Best Practice

Videos for Astronomy Education and Outreach

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This paper presents an unusual project in which astronomy videos were created for education and outreach with students playing a central role, from initial conceptualisation to final distribution of the videos on the Internet. Seventy videos were produced over the past three and a half years, on subjects ranging from tours of local observatories to complex concepts like adaptive optics. Students learned skills such as time management, interdisciplinary teamwork and optimising communication of technical information to the general public. Most of the videos have a strong student voice, and students' experience with social media helped in reaching other young audiences. This paper describes the organisation, management and workflow of the project. The time and money required to create educational astronomy videos are also discussed.

The Rise of Video

The meteoric rise of video content on the internet over the past decade has transformed the way people learn. Videos are routinely used for personal improvement, providing how to instructions for a myriad of tasks, informal learning through massive open online classes (MOOCs), and formal instruction in online classes offered by colleges and universities worldwide. MOOCs in particular have harnessed the power of video content for education (Margaryan et al., 2015; Reich, 2015), including the teaching of astronomy (Impey et al., 2016). At the epicentre of this rapid growth in video content is YouTube, a website started in 2005 and operated since 2006 by Google. YouTube is the second most popular website in the world, with 400 hours of content uploaded every hour, and a billion hours of content viewed every day (Zhou et al., 2016).

Broadband Internet and smart phones are now available to the majority of the population in the United States and a rapidly growing fraction of the world's population (Lee et al., 2015). Thus, video has become an obvious tool for science education and outreach. The video medium allows storytelling, conveying a vivid sense of place, and in the example of astronomy, displaying the visual beauty of the Universe. The use of short-format videos delivered over the Internet and created without any professional production capabilities has grown rapidly and can potentially reach very large audiences. TED talks on science are a well-known example (Sugimoto & Thelwall, 2013). Audiences are not restricted to college or high school students but include adult free-choice learners (Rosenthal, 2017). Early research indicates that although professionally produced YouTube science content dominates in terms of number of videos, user-generated content is significantly more popular (Wellbourne & Grant, 2016). There have been limited experiments with student-generated science videos (Wang & Shao, 2016; Hoppe et al., 2016), but factors that drive engagement with science videos are still being measured at this level (Wade & Courtney, 2013; Yoo & Catrambone, 2016). The most popular science channels on YouTube as of 23 July 2018 are (searched with the categories "education" and "science and technology") Smarter Every Day, Sci Show, Veritasium, Minute Physics, NASA, Minute and Cody's Lab (Reemer, 2018).

Astronomy has long been well served by long-format (television episodes) videos from national media producers such as PBS/NOVA and National Geographic. A sense of the landscape for astronomy videos comes from searching YouTube with a Chrome browser set in the anonymous mode (to avoid bias due to user preferences or viewing history). A search for "astronomy" returns 2.9 million results, with about 5000 new videos added every day. The most popular videos at present are from the *Astronomy Crash Course* series, hosted by Phil Plait and created by PBS Digital Studios. There are 47 videos in this series, ranging from ten to 15 minutes long, with a total of 9.5 million views. The umbrella channel Crash Course, started by John and Hank Green in 2006, has over seven million subscribers and is approaching a billion total views. Other astronomy-specific channels include Sci Show Space, with a million subscribers, and Vintage Space, which is more about space flight than astronomy. Amusingly,

three of the most commonly viewed videos are songs with astronomy in the title by rock groups Metallica, Pink Floyd and Blue Oyster Cult. Other astronomy videos with over a million views are single lectures, typically an hour long, from various public events and television shows for a national audience.

The Project: Active Galactic Videos

From the outset, undergraduate students played a central role in the current project. The lead author (Impey) had been working with students on education and outreach for a decade and had occasionally created educational astronomy videos for teaching non-science majors at the University of Arizona. A lot was learned from the production of videos for two MOOCs. The first, *Astronomy: State of the Art*, has been available on Udemy since March 2013 and has had over 62 000 enrolments. The second, *Astronomy: Exploring Space and Time*, has been running on Coursera since February 2015, with over 75 000 enrolments. The project management team also includes the second author (Wenger) acting as education manager, and the fifth author (Danehy) web programmer and developer. From its inception, this project has had multiple goals: (1) disseminating astronomy through the appealing medium of short-format videos, (2) conveying cutting-edge astronomy research being carried out at one of the world's major observatories and (3) providing undergraduates with opportunities to learn new skills, practice teamwork and apply their creativity to astronomy.

