New Science, New Media: An Assessment of the Online Education and Public Outreach Initiatives of The Dark Energy Survey

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ABSTRACT
We present a case study of the online education and public outreach (EPO) program of The Dark Energy Survey (DES). We believe DES EPO is unique at this scale in astronomy, as it evolved organically from scientists’ volunteerism. We find that DES EPO online products reach 2,500 social media users on average per post; 94\% of these users are predisposed to science-related topics. We find projects which require scientist participation and collaboration support are most successful when they capitalize on participating scientists’ hobbies. Throughout the article, we present recommendations for others interested in facilitating EPO for large science collaborations.

KEYWORDS
Public Engagement; Public Understanding of Science; Public Perception of Science; Public Perception of Scientists

1. Introduction
The landscape of professional astronomy has dramatically transformed over the past fifty years. While the field was once dominated by individuals or small, co-located teams (e.g., a professor and a graduate student), advances in technology have revolutionized the ways in which science is practiced and communicated (Council, 2010b). International collaborations have emerged as the new standard. The primary charge of these large-scale astronomy projects is to use evidence-based research to answer fundamental questions about our Universe. The drive to solve mysteries such as the nature of dark matter and dark energy drive project commissioning, instrument development, project implementation, data products, and analysis (Council, 2010b). Collaboration on such a large scale requires cooperation and respect amongst scientists from a diverse group of ages, genders, and cultures. In addition to the potential for groundbreaking science, this next generation of astronomy collaborations also comes with a wealth of innovative material and experience that can be used to capture the public’s interest in science (Borne et al., 2009).

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The authors would like to thank the following DES collaboration members for their contributions to the writing of this article and the projects described wherein: S. Avila, K. Bechtol, L. Biron, R. Cawthon, C. Chang, R. Das, A. Ferté, M. S. Gill, R. R. Gupta, S. Hamilton, J. M. Hislop, E. Jennings, C. Krawiec, A. Kremin, T. S. Li, T. Lingard, A. Möller, J. Muir, D. Q. Nagasawa, R. L. C. Ogando, A. A. Plazas, I. Sevilla-Noarbe, E. Suchyta, Y. Zhang, J. Zuntz
Education and Public Outreach (EPO) programming has been a cornerstone of nationally sponsored agencies such as the National Aeronautics and Space Administration (NASA) in the USA for decades. The NASA Office of Education is dedicated to designing hands-on activities, creating teacher resources, developing opportunities for students, and inspiring students to pursue careers in the science, technology, engineering, and math (STEM) disciplines [Rosendhal, Sakimoto, Pertzborn, & Cooper 2004]. Similarly, the multi-national European Space Agency (ESA) has a well-developed and actively maintained EPO presence. The NASA and ESA EPO efforts would not be possible without an agreed strategy, support from dedicated, well-trained staff, and an appropriate funding stream.

In the past ten years, many large-scale astronomy programs have devoted funding and personnel to EPO programming, for both in-person activities (e.g., materials for scientists visiting K-12 classrooms and attending science festivals) and online projects. For example, the Hubble Space Telescope (HST) and Sloan Digital Sky Survey created their own EPO initiatives [Griffin 2003; Raddick 2002], including Hubblesite [2] and SDSS Voyages [3], which encourage web-based users to explore publicly available astronomy images and data products through a variety of online lesson plans and hands-on activities. In addition to more conventional avenues of astronomy EPO such as public lectures, science festivals, and planetarium shows, several innovative avenues for connecting science, and scientists, with the public have emerged. For example, citizen science, whereby expert scientists collaborate with members of the public to complete a science project, is growing in popularity year-after-year [Borne et al. 2009; Haywood & Besley 2014].

The importance of EPO activities to modern astronomy is demonstrated by the fact that several projects that are still in the development stage are already investing resources into public engagement. For example, the website of the James Webb Space Telescope (JWST, set to launch in 2019), already includes detailed EPO materials designed for K-12 formal and informal education [4]. The Large Synoptic Survey Telescope (LSST), which will not begin taking data until the end of the decade, describes its EPO program as “as ambitious as the telescope itself.” [5] The LSST EPO program includes plans for citizen science partnerships with The Zooniverse [6] and data visualization projects with several planetaria. Finally, The Wide-Field Infrared Survey Telescope (WFIRST, set to launch in the mid 2020’s) outlines the internal organizational structure of the project and includes EPO as an element of its Science Operations Center [7].

As the examples above demonstrate, EPO programming is now being put at the forefront of collaboration structure well before any data have been taken. In the case of the Dark Energy Survey (DES, founded in 2004), EPO was not embedded during the development stage and had to be “shoehorned in” after survey operations were underway. The full DES EPO program, which includes both online initiatives and in-person lesson plans and demonstrations, evolved from the grass-roots efforts of a small number of collaboration members who are passionate about science communication and outreach. This “bottom-up” approach has been positive in that it has resulted in

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1http://www.esa.int/Education
2http://hubblesite.org/
3http://voyages.sdss.org/
4https://jwst.nasa.gov/teachers.html
5https://www.lsst.org/about/epo
6https://www.zooniverse.org/
7https://wfirst.gsfc.nasa.gov/science/
a variety of innovative EPO projects. However, there have also been some unforeseen challenges. As such, our EPO experience in DES provides a unique perspective that can be used to inspire (and/or caution) teams of scientists and EPO professionals developing EPO programs for the next generation of large astronomy projects.

Throughout this work, we present a detailed case study of the innovative online DES EPO initiatives which were part of the official DES EPO program during its first three years. We remind the reader that this text does not describe all DES EPO projects; we have focused this analysis on online initiatives as an introduction to the DES EPO repertoire and as such projects have quantitative metrics which can be used as an example measure of reach. Several discussions include how various resources were allocated for EPO activities. We note that throughout this article, “resources” refers to both the time spent by DES member volunteers on EPO activities and to the financial support provided, at the discretion of the DES Director, from participating institutions. In Section 2 we outline the guiding principles which motivated these projects. In Section 3 we describe several of the online DES EPO initiatives, including project goals, organization details, and project outputs. For each, we propose recommendations for similar future large-scale collaborations. Relevant DES project links are listed in Table 1. We conclude with a summary of the DES EPO experience thus far in Section 4.

Also included in Table 1 is a link to the general DES EPO research section of the DES website. Additional content provided on this site includes: a summary of DES internal organization and infrastructure; discussion of the evolution of the DES EPO program; discussion and analysis of EPO initiatives in place before the creation of the DES EPO Committee (EPOC, Section 2); evaluation tools used for formative and summative assessment various DES EPO projects. We recommend the reader use these resources as a complement to this article as we refer to these materials throughout the text.

Below, we outline the most significant lessons learned from the DES EPO experience and encourage the reader to see relevant sections throughout the paper for further discussion.

- Organizing EPO for a large collaboration has significant advantages and challenges. An EPO program which relies on the participation of collaborating scientists should be embedded into collaboration infrastructure and culture from the outset.
- The most sustainable projects are those which capitalize on the collective creativity of scientists.
- Social media is a useful tool to engage scientists in EPO and communicate science to the general public. In 2016, the average DES EPO social media post reached ~2,500 users. The reach of social media products both within and between projects was highly variable, with the lowest- and highest-reaching posts reaching 258 and 14,450 users, respectively.
- Despite the logistical advantages of social media programming (e.g., the ability to engage a large diverse audience, or the capacity for scientists to engage in EPO from anywhere in the world), we do not have evidence that DES EPO products inspire new interest in science. According to native platform analytics, 94% of reached social media users demonstrate a predisposition to science-related topics and interests. This suggests that EPO organizing committees should place particularly careful thought into the intended audience and goals of online programming.
• It is difficult to incentivize scientists to participate in EPO programs unless they are already inclined to do so.

