. Overall, we hope this work helps to build a body of accessible literature for researchers of best practices, lessons learned, and modes of effective communication.

2. Case Studies

The case studies presented here are those designed and implemented by the authors. While diverse examples exist, the following examples are ones that the authors have direct involvement in, thereby enabling a direct comment on the impacts that these activities have had on our own outreach practices as researchers. The first example includes direct contact and experience with students, while the second case study presents a format in which the collaboration between researchers and teachers resulted in the development of a classroom tool that was used in schoolrooms worldwide.

2.1. Do You Think That's Air You're Breathing

The air we breathe is often taken for granted, yet it forms a protective layer around the whole planet, the atmosphere, without which life could not exist. "Do You Think That's Air You're Breathing" (hereafter abbreviated as "Do You Think") is an outreach activity that was designed by researchers from the Centre for Atmospheric Science (CAS) at the University of Manchester, and has been delivered to GCSE (The General Certificate of Secondary Education is an academic qualification awarded in a specified subject, generally taken in a number of subjects by students aged 14–16 in secondary education in England, Wales and Northern Ireland) and A-level (The General Certificate of Education Advanced Level—generally termed the GCE Advanced Level or, more commonly, the A Level—is an academic qualification offered by educational bodies in England, Wales and Northern Ireland to students completing secondary or pre-university education) students from the Greater Manchester area from 2013 to the present day.

The format of this outreach is a kind of "circuit training for scientists", in which the students participate in a number of individual activities, to investigate various aspects of the atmosphere. As well as allowing the students to learn more about the air they breathe, this outreach activity also focuses on engaging with the students, so that by the end of the session they have had an experience of working like a scientist, and have a much clearer idea of what research scientists actually do. This enables students to identify with scientists as people like them, rather than as stereotypical caricatures.

The activities themselves range from building a weather station with a Raspberry Pi computer (the Raspberry Pi is a low-cost, credit card-sized computer that plugs into a computer monitor, and uses a standard keyboard and mouse. It was developed by the Raspberry Pi Foundation in the UK to make computer programming accessible to school students), to carrying out simple spectroscopy measurements, using the same basic techniques used in research-grade instrumentation at the CAS laboratories. The students are also encouraged to ask questions, analyze data, and generally think about what it is that makes our atmosphere so unique. "Do You Think" was designed to last between 90 min and 2 h, depending on the availability and flexibility of the schools. From the summer of 2013 to the summer of 2014 "Do You Think" was run at 10 different schools and twice at the University of Manchester, engaging with over 400 school children in the process. On average the class sizes in the workshops were between 30 and 40, and there were usually between 5 and 6 different activities, depending on the number of students. An example of one of these activities is shown in Figure 1.

Figure 1. Students learn about aerosols in the atmosphere.

What makes the workshop programme itself so innovative is that every station is like a puzzle piece, with each student getting to explore all of these separate but related pieces and then, with the help of the facilitators, putting these pieces together to form a bigger picture of the overall importance of the atmosphere. This methodology places emphasis not just on the take-home message, but also on the narrative that is unique to each student.

The teachers gave consistent feedback as to the excellence of not just the learning outcomes and deliverables, but also the ability of the facilitators to engage with both the subject matter and the students in an effective and appealing manner. This feedback was collected from the teachers by asking them what the benefits of the activity were to their students, and also from letters of support that were received from the schools. Typical quotes from teachers, in response to this question included: "The session was truly inspiring for our students, and we were impressed by the enthusiasm and intelligence of the researchers"; "The use of technology in the classroom was an excellent way of showing our pupils how scientists work in the real world"; it went a large way to dispel the priori misconception that scientists are all old men in white lab coats;" and "this activity should be recognised as an example of good practice".

The sustainability of the project was strengthened by the training and use of the facilitators, with new Ph.D. students and postdocs trained up on a regular basis (approximately one a month for the duration of this project), thereby ensuring that the project was never over reliant on one group of people, whilst offering training benefits to all. This training took the form of a combination of one-to-one sessions on communication skills, practicing the activities on fellow postgraduate and undergraduate students, and receiving detailed and personalized feedback following on from the delivery of each session.