Students involved in the project enthusiastically embraced the idea of systematically creating a series of videos to communicate astronomy concepts to wide audiences and to highlight the research going on at Steward Observatory, which is one of the world's prominent astronomy centres. The title selected by the students for the project, the associated website and the YouTube channel was Active Galactic Videos. The YouTube channel was launched on 21 July 2015. As of late July 2018, it hosts 68 videos and has around 6100 subscribers and 110 000 total views (Figure 1). While viewership is modest, it is rising and the audience will grow as new content is added and the site is promoted through social media networks.

The Active Galactic Videos project got a big boost at the beginning of 2018 when one of our videos was featured in a guest spot on the YouTube channel operated by the British science populariser Tom Scott. He has 1.1 million subscribers and his videos have had 210 million views since 2006. Our tour of the Steward Observatory Mirror Lab got nearly a quarter of a million views on this site within two weeks of being posted, several times the total number of views of the Active Galactic Videos YouTube channel (at the time the video was launched). This boost to the project highlights the role of prominent social media influencers in drawing attention to a new video channel.

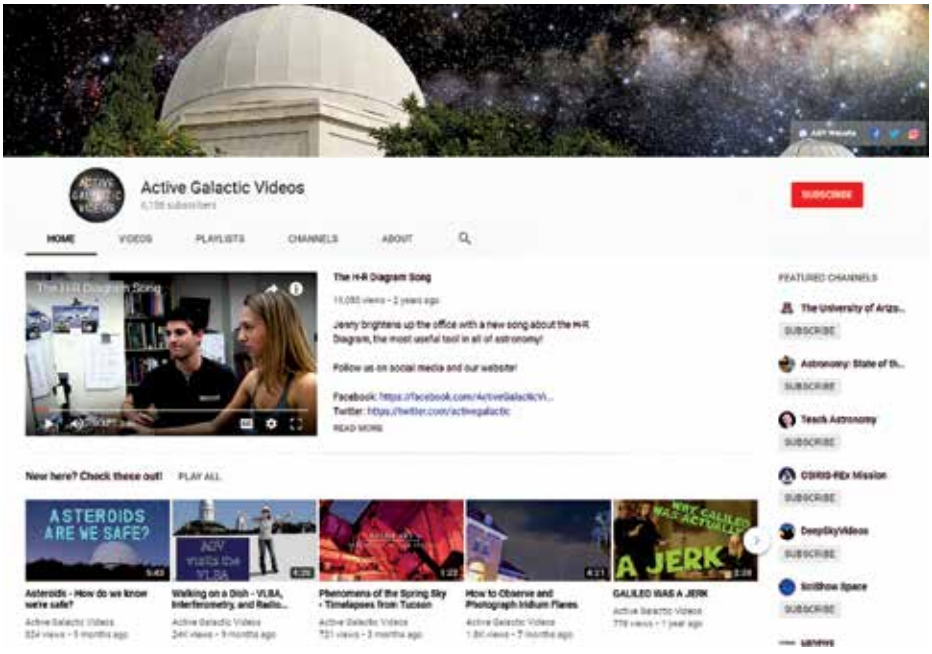

Figure 1. *The YouTube page of the Active Galactic Videos project (viewed July 2018). The homepage is set to highlight new releases and provide a sampler of the content. Below that are the most popular videos and the various playlists with videos grouped according to themes. Credit: Active Galactic Videos*

Project Management

The Active Galactic Videos activity is part of a larger education and outreach effort centred in the Department of Astronomy at the University of Arizona, which includes the development of astronomy content for the Teach Astronomy website and support for two MOOCs, as described earlier. Over twenty undergraduate students have been employed to make videos over the past two and a half years. Most of the students are juniors and seniors with a full class load, able to work 10 to 15 hours per week. The project is supervised by the first author, a distinguished professor of astronomy and an associate dean of the College of Science. Day-to-day management is handled by the second author (Wenger), a full-time member of the Steward Observatory scientific staff with the title of Education Manager.