2. Guiding Principles and Social Media Strategy

We begin this section with an outline of the primary guiding principles which motivated the DES EPO effort (Section 2.1). These principles were formulated from the previous experiences of the founding co-coordinators of the DES Education & Public Outreach Committee (EPOC): B. Nord, A. K. Romer, and R. C. Wolf (hereafter NRW; the authors of this article).

Over time, the EPOC grew to include other collaboration members. Further details regarding DES science, organizational structure, and the evolution of the EPOC are described on the DES EPO research website (Table 1). We conclude this section with a summary of the DES EPO social media strategy as social media has been a primary vehicle for DES EPO online product distribution (Section 2.2).

2.1. DES EPO Guiding Principles

• GP1: EPO is an important, worthwhile, and enjoyable activity for individual scientists.
• GP2: EPO is an important and worthwhile activity for science collaborations (especially those which benefit from public funding).
• GP3: The public are interested in scientists as well as the science.
• GP4: It is possible to challenge the public’s perception of scientists (as “old white males”) through EPO.
• GP5: DES should have a strong social media presence. This should consist of frequent posts with high-quality content.
• GP6: DES should have a professional website with high-quality embedded content.
• GP7: DES EPO should not be restricted to the English language.
• GP8: The broader DES membership would be motivated by the EPOC when presented with EPO opportunities.
• GP9: The EPOC will manage, organize, and coordinate all DES EPO efforts.

These tenets laid the foundation for nearly three years of DES EPO programming. They also informed interactions between the EPOC and other groups within the DES organizational structure (DES EPO Research, Table 1). While the DES EPO program at large was motivated by GP1 and GP2, specific initiatives had more targeted goals. Implemented DES EPO initiatives were drawn from a substantial list of creative ideas, but were limited by the lack of time that the EPOC could contribute in addition to their regular duties (and to a lesser extent, the lack of a dedicated funding stream). In Section 3, we detail specific projects and how, where relevant, these principles contributed to project development. We stress that these guiding principles stemmed from the previous EPO experience of NRW, rather than being informed by the literature in the science communication field. In hindsight, it is clear that the EPOC would have benefited from some external guidance before launching into project work (see Section 4).
2.1.1. Diversity and Inclusivity

NRW followed what they believed were best practices in developing materials for dissemination on social media (based on private conversations with communication professionals), and in convening and organizing the outreach efforts of colleagues. In particular, addressing the lack of diversity and inclusion in scientific work environments [Ivie, Anderson, & White 2014, Stassun 2003] was a consistent thread in our activities, despite not being an explicit Guiding Principle. For example, NRW put thought into project design such that all language and visual information was presented in way so as to be inclusive of under-represented minorities (of all genders) and white women. Additionally, NRW recruited DES scientists from diverse backgrounds to participate in EPO activities (both online and in person). We urge other large collaborations/organizations planning EPO science programs to include diversity and inclusivity as fundamental organizing pillars.

2.2. DES Social Media Strategy and User Summary

Social media (e.g., websites and applications used for content sharing and social networking) has been one of the main vehicles for distribution of DES EPO content online. Facebook and Twitter are two of the many popular social media platforms currently available, and were the platforms of choice for DES EPO. The DES Facebook account was created in November 2010; the Twitter account followed in October 2013 (Table 1). Prior to the creation of the EPOC, social media posts were sparse, with updates roughly once per month. When the EPOC formed in October 2014, NRW decided to centralize the social media effort and make regular posts a priority (GP3, GP5, GP9; Section 2.1). For this reason, most of the online DES EPO projects have been driven by the need for a regular stream of social media content. Since early 2015, there have typically been Facebook (and mirrored Twitter) posts at least five times per week: DEST4TD (Section 3.2) on Mondays, Tuesdays, and Thursdays, DarkBites (Section 3.3) on Wednesdays, DEScientist of the Week (Section 3.4) on Fridays, and MLDES (Section 3.5) on Sundays. We note that we opted to post content manually per platform, rather than use a social media management dashboard.

From October 2014 to April 2017, the number of Facebook page “likes” increased from \( \sim 5,100 \) to \( \sim 8,000 \) and the number of Twitter followers increased from \( \sim 30 \) to \( \sim 1,400 \). Since the formation of the EPOC, both the DES Facebook and Twitter followings have increased roughly linearly, with \( \sim 5 \) new followers added per day.

Throughout this article, we present various metrics used to assess the social media strategy and reach of several DES EPO initiatives.\(^8\) We use these metrics as an initial measure of impact, but note that they do not provide a complete picture of how users interact with, and learn from, DES EPO material. Many of these metrics were obtained from Facebook Insights and Twitter Analytics (native, integrated services offered by the respective social media platforms to the user for account analysis). Any categorical information (e.g., the gender of the users) used from these metrics is defined by the platforms. We have also conducted formative surveys within the collaboration (DES EPO Research, Table 1) and extracted our own data from the social media sites.

Figures 1 and 2 present Facebook demographic information for DES’ three primary social media user groups, based on level of engagement. Users who have “liked” or “followed” the Facebook page are categorized as “Followers,” users who are exposed to DES social media posts (e.g., who simply see the post on their mobiles phones)

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\(^8\) These metrics were taken at the time of writing: April 2017.
as “Reached,” and users who actively engage with content (e.g., who comment on, or share, material) as “Engaged.”

In Figure 1 we analyze each user group by age and gender (as gathered by Facebook). The DES Facebook follower base is roughly 75% men and 25% women \((n = 7914)\). Of these, the Engaged users are roughly 60% men and 40% women \((n \approx 500)\). The largest user age group \((\approx 20\%)\) is aged 25-34, for both men and women and across each of the three user groups. According to Twitter metrics, most of the Twitter followers have self-identified an interest in science. Ninety-four percent of DES followers express an interest in “Science News” and 89% of DES followers express an interest in “Space and Astronomy” \((n = 1402)\).

Figure 2 displays the five most popular user-identified countries of origin and languages of the Facebook users in the three user groups. As shown in Figure 2, the majority of the Facebook users in each of the three primary user groups are located in the United States and speak English (US). Each user group also includes users from India, the UK, and Brazil. In addition to English (US), English (UK) and Spanish are both in the most popular languages for each user group. We note that the fifth most popular country for each user group is unique; the “Followers” are found in Mexico, the “Reached” in Turkey, and the “Engaged” in Australia.

We find DES social media user demographic information, for the most part, unsurprising. While the majority of Facebook users in general are young women (Duggan & Brenner 2013), the fact that the majority of DES followers are young men is consistent with known issues concerning women in astronomy and astrophysics (Ceci, Ginther, Kahn, & Williams 2014; Council 2010a; Ivie & Ray 2005): 1) lower documented interest, 2) lower academic retention rates, and 3) professional underrepresentation. Furthermore, DES social media primarily reaches people predisposed to an interest in science, and does not necessarily inspire new interest. According to these statistics, we have not yet succeeded in reaching and maintaining audiences underrepresented in STEM (Section 2.1.1).

As expected, most DES followers are in the United States and English speakers. Perhaps the most puzzling demographics are those describing where DES followers are located. We are unsure why one of primary locations of “Followers,” Mexico, is not included in the primary locations of people “Reached” or “Engaged.” We are also unsure why DES posts are particularly popular in Turkey. Investigating these demographics in further detail will be explored in a later publication.

As shown in Figure 2, Spanish-language speakers are in the top five the DES Facebook “Followers,” “Reached,” and “Engaged” user groups. Combined with the fact that DECam is based in a predominantly Spanish-speaking country, this evidence suggests that translating DES content to Spanish is a worthwhile use of EPO resources and supports GP7 (see Section 3.5 for more discussion of the translation of EPO content from English).

Based on these metrics, we find that although the number of people following DES on social media has increased, it has not increased at the rate we expected. We also conclude that although we may have increased awareness of the DES project, it appears the primary audience are those who already self-identify as having an interest in astronomy or science in general. It is unclear if these users are scientists themselves or enthusiastic members of the public. It is unlikely that we have inspired new interest in astronomy. If other large collaborations/organizations planning EPO science programs seek to use social media to captivate an audience that is not already interested in science, we suggest 1) that the social media strategy be structured for a specific target audience and 2) there is an emphasis on social media products that require only
a few seconds to read and understand (e.g., “memes”), preferably with links to more in-depth materials.