Of the 7 Ph.D. students and postdocs that were surveyed for their experiences of this outreach activity, 100% of them responded that their overall experiences from the outreach project were "extremely positive", with 71% saying that it had been either "extremely beneficial" or "very beneficial" to their scientific careers, although some participants noted that it was still too early in their scientific careers to say for sure. 100% of the participants felt that the outreach activity had helped their communication abilities either "a great deal" or "a lot", and 86% of the participants also felt that it had helped their confidence either "a great deal" or "a lot". The main positives to be drawn from the activity included, "Having an opportunity to present the work we do in an engaging and exciting way to young people," "Inspiring students about science", and "Remembering why I like science." The biggest negatives centered on either the occasional lack of engagement from the students or a supposed lack of internal support and/or acknowledgement from within the University. Whilst the number of participants in this survey is relatively small, all of them have continued with their own personal outreach development, with five of them having gone on to develop and lead outreach activities of their own including workshops for students between the ages of 5 and 11 that investigate the notion of "Who is a Scientist?".

2.2. Flakes, Blobs and Bubbles: An Ice Core Art Project

Following the momentum of the 2007–2008 International Polar Year (IPY) the Association of Early Polar Career Scientists (APECS) aimed to continue aspects of this successful polar research and outreach campaign [13,14]. Following the established IPY model of "Polar Days" [13], the APECS Education and Outreach committee adopted and developed the International Polar Week (IPW), a bi-annual event currently held around the equinoxes each year. In 2012, the focus of the September IPW was to generate, and then translate, a classroom activity that was scientifically sound, and then appropriate for use in the classroom.

While the 2012 IPW was hosted by APECS, the IPW sponsors and direct organizers were, in large part, members of the educational community. This split the demographic in both the planning and execution stages of this outreach endeavor, inspired connection between both the educational and research communities, and built on the expertise of both. This collaboration resulted in the generation of activities that were both scientifically accurate and functional in the classroom.

The activity called "Flakes, Blobs and Bubbles: An Ice Core Art Project" (hereafter abbreviated as "Ice Core Art") designed by researchers [15] was chosen by the IPW planning committee after a solicitation of submissions from both scientists and teachers. Prior to making it publically available, teachers reviewed and modified the activity by suggesting improvements in the language, level of scientific content, and external resources provided. A webpage (http://icecoreart.weebly.com/) was generated to support this activity and provided a platform for access, thereby enabling conversation between participants from around the world. To make the activity even more widely accessible, international members of APECS volunteered to translate the activity and accompanying PowerPoint presentation (see below). By the time of the September IPW, the activity was available in 21 different languages.

"Ice Core Art" aimed to explore the formation of ice and how ice cores can be used as recorders of environmental change. The activity included two parts: (a) a PowerPoint presentation explaining the snow-firn-ice process and how ice cores can act as climate recorders or proxies, along with links to supplementary information and videos, and (b) an art activity that asked students to draw the three different "phases" of ice formation, including snow (flakes), firn (blobs), and ice (bubbles). The students' images were then submitted to a dedicated email address and were processed by a computer code written by [15]. This program collated the images by color density and automatically sorted the numerous submissions into a visual snow-firn-ice or "global ice core" image (Figure 2). Polar-themed mosaic images were also produced and participants were encouraged to produce and share their own mosaics using online freeware (Figure 3). The submitted images and mosaics were shared online and through the APECS and IPW partners' webpages.

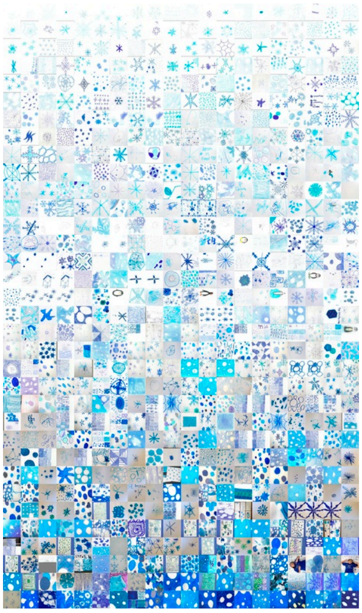

Figure 2. An example of the snow-firn-ice profile, or "global ice core" generated from the global submissions. Image created by the author Heidi Roop in collaboration with Dan Zwartz.

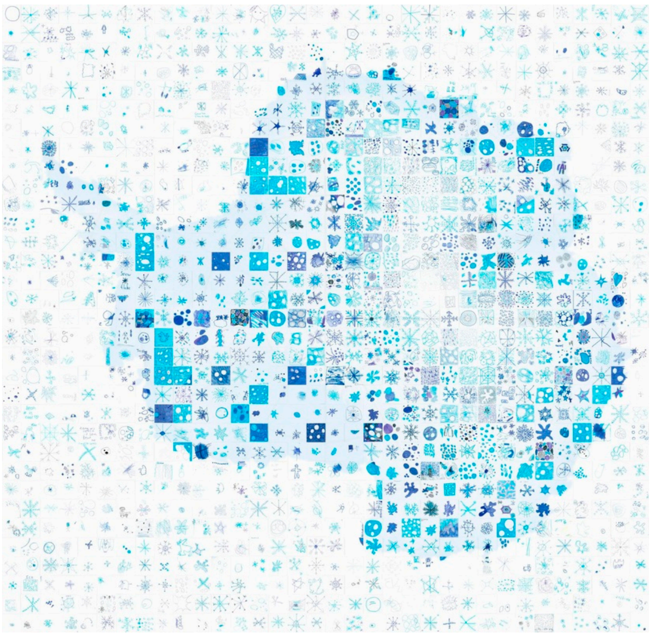

Figure 3. An example of a polar-themed mosaic, with the shape of Antarctica generated from image submissions. Image created by the author Heidi Roop in collaboration with Dan Zwartz.

In total, approximately 35 researchers and teachers participated in the generation of this activity and its translations, which resulted in more than 1000 submissions from approximately 30 classrooms, communities, and science festivals (e.g., NZ IceFest; http://nzicefest.co.nz/); the students taking part in the activity ranged from 10 to 18 years in age. This activity had to be simplified to enable translation by volunteers and improve ease of use in the classroom. However, the process still engaged a large audience and importantly, resulted in direct collaborations between researchers and teachers. The September 2012 International Polar Week was designed and executed collaboratively by researchers and teachers, and many teachers hosted researchers in their classrooms. Further, the "Ice Core Art" activity was designed by researchers but edited and improved by the teachers, providing constructive feedback to researchers on appropriate lesson plan development.

One of the highlights of this outreach effort was the willingness and enthusiasm of the teachers and scientists to serve as resources for one another, with both able to share their respective expertise while improving understanding of the others' discipline. Furthermore, more than a dozen researchers took this activity into their local communities. For those unable to participate directly in the classroom, the act of translation offered a means of engagement, resulting in a tangible output, and exposing many to an educator-vetted activity, which may help to guide their future classroom-based communications.

3. Discussion

While the authors recognize the breadth of research conducted on the topics of science communication and the role of scientists as communicators, particularly within the social sciences community, the aim of these case studies is to present both our perceived strengths and weaknesses of specific scientist-led outreach efforts. By sharing these experiences and ideas, the hope is to share our approach, expose needed areas of improvement, distribute our best practice techniques in an accessible format, and advance the dialogue about how to improve such scientist-led engagement efforts.

In both case studies, the act of outreach extended beyond a positive experience into one where the researchers built valuable skills. Based on the survey from "Do You Think" and anecdotal evidence from "Ice Core Art", the key transferable skills that were acquired by the researchers can be summarized as:

- Improved communication and organizational skills;
- Increased confidence;
- Enhanced teamwork and interpersonal skills;
- Acquired ability to "translate" scientific expertise into accessible terms;
- Greater understanding as to the benefits of knowledge exchange;
- A reminder as to why a career in science was pursued in the first instance.

These outcomes are well aligned with previous work by [1,6], *i.e.*, that the process of clarifying research objectives and explaining complex scientific concepts in tangible, related terms extends well beyond the classroom. The most obvious impact of these cumulative skills is that researchers can directly transfer these skills into the communication of their research *within* the broader scientific community and in University-level teaching. "In reach" and teamwork skills are essential to success within interdisciplinary scientific research. It should be pointed out that whilst the scale of these two case studies is relatively large in terms of both resource and workforce, these transferable skills are still relevant to school outreach activities that are done on a much smaller scale (e.g., one-to-one interviews between school students and GEES researchers).

Importantly, aspects of both of these projects embraced a "deliberative science communication" [16] or "participatory" [17] approach to engagement. While perhaps not strictly participatory in nature as described by Bucchi, 2008, a conscious effort was made to avoid the classic "deficit" model approach where there is an assumed lack of knowledge and interest of the non-expert audience [17–19].