2.2.1. Other Online Platforms

The discussion above is focused on Facebook and Twitter. However, DES EPO has also used other platforms, e.g., Tumblr\(^9\) for the Dark Energy Detectives project and Flickr\(^10\) for image curation (both discussed on the DES EPO research website; Table \(\text{Table 1}\)). We also rely on our collaboration website (Table \(\text{Table 1}\)) as a mechanism to archive social media content, and to provide a repository of in-depth information that can be linked to social media.

3. EPO Programming for a Collaboration

In this section, we discuss the primary online\(^11\) DES EPO initiatives organized by the EPOC\(^12\) since Fall 2014. For each initiative, we present a summary of the project and discuss its implementation as well as project strengths and challenges. We also offer recommendations for EPO efforts connected to other large collaborations/organizations planning EPO science programs (e.g., LSST). Corresponding logic models detailing the specific inputs (e.g., time, funding), outputs (e.g., online content, lesson plans), and outcomes (e.g., number of participants, public and scientists’ reactions to projects) for many of the initiatives presented here can be found on the DES EPO research website (Table \(\text{Table 1}\)). In some cases where project products were distributed via social media, we present specific Facebook reach statistics over the 2016 calendar year (we find the Twitter statistics roughly mirror these trends). We use reach statistics only from 2016 as there was the greatest temporal overlap between projects. We compare these metrics to the global reach of all DES products featured on social media (see Figures \(\text{Figure 3}\) and \(\text{Figure 4}\)) as a benchmark for impact. We note that many of the projects described below are on-going, so the discussion presented here is limited to our experience until April 2017.

3.1. The DArchive: DES Results in a Nutshell

The fundamental charge of DES is to conduct innovative, high-caliber research. As a large-scale (> 400 members) science collaboration, DES scientists work together to produce new science results that are published in peer-reviewed academic journals. While members of the academic community know how to access and interpret these papers, they are not easily accessible to or digestible by the public due to the use of technical, scientific language. The “DArchive: DES Results in a Nutshell” project was designed with the goal of dissolving these barriers and making DES science more accessible to the public (GP3; Section \(\text{Section 2.1}\)). The project name was inspired by the arXiv\(^13\) (pronounced “archive”), an online open-access repository where many physicists, astronomers, and astrophysicists post their scientific publications. Our intent was such

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9[www.tumblr.com](http://www.tumblr.com)
10[www.flickr.com](http://www.flickr.com)
11These “primary online” initiatives comprise only a fraction of the entire repertoire of DES EPO activities.
12[Education & Public Outreach Committee, as defined in Section 2](#)
13[https://arxiv.org/](https://arxiv.org/)
that each DArchive would feature a summary of a DES paper, using language and analogies intended to connect a public audience with the science.

The initial goal of the project was to have a complementary DArchive featured with the release of each DES paper. In an internal collaboration-wide survey, 91% of respondents (n = 69) indicated their support for the project as they believed it to be a worthwhile DES EPO effort. Between May 2015 and January 2017, there were 89 DES papers submitted to academic journals; yet there were only 15 published complementary DArchive articles (Table 1). Published DArchive posts were featured both on the DES website and on the DES social media platforms.

3.1.1. Project Organization and Implementation

Since its inception, the DArchive project has gone through three iterations of organization, which are summarized in Figure 5.

In Iteration 1, we expected the paper summaries would be primarily led by the paper authors (GP8). The EPOC created a DArchive template document, intended as a guide to help the authors draft their pieces, and sent this template, along with a request for a DArchive, to paper authors. Authors who responded to the request (typically graduate students or postdoctoral researchers) drafted a paper summary, and the EPOC worked with the authors to finalize the DArchive.

During this iteration of the project, we encountered several key issues with author participation. Despite our efforts to get in contact with paper authors, the response rate, and willingness to participate was very low. We expected this might be due to the point at which during the publication process we contacted the authors, i.e., once the paper had been submitted for internal collaboration-wide review or after it had been published in a journal, but found no correlation with request timing and response rate. Some authors found it particularly difficult to translate their work for a public audience, and therefore the EPOC often had to spend hours editing a particular piece to meet the DArchive communication goals. Additionally, some paper authors did not understand the importance of eliminating or rephrasing some scientific terminology, and would argue with the EPOC about how to best convey a topic, significantly lengthening the DArchive writing and editing process.

The goal of Iteration 2 was to decrease the amount of time and effort required by the paper authors. As part of this iteration, we assembled the DArchive Team: a group of five authors (including NRW) and one editor-in-chief. The goal of this iteration was to distribute the DArchive authorship and improve consistency and quality amongst posts. As part of Iteration 2, the DArchive team created a new DArchive submission form to help paper authors condense the most significant sections of their analyses. Questions on this form included:

- In one or two sentences describe the main hook of the paper.
- In three or four sentences, describe your conclusions, results, and the reasons why you are excited about this work.
- In a paragraph, describe how you came to these conclusions. Outline the main steps that lead to your results. Try to avoid too many technical details about systematic checks, etc.
- In a paragraph, describe how your conclusions contribute to the advancement of

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14 See the DES EPO research website (Table 1) for the internal survey used for formative evaluation of the DES EPO program after its first year.

15 Education & Public Outreach Committee, as defined in Section 2
knowledge about dark energy, cosmology etc.

This form was sent to paper authors, and the DArchive Team drafted paper summaries based on authors’ submissions. Unfortunately, the issues of Iteration 1 were also present in Iteration 2. The most significant problem was lack of participation from the paper authors. However, having a dedicated team of DArchive writers helped streamline the DArchive process and improved consistency between pieces.

To further reduce the need for author participation, the DArchive Team adopted Iteration 3. Summaries in this iteration were driven primarily by the DArchive Team. A DArchive Team member would read a DES paper, write the paper summary, and then offer the DES paper author(s) a chance to include revisions. While the structure of this iteration gave the DArchive Team more autonomy, DArchive writers had a difficult time balancing the time commitment necessary to complete a DArchive summary with the demands of their other duties (research, teaching, administration, etc.). We found the total amount of time needed to complete a DArchive, from both the paper author(s) and the editing team, was roughly ten hours. This translated to the release of about one DArchive feature per month.

3.1.2. Social Media Reach: The DArchive

Figure 4 presents the Facebook reach of DArchive-related posts in 2016. Note that while most of these statistics are derived from individual DArchive posts, general DArchive announcements, e.g., a link to the DArchive page on the DES website, also contribute. As shown in Figure 4, the number of people reached per DArchive-related post is variable, and is typically below the median number of users reached across all DES EPO social media products. The mean number of users reached is 1,310 while the median is 907. Figure 4 also indicates that unlike the other DES EPO social media products, DArchive posts were featured only roughly once per month during seven months of the year.

3.1.3. Discussion

As made evident during each iteration of the DArchive structure, the time commitment was the biggest obstacle blocking the project’s success. It was challenging to get paper authors, who had already written an academic paper, and DArchive writers, who enjoy written science communication, to devote the time necessary for each DArchive summary. Throughout the iterations, the EPOC tried various approaches to incentivize participation in the project, including:

- Asking the DES director to publicly support the project at collaboration meetings.
- Requesting that the DArchive process be streamlined into the official publication policy.
- Offering infrastructure credit towards data rights and DES Builder status for participation (see the DES EPO research website for discussion of collaboration organization and infrastructure; Table 1).

None of these approaches proved entirely successful. While the director offered public support for the project, the lack of official status within the publication policy made it difficult to encourage or motivate participation. We found the amount of time necessary to write and edit a polished piece was simply not realistic for full-time scientists who can only contribute to EPO on a voluntary basis.
3.1.4. Take-Home Messages

Although an efficient DArchive strategy has not yet been reached and we have not published DArchives at our goal rate, experiences in each iteration were incredibly valuable. Overall, we learned that aiming for a DArchive summary for each DES paper was too ambitious, and likely unnecessary as occasionally papers would overlap with similar material (i.e., papers from ongoing analyses would build upon one another). We also learned that the background information needed to provide context for the scientific analyses was repetitive from piece to piece. We began writing static background articles (i.e., about concepts like redshift or gravitational lensing) which were shared on the DES website and intended to provide relevant links in each DArchive, but have not yet published them, due to lack of time. We found that having a “DArchive Editor-in-Chief” was essential, as it not only made the posts more consistent, but made the process easier for the writers and the paper authors.

In addition to providing an EPO output for the public, we also found the DArchive project had unexpected value for DES scientists. Writing these pieces gave their authors opportunity to improve upon their science communication skills. Moreover, DArchives make DES science results more accessible to DES members who were not directly involved. Rather than having to read the whole of an academic paper, DES members can read a DArchive piece and learn the salient background and results. Furthermore, should those DES members be invited to give a general DES presentation to peers or to the public, the DArchives can be used to effectively convey the information in a given paper to the audience.

We believe that projects like the DArchive involving high-quality science writing would greatly benefit from professional experience and dedicated funding. Rather than being written by full-time scientists, we recommend these pieces be written by a professional science writer. These pieces are important “legacy” content for DES, and are part of the static content on the DES website. We would also recommend finding a more impactful means of product distribution other than social media. The reach statistics presented in Figure 1 are lower than other DES EPO projects. We conclude that long-form EPO content will have a greater reach if shared on Tumblr, rather than just on Facebook or Twitter (see discussion of Dark Energy Detectives on DES EPO research website; Table 1). That said, this type of content should still be archived on a collaboration’s/organization’s website.

3.2. DES Thought for the Day (DEST4TD)

As described in Section 2.2, one of the first priorities of the EPOC\textsuperscript{16} was to revitalize the DES social media presence and create a vehicle by which we could increase public awareness of DES (GP5; Section 2.1). NRW hypothesized that providing a regular stream of social media content would be the best way to engage an audience that might otherwise be unaware of or uninterested in DES. However, as working researchers, NRW did not have the time to be the sole generators of daily original content. Therefore, NRW asked collaboration members to contribute by submitting a DES Thought for the Day (DEST4TD): a short statement about their work, science interests, or daily routine. In addition to providing the EPOC with social media content, i.e., to post on Facebook and Twitter, DEST4TD also provided the opportunity for collaboration members to engage with the public using a new, unconventional medium which would not require much time or preparation (GP8).

\textsuperscript{16}Education & Public Outreach Committee, as defined in Section 2
DEST4TD was also intended to serve as a channel through which we could share real-life experiences of DES scientists with the public and contribute to our long-term goal of making science and scientists more accessible to those outside academia (GP3) and those not typically represented in STEM fields (Section 2.1.1).

We anticipated that the project would be well-received by the collaboration as it provided a means of reaching a large audience without requiring any previous experience. We also anticipated that collaboration members would respond to email requests for participation as they would be required to spend no more than five minutes on an individual DEST4TD. When asked about the project, 70% \((n = 30)\) of collaboration members responded that they believed DEST4TD was a worthwhile DES EPO project. By April 2017, 127 different collaboration members contributed a DEST4TD; 13 members contributed more than five unique submissions. By comparison, only 3 DES members had contributed to DES social media prior to the creation of the EPOC.

3.2.1. Project Organization and Implementation

Developing the most effective project strategy required substantial trial and error in the early stages. Ultimately, we converged on a process whereby collaboration members were emailed each weekday using programming scripts scheduled on a server. Members receiving the emails were selected from the full collaboration member list (derived from a membership database) at random without replacement. Once the pool of remaining names had dropped below twenty, the full list was re-implemented. The subject line contained the member’s first name to make the emails seem personalized. Those receiving the emails were asked to respond to a prompt that was selected at random from the following list:

- This week for DES, I’m working on ...
- The most exciting thing about working on DES is ...
- The most difficult / frustrating thing about working on DES is ...
- My favorite thing I’ve learned by working on this project is ...
- The biggest mystery in [your specialism in DES] is ...
- When I went observing for DES, I was surprised by ...
- When I went to [my first, the most recent etc] DES collaboration meeting, I was surprised by ...
- Submit a photo from observing or a figure from your research (if the latter, please make sure it has been approved for public dissemination)

A longer list of suggestions was also included, in case the selected prompt did not inspire a response.

The response rate to DEST4TD email requests varied throughout the calendar year. Generally we received bursts of participation around the time of collaboration meetings and during the observing season (while scientists were at the telescope). As the project developed, the rate of response dropped off. At the time of writing, the strategy was to send ten requests per day to ensure an average response rate of one per day. Occasionally (roughly once per month) we receive spontaneous DEST4TD content, i.e., a submission not prompted by an email.

DEST4TD submissions were posted daily to the DES Facebook and Twitter accounts. This required: vetting of the source material, i.e., ensuring that any new sci-

\(^{17} \text{See the DES EPO research website (Table 1) for the internal survey used for formative evaluation of the DES EPO program after its first year.} \)
ence results were allowed to be publicly released and that submissions were sensitive to the diversity of cultures among the DES membership and DES social media followers; condensing posts to 140 characters for Twitter posting; finding related images and relevant article links. This process took \(\sim 5 - 10\) minutes per day. Although we could have added further automation by utilizing a social media dashboard, we opted to post manually as it was more convenient to devote time according to personal work schedules. Maintaining a regular posting schedule required a moderator who was confident managing several social media platforms and passionate about using social media as a vehicle for EPO.

3.2.2. Social Media Reach: DEST4TD

Reach statistics for DEST4TD are presented in Figure 4. Measured over a calendar year, the average reach per post was 2,649 users and the median was 1,567 users. We note that the spike in August occurs in the same month as the beginning of the DES observing season. As shown in Figure 3, the reach of DEST4TD posts is the most variable amongst the four DES EPO products. The minimum number of users reached was 303, while the maximum number of users reached was 14,450.

The three most popular DEST4TD submissions, as determined by reach on social media, are presented in Figure 6. As displayed in Figure 6, there does not seem to be a unifying theme amongst these most popular posts. The most popular post of January featured a masked image of a Messier galaxy that was presented in the context of Pop art. The most popular post of September featured an image of the Blanco telescope and surrounding instruments. One of the last posts of the year, and the most popular of 2016, featured a photo-shopped HST lens image, and a whimsical play on the Christmas holiday and cosmological parameter inference.

3.2.3. Discussion

The DEST4D initiative tapped into the creativity of hundreds of active scientists. As a result, the posts have been characterized by freshness, authenticity, and (often) quirky humor. Since participating in DEST4TD required no previous experience, the project proved to be an effective tool for recruiting participation in DES EPO.

Throughout the course of the project, we found that the popularity of a particular DEST4TD was rather unpredictable. Photographs colleagues submitted during or after observing, e.g., of the telescope site or flora or fauna on the mountain, were generally the most popular and reached thousands of social media users. We have thus far been unable to assess if DEST4TD has made any progress in better connecting DES science and scientists to the public.

Perhaps some of the most valuable information we learned from DEST4TD was not about developing and distributing social media content, but rather about how scientists perceive themselves and their ability to engage in outreach on social media. In a DEST4TD follow-up survey, we asked collaboration members about DEST4TD emails and responses to learn how to improve project participation. While only 6% responded that they reply to email requests right away, 20% responded that they submit a DEST4TD once they felt a bit more inspired, and 30% responded that they simply forget to respond to the request \((n = 59)\). When asked why they did not respond to DEST4TD requests, 12% of collaboration members noted that they “did not have anything interesting to share.”
3.2.4. Take-Home Messages

We advocate that "crowd sourced" social-media based initiatives such as DEST4TD are a net positive when it comes to increasing scientists’ public engagement. They provide a steady stream to engage current social media “Followers” (Section 2.2) between official press releases describing major new science results. In addition, they give scientists who may otherwise have little or no EPO experience an opportunity to engage with a public audience without the need to overcome a steep learning curve.