For "Ice Core Art", teachers vetted the information and mode of communication, with the educational community helping to inform the quality and accessibility of the activity and its content. In essence, the success of this activity hinged on the expertise of the teachers, engaged them in the conversation about their needs, and did not solely involve researchers "passing on" information. Of direct benefit to the researchers involved is that this method exposed them to pedagogy and aspects of how to generate age-appropriate classroom activities, a skill not typically formally acquired as a scientist. In academia, this can be directly beneficial to a researcher's own University-level teaching practices; the lessons that are learned in the school classroom can be directly transferable to the University learning environment, with participating researchers able to put into practice the experiential and active learning techniques that they have developed during the outreach activities, thus benefitting the University-level students.

For "Do You Think", the activities were designed to work in symbiosis with the science curriculum that the students were already studying, and were developed with teachers to ensure that a solely deficit-based approach was avoided. The aim of the activity was to inspire the students to what they themselves could do with the science that they had studied, rather than to alienate them with theoretical concepts that were beyond their level of understanding. As well as benefiting the teachers and the learners, this was of direct benefit to the researchers, as this structure meant that they had to think about how their own research could be explained at this level, which fostered a deeper understanding of their work, and also encouraged them to get "back to basics". Many of the researchers commented that it was this approach that helped them to rediscover why they had decided to pursue a career in research, with the activity acting as a stimulus to their research once they had returned from the classroom.

It is important to note that despite the differences in approach between these two case studies ("Do You Think" involved a personal interaction compared to the remote interaction offered by "Ice Core Art"), both projects were still successful in engaging with a large number of school children. Furthermore, both of these case studies offered a means of developing early career scientists, who represent the future of scientific research. By fostering the skills outlined above we potentially start to build a community of scientific experts, who are also effective science communicators with an understanding and a respect for the value and impact of engaging outreach.

4. Recommendations

On the basis of the case studies discussed in this work, as well as the numerous other school outreach activities that the authors have been involved in, and also from the available literature on this subject, the authors would like to make the following three key recommendations that are necessary in order for research scientists to gain maximum benefit from school outreach activities:

1. **Involve the teachers:** In the development of any outreach activity, scientific researchers should utilize a model of increased participation, including working directly with educational professionals to identify their needs, as well as those of their students. In addition to enabling the development of effective outreach programs, such practices will also generate a further understanding of pedagogy and curriculum development, both of which are key to being successful academics.

Initiating dialogue with the "non-specialist" audience, which here refers to teachers and students, appears to be a key ingredient for gaining key skills as a science communicator. Further, it is important to recognize the expertise of, and to encourage the engagement with, teachers who are able to facilitate proper curriculum design and modes of knowledge sharing. As demonstrated by both case studies, working directly with teachers is an excellent way to ensure the accessibility and quality of content being presented, which are skills often applied later in a scientific career through University-level teaching.

2. **Evaluate the activity:** An evaluation of the outreach programme is essential; by allowing for a means of identifying and sharing best practice the outreach activities and skillset of the researchers can be improved greatly. As has been shown by [1], even a qualitative approach to evaluation can yield marked improvements. Importantly, evaluation requires planning and the establishment of clear goals and desired outcomes. The practice of defining these goals can help to clarify objectives and thus improve the impact of an outreach activity. However, effective evaluation tools, theories and methodologies, while well embedded in the social sciences, appear to be lacking in many outreach events (Jensen, 2011 [20]). In the case studies presented here, better structured evaluation tools, or in the case of "Ice Core Art", any evaluation, would have: (a) helped to define clearer objectives for the engagement activities, and (b) provided more robust data in order to quantitatively evaluate the impact of these activities.

While there is a recognized difficulty in quantitatively evaluating relatively short-term outreach efforts such as those presented here [6], there is also a clear need for empirical research to help improve science communication [21]. An evaluation of an activity, even if done qualitatively, may help to inform the true reach and impact of such outreach efforts. Through evaluation and quantification of these efforts, the visibility and credibility can be increased within the research community, thereby representing a potential step towards meaningful academic recognition (see below). Evaluation also offers a means to extend outreach beyond something that "should be done", to an activity that is professionally relevant and valued sufficiently to ensure effective and accurate communication within school classrooms *and* with the wider public.