However, our experience developing and implementing DEST4TD illuminated some key issues that we had not anticipated at the outset: 1) social media is an excellent tool by which scientists can engage with the public, but reaching a target demographic is nontrivial; 2) scientists need to be reminded that the public are fascinated by the process of doing science, not just the final results; 3) providing daily original content is not sufficient to “exponentially” build a social media following (at the time of writing, the DES social media following was increasing by one or two users per week); 4) resources must be explicitly allocated for engaging users who interact with (e.g., comment on) posted content; and 5) resources must be allocated to manage the infrastructure and to curate the best material in DES4TD posts (as these could have provided legacy content for DES).

With regard to issue 1), we suggest that specific social media strategies be developed to ensure posts reach target user groups. These strategies could be informed and evaluated by focus groups and market research. Sufficient resources (personnel and budgetary) for this process should be allocated from the outset. With regard to issue 5), the DEST4TD project heavily relied on automated emails and post vetting and management. One challenge was that these emails were frequently being returned to sender, often because the DES membership database was not kept up-to-date; at least 20% of sent emails were returned. Another significant challenge was maintaining the posting content and schedule without the primary DES social media manager (e.g., if the manager were sick or on vacation). We recommend that future groups interested in pursuing a similar project invest resources into membership database management and find several people who can assume responsibility for automated emails and are confident in their social media abilities.

3.3. DarkBites

The DarkBites project was inspired by the popularity of short, astronomy-related media that include analogies or ties to popular culture (GP3; Section 2.1). In particular, we sought to emulate the style of well-known astrophysicist Neil deGrasse Tyson\[18\] and, as a result, reach a different audience to those following DEST4TD (Section 3.2) or the DArchive (Section 3.1). The initial concept was to generate short (one or two sentences), astronomy and cosmology sound bites that would surprise and inspire the public. The EPOC\[19\] envisioned that these would be written in such a way that they would be accessible to anyone over the age of 10. At the Fall 2015 collaboration meeting, the EPOC identified a DES colleague (a graduate student) who was excited by the concept and was never short of ideas; he agreed to supply the text for the project. At about the same time, it came to NRW’s attention that one of the DES postdoctoral researchers was a talented and prolific artist. NRW approached her to ask if she would be interested in providing occasional illustrations for the DarkBites project. She

\[18\]https://twitter.com/neiltyson
\[19\]Education & Public Outreach Committee, as defined in Section 2
was genuinely delighted to do so, and created accompanying artwork for the weekly DarkBites text. Additional fact-generators and artists joined the project in the latter stages; the final DarkBites product consisted of 52 pieces of text and artwork.

3.3.1. Project Organization and Implementation

Participation in the DarkBites, which lasted roughly one year, was openly advertised to the entire collaboration. Throughout the duration of the project, the DarkBites team was comprised of two dedicated fact-creators and three dedicated illustrators. Artistic decisions were made entirely based on the preferences of the project illustrators. There was no need for editorial input, which was fortunate as resources for input were insufficient. DarkBites facts were composed on a shared online document and illustrations were kept in a shared online folder. Over the course of a year, DarkBites were posted on social media and the DES website. DarkBites were archived on their own section of the DES website, and therefore could easily be used for subsequent posts and projects. Figure 7 features an example DarkBite image and caption (Table 1).

3.3.2. Social Media Reach: DarkBites

The number of users reached on Facebook by DarkBites posts is featured in Figure 4. As shown in the Figure, the median number of users reached was fairly consistent from January-June, and roughly plateaued from August-December. Over the course of the year, the mean number of users reached was 3,843 and the median was 2,873. If we consider only January-June, the mean and median number of users reached were 2,320 and 2,202, respectively; for the latter half of the year, the mean and median number of users reached were 5,800 and 6,360, respectively.

We believe the increase in DarkBites reach after May could be attributed to two factors. At that time, two new illustrators joined the project and we began featuring images in color. It is also possible that this increase in reach was just a natural buildup of project followers over time. As shown in Figure 4, the highest-reaching DarkBites of 2016 were featured during the month of August. These two DarkBites were both related to sports, with the most popular referencing the ongoing Rio 2016 Olympics. Figure 4 clearly shows that DarkBites posts were consistently some of our most popular on social media. The average and median reach of DarkBites posts were roughly equivalent to or greater than the global average EPO product reach.

3.3.3. Discussion

Perhaps the most valuable experience from the DarkBites project was witnessing the effect and impact of collaborative creativity. This project would never have succeeded without the artistic talents, creativity, and enthusiasm of our colleagues. We also observed how combining science with popular culture can be an effective tool for science communication. The most popular DarkBites posts of 2016 featured references to topical world events, suggesting that integrating science with “trending” topics may increase content reach.

3.3.4. Take-Home Messages

We found that a powerful way to inspire others to engage in EPO is to appeal to their personal hobbies or interests. We highly recommend that future EPO collabo-
rations/organizations consider projects that capitalize on the talents of collaboration members.

Furthermore, the DarkBites project became a branching point for other EPO projects. Finished DarkBites were used by members of the EPOC to complement formal education curricula for elementary school children and in outreach events to inspire children to draw their own DarkBites images. We also designed a follow-up project, the “DarkBites Unplugged,” as a vehicle to further explain and define the astronomical information included in the original DarkBites.

Through the organic evolution of the project came the surprising added benefit of its versatility. Products such as DarkBites which can be used in a variety of venues have become a valuable asset for our EPO repertoire. They have allowed us to develop additional activities using the same content, thus leveraging the initial investment of the time involved to develop DarkBites. In hindsight, we would have designed more projects with this in mind and recommend other projects consider this in the future.

3.4. DEScientist of the Week

The DEScientist of the Week initiative was designed to increase scientists’ accessibility to the general public (GP3, GP4; Section 2.1). First and foremost, we sought to highlight the diversity in race, gender, and personality of collaboration members and scientists in general (Section 2.1.1). We also wanted to provide our colleagues with a means of speaking openly and honestly about their experience as professional researchers (GP8).

3.4.1. Project Organization and Implementation

Each DEScientist of the Week piece featured a profile of a randomly selected DES collaboration member. This profile included a photograph (if desired), a small summary of research interests, and a short-form interview. Interviews were conducted using an online survey that included questions such as:

- What is your favorite part about being a scientist?
- When did you know you wanted to be a scientist?
- Do you have any hobbies or play any sports?
- What motivates/inspires you?
- If you weren’t a scientist, what would your dream job be?
- Any advice for aspiring scientists?

The profiles were posted weekly on their own subpage of the DES website (Table 1) and linked on social media.

3.4.2. Social Media Reach: DEScientist of the Week

Figure 4 presents the Facebook reach of DEScientist of the Week posts. The average number of users reached was 1,285; the median number reached was 977. As shown in Figure 4, most DEScientist of the Week posts consistently reached less than the DES EPO global median and mean number of users. The post with the highest reach was featured in January and highlighted a female collaboration member from a DES institution in the United Kingdom. This post was not the first of the year, nor the first feature of a female scientist. This profile was however featured the day after one of our highest reaching DEST4TD posts (Section 3.2).
3.4.3. Discussion

Thus far, we have featured over 80 scientists as DEScientist of the Week. Initially, we asked only those who self-selected for the internal DES EPO LISTSERV (electronic mailing list) to participate and the response rate was nearly 100%. After opening the project to the rest of the collaboration, the total response rate was 60% \((n = 149)\), despite the fact that 82% \((n = 85)\) of surveyed collaboration members responded that they believed project was a worthwhile EPO effort. This response rate is much higher than that for DEST4TD (Section 3.2), which varied between 10% and 20% depending on the time of year. We believe this higher response rate was primarily due to the fact that while scientists may feel apprehensive about talking about their research with the public, they feel flattered when asked to talk about themselves. Some collaboration members have even asked to be featured as DEScientist of the Week to coincide with job applications.

3.4.4. Take-Home Messages

As our colleagues generally have responded favorably to the project and it did not require a great amount of administrative effort, we recommend facilitating similar scientist profile/interview initiatives, as they highlight the diversity in the scientific community and they have potential for significant long term-impact. The infrastructure of large collaborations/organizations is well-suited for this project, and we believe extensions to specific university departments or any individual with access to a network of scientists would also be impactful. Given our observed response rate, we suggest polling a network of roughly 200 scientists to create a sizable repository.

We continue to work toward the long-term goal of changing public opinion of science and scientists, which may ultimately include updating the structure of the project. As demonstrated in Figure 4, DEScientist of the Week posts did not reach as many followers as other DES EPO initiatives. This suggests that the current structure may not be the most effective strategy for content distribution. However, interactions with DES social media users, including shares, likes, and comments, lead us to believe we are indeed making an impact, even if only on the smallest scales. For example, social media users have commented they find the pieces inspiring.

3.5. Multilingual EPO

As DES is an international collaboration of scientists from seven different countries and a survey relying on data from the Blanco Telescope at CTIO\(^{21}\), we sought to allocate EPOC\(^{22}\) resources towards projects that we believed would reach the broader, international community (GP7; Section 2.1). Without funding to pay for translation services, we relied on volunteers in the collaboration to meet this goal. We were fortunate that several bilingual collaboration members, particularly Spanish speakers, are passionate about communicating science in languages other than English. While there has been some original content created for international audiences, most of this effort focused on translating existing DES EPO content.

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\(^{20}\)See the DES EPO research website (Table 1) for the internal survey used for formative evaluation of the DES EPO program after its first year.

\(^{21}\)http://www.ctio.noao.edu/noao/

\(^{22}\)Education & Public Outreach Committee, as defined in Section 2
3.5.1. Project Organization and Implementation

**Translation of website** — The most ambitious of these translation projects was a full translation of the DES website, including sub-page content, into Spanish. There is now a Spanish version of the DES website. To allow this version to be embedded within the English version, professional web-development expertise was needed, and this required an investment of \( \approx \$1000 \). Translations were done by a group of four native Spanish speakers in the collaboration who volunteered to translate website content.

**Many Languages of DES** — We attempted to geographically broaden the DES reach via the “Many Languages of DES,” or MLDES, initiative. In this project, we asked bilingual members of the collaboration to translate DarkBites (Section 3.3), DEST4TD (Section 3.2), or other short-form, online DES EPO content on a weekly basis. Throughout the duration of the project, translated languages included: Spanish, Portuguese, French, Italian, German, Chinese, Farsi, Russian, Greek, and Serbian. Translators were reminded weekly to submit any translations by Friday afternoons. Translations were generally posted on social media on Sundays. The posting strategy for MLDES evolved throughout the lifetime of the project, and as a result, there was no straightforward mechanism to obtain reach statistics over time like those presented in Figures 3 and 4.

**Miscellaneous** — Several other DES multilingual initiatives emerged organically from volunteers. For example, some DES colleagues based in, or native to, non-English-speaking countries frequently produced DES-related content in their native languages, e.g., via writing press releases for their institutes (and then working with local journalists who see the releases) or posting about DES on their personal social media accounts (with content they produced themselves and/or translations of content produced by the EPOC). Another small group of collaboration members manage an official DES account on Weibo, a Chinese hybrid of Twitter and Facebook. Weibo posts are roughly 40% original content (loosely based on existing DES posts) and 60% direct translations of DEST4TD or DarkBites. The Weibo page has roughly 2,000 followers and the average post reaches 1,000 users. The Weibo post with the largest reach (\( \approx 30,000 \)) featured an image of an Einstein ring discovered by DES reminiscent of the logo for Youku (Chinese YouTube).

3.5.2. Discussion

**Translation of website** — This was a worthwhile endeavor. It was also quite straightforward to manage because bilingual volunteers were passionate about the project, volunteered many hours of their personal time, and required very little input from the EPOC. Indeed, our only regret is that we did not embed a Spanish version of the website from the outset.

**Many Languages of DES** — The translated posts did not have a large reach (\( \approx 200 \) users per post). For this reason, the project was terminated in Fall 2016. We speculate that this was because the posts appeared on primarily English language distribution platforms, i.e., which had a user base that was already proficient in English, even if as a second language. In hindsight, we should have asked the MLDES translators to set up DES social media accounts in their respective languages.
Miscellaneous – The DES Weibo account was initiated spontaneously by a Chinese member of DES, and then enthusiastically supported by a handful of her compatriots. Unlike MLDES, this was a social media account designed specifically for a particular language market and consistently had a higher reach. Similarly, DES colleagues with a strong personal social media following in their native language have generally had a better response to their DES related posts than did MLDES.

3.5.3. Take-Home Messages

The wealth of translated content now available is entirely due to the participation and leadership of bilingual volunteers. Translation initiatives are an excellent example of designing projects which utilize skills and talents of collaboration members. We recommend that other large collaborations/organizations planning EPO science programs plan for multilingual versions of their webpages from the outset. We further recommend that if a collaboration/organization wishes to foster an international DES audience using social media that they maintain separate accounts for the different target audiences.

4. Conclusions

In this article, we described the strategy and programming of online Education and Public Outreach (EPO) in the Dark Energy Survey (DES). Unlike many other current large-scale optical astronomy EPO initiatives, DES EPO was not based on published data products, but rather inspired by the foundational science, data processing pipelines, and community of scientists that comprise the DES collaboration. Throughout this article, we detailed the strengths and weaknesses of a variety of DES EPO initiatives and provided recommendations, where appropriate, for other large collaborations/organizations planning EPO science programs.

Through the grass-roots approach of the DES EPO program, we generated a suite of novel and innovative online astronomy EPO initiatives. This was largely due to the passion and creativity of collaboration members eager to both contribute to Education & Public Outreach Committee (EPOC)-organized activities and to develop new material on their own. The creation of legacy content, such as the DArchive summaries, in addition to more dynamic social media projects, such as DES Thought for the Day, provided a wealth of opportunity for scientists to connect with the public and with others in the scientific community. These activities would have perhaps been even more effective (in terms of content reach and scientist participation) had we focused our efforts on a few key projects rather than continue to develop and launch new initiatives. Upon reflection, the summative take-home message of the DES EPO experience thus far is to concentrate resources and effort on a select, smaller group of projects. However, it is important to recognize that it was only through the exploration of such a variety of initiatives that we were able conclude which projects which more deserving of limited effort and resources.

One of the most significant obstacles faced by the DES EPO program was the lack of time the EPOC coordinators and community members could devote to DES EPO programming. Given the amount of time necessary to complete projects such as a DArchive summary (Section 3.1), the participation rate was lower than predicted from our polling of collaboration members’ views. This mirrors other studies that have shown that generally scientists are in favor of EPO.
Shamatha, & Melton (2005), Ecklund, James, & Lincoln (2012), Poliakoff & Webb (2007), but that their motives for and deterrents from participation in EPO remain unclear. For example, Dang and Russo (2015) assert that barriers to astronomers’ participation in EPO include 1) the perceived academic cultural norm that one can only spend time on EPO after completing necessary academic duties (Ecklund et al., 2012), and 2) the lack of financial (institutional and grant) support for EPO. However, Dang and Russo (2015) also find that astronomers in particular are widely supportive of EPO. We will further explore DES members’ EPO engagement practices and personal EPO motives and/or barriers in a future publication (Farahi et al., in prep.).