3. **Increased professional recognition is vital:** In this work, the key dissatisfaction from scientists engaging in outreach was the lack of internal support from within the University, as well as the lack of professional recognition.

Despite the professional recognition that can come with the publication of the evaluation of such outreach activities, it is important to stress that this should not be the sole methodology in which the importance of outreach activities are recognized. Many scientists believe that communication should be integrated into their jobs and not seen as a peripheral component of their work [22]. Yet, despite the apparent interest and recognition of the importance of scientists as communicators, most lack training and very few (11%) of those surveyed by [3] strongly agreed that outreach was either a positive résumé builder or way to garner professional recognition. Andrews, Weaver, Hanley, Shamatha and Melton [1] noted in their extensive survey of scientists who engage in outreach, that one of the key points of dissatisfaction for scientists is the low value and recognition given to those participating in outreach. Often departments place little value on those participating in outreach, with postgraduate students often left feeling unsupported by their advisors when engaging in outreach activities, whilst those pursuing careers in academia indicated that their engagement in science communication was not part of the tenure process, thus making it difficult to justify, given the amount of time needed to produce and participate in effective outreach programmes.

While teaching and research are still considered by most people as the two major tasks of the universities and therefore academics [23], there currently exists little or no professional incentive or recognition for producing well-delivered outreach activities [24]. This, despite the fact that producing high-quality science communicators not only benefits the researchers involved, but also the universities that they represent.

External recognition of excellent school outreach activities, such as that provided by the National Co-ordinating Centre for Outreach (NCCPE; [25]), in the UK, or the Wellcome Trust can certainly help to achieve the credit that is needed in order to continue to develop sustained and engaging activities. However, the need for external recognition in order to provide internal support points to a system that is in need of review.

Access to and placing a priority on training is increasingly important as the society-science interface expands with increased access to information through social media, media coverage, and an ever-growing number of scientist blogs [19,20,26]. Overall, while the benefits to researchers are clear, the need to address the shortcomings of the scientist-led outreach is also clear; scientists need proper training and a professional means of assessing and sharing best practice, while gaining genuine professional recognition for their contribution to increasing public awareness of science.

With continued calls for researchers to be clear and effective communicators [12], the need for action to support researcher training is paramount. When there are direct benefits to researchers (including transferrable skills that directly impact their abilities in the academic environment as highlighted through this work) why do the barriers and deterrents continue to be the same as those noted in early studies [4,27]? Why do many researchers feel that the culture of science actively discourages them from becoming involved in public outreach, because it would somehow be bad for their careers [24]?

Science 2.0 proposes a systemic change in the modus operandi of doing research and organizing science, in which science communication will play a key part [28]. According to the European Commission's public consultation into Science 2.0 [29], there is a need to "develop researcher and researcher reward schemes that reflect this (new) approach". With potential reward schemes attributed to science communication activities, as well the creation of new job positions to fill these roles, there is hope that at a European level things are potentially moving forward in the right direction.

For those scientists who wish to pursue a career outside of academia at the end of their Ph.D. or postdoctoral positions, these outreach activities provide communication and other key transferable skills. The initiative shown in participating in these activities can also look encouraging to employers, and demonstrates that the candidate has experience of working outside of academia, and communicating with the real world.

In order to truly integrate science and society, and ensure improved and effective communication practices, greater value needs to be placed on those participating in outreach campaigns. Whilst the professional recognition that participation in such activities deserves is likely to be a long and difficult journey, by providing greater internal support universities could help to make a significant step in the right direction.

We conclude by acknowledging that researchers often have little working knowledge of the social science aspects of the science communication literature and appropriate evaluation methods, and that this is a large shortcoming. We also acknowledge that this was largely true for the case studies presented here, but that currently the practicing community (GEES researchers) and theorists (social scientists) are working largely independently of one another. Whilst these activities could benefit from a more solid underpinning in social science methods, they are still useful examples of sharing best practice (and shortcomings). Writing about outreach activities in this way, helps to elevate this conversation and encourages other researchers to begin thinking about sound, evidence-based research plans for assessing the outcomes of their outreach. Papers such as this one are also a necessary step in working towards receiving professional credit for these activities. Furthermore, we hope that this paper forms the starting point of further collaborations between GEES researchers and social scientists.

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Author Contributions

Samuel Illingworth and Heidi Roop conceived and designed the activities, performed the activities, analyzed the activities, and wrote the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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