Many of the online DES EPO projects thus far have focused, at least in part, on changing the public perception of science and scientists. It is clear that this goal of changing the status quo is well-founded. Despite more recent integration of science into popular culture, e.g., books, television shows, movies, public perception of the “typical scientist” remains outdated. Fifth grade students largely still imagine scientists as “white, eccentric males” who work in a laboratory (Barman, Ostlund, Gatto, & Halferty, 1997). This perception is generally similar for many adults, as the media tends to give very little coverage to scientists or the scientific method, making scientists seem removed from the general public (Losh, 2010). We hoped that by making scientists less “distant” from the public that we might positively affect perceptions of scientists and their careers (Losh, 2010). We leave a long-term assessment of this aspect of the DES EPO program for analysis in a future publication.

Reflecting on our experience holistically, we believe that many of our initial guiding principles were not realistic given the collaboration organization and structure when the EPOC was created. Although the EPOC coordinators and many of the EPOC community members share an enthusiasm for science education and outreach, it is clear that GP1 and GP2 (Section 2.1) have not been embedded into collaboration culture. Obviously we cannot expect that every collaboration member will share our goals, but perhaps officially integrating EPO into collaboration structure at the onset would have impacted general attitudes towards public engagement. Such structure may have also improved our experience trying to coordinate and incentivize EPO efforts (GP8, GP9). With regard to GP9, over the last three years we have noticed that some DES members with a passion for EPO continue to carry out their EPO activities unilaterally, despite repeated requests to coordinate those activities with those being organized and implemented by the EPOC. Some of these unilateral initiatives have been of exceptional quality, including info-graphics (still and video) and articles for major media outlets. However, the lack of coordination has, on occasion, lead to a dilution of the DES EPO brand and negatively impacted the motivation of the EPOC.

We draw the following conclusions and make the following recommendations for others looking to pursue similar EPO endeavors:

1. **Integrate EPO into collaboration structure, policy, and culture.** As described throughout this article, we encountered several issues that could have been avoided had DES EPO been more well integrated into the DES collaboration structure (see the DES EPO research website for organization details; Table 1). For example, the publication policy could outline that submission of each academic paper be accompanied by a short description and public-friendly figure which could then be featured on various EPO platforms. Although we received vocal support from the DES director, lack of official DES policy regarding EPO resulted in duplicated or inefficient EPO efforts and missed opportunities for targeted EPO projects for specific science results.
(2) 

Establish an EPO budget before program development. The EPOC was formed under the assumption that funding for DES EPO activities would be quite limited. However, an annual budget was never explicitly established. We requested funding as needs arose (e.g., for the development of the DES website). This system meant that we were never guaranteed funding for an EPO program. One area where we were unable to secure funding was to engage professional science writers to assist with the DArchive project. If we instead had firmly established a budget upfront, then we may have allocated resources differently and more strategically, i.e., ensuring undertaken projects reached their full potential (even at the expense of starting new projects).

(3) 

Develop EPO initiatives with a range of required time commitments to increase the likelihood of scientist participation. Collaboration members can only devote a small fraction of their time to organizing and engaging in EPO. However, designing, managing, and evaluating EPO programs requires a substantial amount of time. Unfortunately, spending time engaging in EPO remains undervalued in the astronomy community. This is reflected not only in personal attitudes but in funding. While we have created many innovative DES EPO programs, the list of projects that we have either not completed or not even started is much longer. This may be due to the fact that some of our goals were unrealistic and that we equated “success” with ∼100% scientist participation. We believed we could incentivize participation by offering credit towards data rights to collaboration members, but this did not prove sufficient; in the end most of substantive EPO work (i.e., not DEST4TD) was carried out by DES members who self-selected as EPO supporters. It was difficult to mobilize scientists to participate in EPO programs if they were not already inclined to do so.

(4) 

Contract professionals if budget allows. If there is not adequate funding, set limits on how much time can be dedicated to a particular project. When developing an EPO project, we recommend reflecting on how your expertise as a scientist will be utilized. If pieces of the project can be accomplished without your constant support, and if budget allows, consider external contractors for the task. If funding is unavailable, prioritize projects which balance time commitment and necessary experience.

(5) 

Identify a specific target audience and methods for reaching that audience for each program. Many of the discussed DES EPO projects were designed to inspire a general public interest in science. We hoped our online initiatives would reach people who might not otherwise be inclined towards the STEM disciplines. As social media metrics revealed, we were not successful in reaching this target audience. We encourage future EPO coordinators to think critically about content distribution and how to best interact with the desired audience. For example, we found that Tumblr (see discussion of Dark Energy Detectives on the DES EPO research website; Table 1) had a larger reach for long-form content, and that Weibo (Section 3.5) was a more effective means to reach and international audience, than posting directly to English-based social media accounts. We also speculate that the DES EPO effort may have been more successful if we had explored other social media platforms, e.g., Instagram and Snapchat.

(6) 

Inspire other scientists to participate in EPO by designing programs that utilize their personal interests and skills. Some of the more innovative DES EPO

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23https://www.instagram.com/?hl=en
24https://www.snapchat.com/
projects, e.g., DarkBites, evolved from colleagues’ artistry and creativity. We also found that collaboration members were more inclined to participate in projects which appealed to their personal interests. This included projects centered around graphic design, astrophotography, video editing, and written science communication. We also believe these projects garnered more participation because colleagues could dedicate as much or as little time as they pleased, without feeling pressure to complete a project within a deadline. If EPO activities can align with scientists’ interests, then perhaps time which might otherwise be spent on hobbies could be shared with EPO.

(7) *Keep in mind that some scientists will not follow centralized guidelines and/or will pursue their own projects which may conflict with attempts to centralize collaboration-wide efforts.* The EPOC actively encouraged EPO participation amongst collaboration members both on initiatives specifically coordinated for DES and on individual projects. In some cases, we worked to consolidate personal and collaboration-sponsored efforts. This was often difficult, however, as individual members would not communicate their efforts with the EPOC. As it is impossible to change individual behavior and enforce such lines of communication, we strongly suggest that future EPO committees develop official policy (e.g., quality standards, promotion rules) related to any collaboration-related EPO products. We stress that we encourage this coordinated effort largely because some EPO work that comes out of unilateral activities can be superb and should be distributed to the (likely) larger audience garnered by collaboration-sponsored activities.

(8) *Clearly distribute roles and responsibilities amongst EPO coordinators.* For the majority of programs listed in this article, the EPOC coordinators were responsible for developing new ideas, recruiting participation, implementing activities, and activity evaluation. Although this freedom was instrumental in the evolution of the EPO program, it also meant that it was sometimes difficult to assess an activity objectively. We recommend assigning explicit roles or creating advisory positions to ensure that resources are being allocated practically and that project implementation aligns with project goals.

(9) *Consider organizing and/or attending science communication training sessions led by professionals.* Finally, we strongly recommend the organization of science communication workshops and training. We believe that DES collaboration members, including the coordinators of the EPOC, would significantly benefit from the professional experience of science communication experts. If scientists are expected to be at the forefront of knowledge, they should be cognizant of the most effective means to communicate that knowledge.

**Acknowledgments**

The authors thank all of the DES members who contributed time and effort to the DES EPO program. R. C. Wolf is grateful to E. Bechtol and S. Pasero for useful discussions and professional EPO expertise.
Funding and Support

Parts of this research were conducted by the Australian Research Council Centre of Excellence for All-sky Astrophysics (CAASTRO), through project number CE110001020. Funding for the DES Projects has been provided by the U.S. Department of Energy, the U.S. National Science Foundation, the Ministry of Science and Education of Spain, the Science and Technology Facilities Council of the United Kingdom, the Higher Education Funding Council for England, the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign, the Kavli Institute of Cosmological Physics at the University of Chicago, the Center for Cosmology and Astro-Particle Physics at the Ohio State University, the Mitchell Institute for Fundamental Physics and Astronomy at Texas A&M University, Financiadora de Estudos e Projetos, Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro, Conselho Nacional de Desenvolvimento Científico e Tecnológico and the Ministério da Ciência, Tecnologia e Inovação, the Deutsche Forschungsgemeinschaft and the Collaborating Institutions in the Dark Energy Survey.

The Collaborating Institutions are Argonne National Laboratory, the University of California at Santa Cruz, the University of Cambridge, Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas-Madrid, the University of Chicago, University College London, the DES-Brazil Consortium, the University of Edinburgh, the Eidgenössische Technische Hochschule (ETH) Zürich, Fermi National Accelerator Laboratory, the University of Illinois at Urbana-Champaign, the Institut de Ciències de l’Espai (IEEC/CSIC), the Institut de Física d’Altes Energies, Lawrence Berkeley National Laboratory, the Ludwig-Maximilians Universität München and the associated Excellence Cluster Universe, the University of Michigan, the National Optical Astronomy Observatory, the University of Nottingham, The Ohio State University, the University of Pennsylvania, the University of Portsmouth, SLAC National Accelerator Laboratory, Stanford University, the University of Sussex, Texas A&M University, and the OzDES Membership Consortium.

AKR acknowledges support from the Science and Technologies Research Council, in particular from grant awards ST/N001087/1, ST/P000525/1, ST/M003574/1.

References

Andrews, E., Weaver, A., Hanley, D., Shamatha, J., & Melton, G. (2005, 5). Scientists and public outreach: Participation, motivations, and impediments. *Journal of Geoscience Education, 53*(3), 281–293.

Barman, C. R., Ostlund, K. L., Gatto, C. C., & Halferty, M. (1997). Fifth grade students' perceptions about scientists and how they study and use science. In *1997 aets conference papers and summaries of presentations* (p. 711).

Borne, K. D., Jacoby, S., Carney, K., Connolly, A., Eastman, T., Raddick, M. J., ... Wood-Vasey, M. (2009). The revolution in astronomy education: Data science for the masses. In *astro2010: The astronomy and astrophysics decadal survey* (Vol. 2010).

Ceci, S. J., Ginther, D. K., Kahn, S., & Williams, W. M. (2014). Women in academic science. *Psychological Science in the Public Interest, 15*(3), 75-141. Retrieved from [http://dx.doi.org/10.1177/1529100614541236](http://dx.doi.org/10.1177/1529100614541236) (PMID: 26172066)

Council, N. R. (2010a). *Gender differences at critical transitions in the careers of science, engineering, and mathematics faculty*. Washington, DC: The National Academies Press.

Council, N. R. (2010b). *New worlds, new horizons in astronomy and astrophysics*. Washington, DC: The National Academies Press.
Dang, L., & Russo, P. (2015, September). How Astronomers View Education and Public Outreach: An Exploratory Study. *Communicating Astronomy with the Public Journal, 18*, 16.

Duggan, M., & Brenner, J. (2013). *The demographics of social media users, 2012* (Vol. 14). Pew Research Center’s Internet & American Life Project Washington, DC.

Ecklund, E. H., James, S. A., & Lincoln, A. E. (2012, 05). How academic biologists and physicists view science outreach. *PLOS ONE, 7*(5), 1-5.

Farahi, A., Gupta, R. R., Krawiec, C., Plazas, A. A., Wolf, R. C., Bechtol, E., . . . Horwitz, J. (in prep.). Astronomers’ and Physicists’ Attitudes Towards Education & Public Outreach: A Case Study with The Dark Energy Survey.

Griffin, I. (2003). The hubble space telescope education and outreach program. In A. Heck & C. Madsen (Eds.), *Astronomy communication* (pp. 139–156). Dordrecht: Springer Netherlands.

Haywood, B. K., & Besley, J. C. (2014, 1). Education, outreach, and inclusive engagement: Towards integrated indicators of successful program outcomes in participatory science. *Public Understanding of Science, 23*(1), 92–106.

Ivie, R., Anderson, G., & White, S. (2014). African americans & hispanics among physics & astronomy faculty: Results from the 2012 survey of physics & astronomy degree-granting departments. focus on. *Statistical Research Center of the American Institute of Physics*.

Ivie, R., & Ray, K. (2005). Women in physics and astronomy, 2005. In *American institute of physics report*. Retrieved from [https://www.aip.org/statistics/reports/women-physics-and-astronomy-2005](https://www.aip.org/statistics/reports/women-physics-and-astronomy-2005)

Losh, S. C. (2010). Stereotypes about scientists over time among us adults: 1983 and 2001. *Public Understanding of Science, 19*(3), 372-382.

Poliakoff, E., & Webb, T. L. (2007). What factors predict scientists’ intentions to participate in public engagement of science activities? *Science Communication, 29*(2), 242-263.

Raddick, M. J. (2002, December). SkyServer: Education and Outreach with Sloan Digital Sky Survey Data. In *American astronomical society meeting abstracts* (Vol. 34, p. 1150).

Rosendhal, J., Sakimoto, P., Pertzborn, R., & Cooper, L. (2004). The nasa office of space science education and public outreach program. *Advances in Space Research, 34*(10), 2127–2135.

Stassun, K. G. (2003). Enhancing diversity in astronomy: Minority-serving institutions and reu programs: Strategies and recommended actions. *Bulletin of the American Astronomical Society, 35*(5), 1448.
Figure 1. Percent of Facebook followers (dark blue), users reached (blue), and engaged users (light blue) over various user ages. Information is also separated into men (left) and women (right) user groups. The 25-34 user age group is the most popular in each user group and for both men and women. While the men are roughly 75% of the total page followers \((n = 7914)\), women make up nearly 40% of the total engaged users \((n \approx 500)\).
Figure 2. Percent of Facebook followers (dark blue, \( n = 7914 \)), users reached (blue, \( n \approx 15000 \)) and engaged users (light blue, \( n \approx 500 \)) in the five most popular user-identified countries and languages of origin.
Figure 3. Global distribution of Facebook likes per post for DES EPO products featured on social media described in this work (DArchive – Section 3.1; DEST4TD – Section 3.2; DarkBites – Section 3.3; DEScientist of the Week – Section 3.4). The mean reach (upper panel, dashed line) was 2,525 users; the median reach (upper panel, solid line) was 1,575 users. The bottom panel features a stacked histogram showing the number of posts per EPO product discussed in this section.
Figure 4. Comparison of Facebook user reach for each of the social media DES EPO products featured in this section. Points represent the median reach of a project in a given month. Error bars represent the range of post reaches in a given month; i.e., no error bars indicate there was only a single post of that type. The height of the light gray bar signifies the average reach of all the posts from the 2016 calendar year (dashed line, upper panel of Figure 3); the height of the dark gray bar signifies the median reach (solid line, upper panel of Figure 3). We note that the general observed peak in activity around August-September corresponds to the beginning of the DES observing season.
Figure 5. DArchive work flow for each of the three project organization iterations.
Figure 6. Three most popular DEST4TD posts of 2016 submitted by collaboration members as determined by social media reach. Posts were submitted in January 2016 (bottom left), September 2016 (top), and December 2016 (bottom right), respectively.
Figure 7. An example DarkBite image. The associated caption: If the lifetime of the universe were compressed to a single calendar year, the entirety of human history would occur in the last 15 seconds of December 31. Image Credit: Chihway Chang, University of Chicago; Fact Credit: Daniel Nagasawa, Texas A&M University.
| EPO Resource            | Website URL                                      |
|------------------------|--------------------------------------------------|
| DES Website            | www.darkenergysurvey.org                         |
| DES Facebook           | www.facebook.com/darkenergysurvey                |
| DES Twitter            | www.twitter.com/theDESurvey                      |
| The DArchive           | www.darkenergysurvey.org/news-and-results/darchives/ |
| DarkBites              | www.darkenergysurvey.org/education/darkbites/    |
| DEScientist of the Week| www.darkenergysurvey.org/education/scientist-of-the-week/ |
| DES EPO Research       | www.darkenergysurvey.org/education/des-education-outreach-science-communication-research/ |

**Table 1.** List of Online DES EPO resources.