At the beginning of the project, astronomy majors and minors were mostly hired. We quickly discovered that our students excelled at developing ideas for videos and creating the associated content. We also found that many of the best astronomy students had hobbies such as singing and photography in addition to their science training. These students with varied backgrounds in music, English, film and television and acting produced the best videos. Beginning in the second year of the project, we began to specifically hire students who were non-science majors. We matched students with majors in filmmaking, cinematography, sound design and creative writing with students majoring in astronomy to create the best and most well-received videos. When we first hired students with sound and video expertise, we had them recommend video and sound equipment that would improve the production value of our project. There was

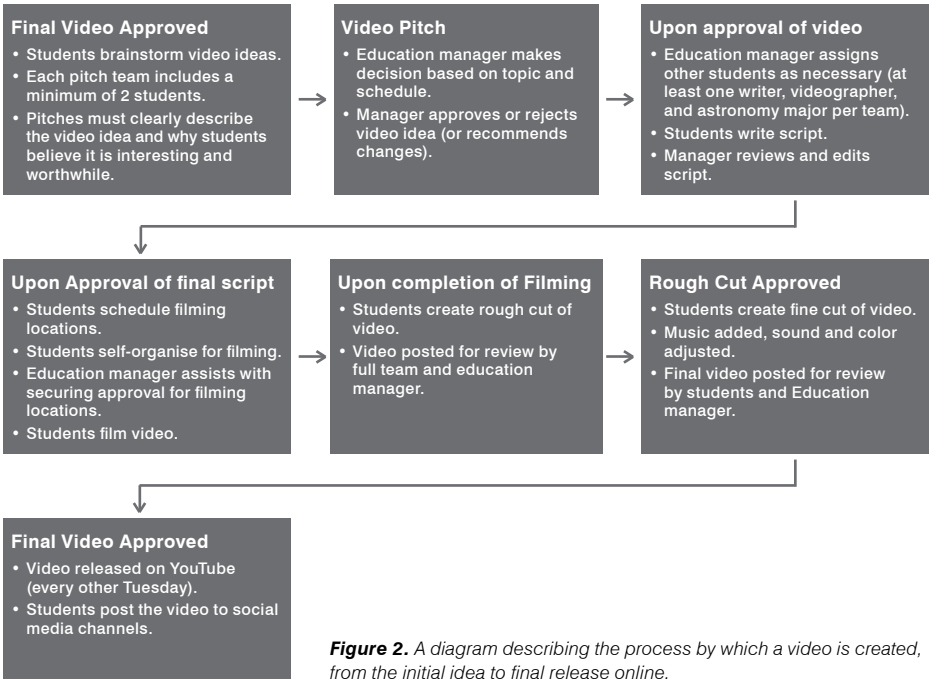

Figure 2. *A diagram describing the process by which a video is created, from the initial idea to final release online.*

an immediate and noticeable improvement in the quality of the videos, based on changes in equipment alone. This aspect continued to improve as the students became more familiar with the equipment and their skill level increased.

On the basis of several years of experience, we came up with a system to pitch video ideas. The first requirement was that at least two students had to work on every pitch. We found that this helped weed out ideas that sounded entertaining but were too gimmicky or had a flawed premise. This process also helped eliminate projects that initially seem like a good idea but ended up being too simple to underlie a whole video or were too complex to pull off. Next, the students had to present the idea, including an overview of the purpose and goals of the video and a plan for how to film it. We found that by thinking through these components of the video ahead of time, we spent less time backtracking on videos that were not feasible.

The overall goal of the project is to create appealing videos with a high production value and a strong and authentic student voice. Creation of the videos is a rich learning experience for the students involved (Smith, 2014). Our videos ranged in length from two to six minutes. Some were standalone ideas such as *Why are Barns Red?*, *Galileo was a Jerk and Asteroids — How Do We Know We're Safe?* Others had a timed release linked to a particular astronomical event, like *Lunar Eclipse 2018* and *Highlights of the Cassini Mission*. A third category had a general theme explored with multiple examples: these videos were predominantly observatory tours, such as *AGV visits the VLBA* and *Astronomy Research at the MMT*. A fourth category was a series of videos with a consistent format or a single theme, like *Five Facts* and *Einstein Out West* (Figure 2). Although there is some evidence that videos using a single, consistent science communicator are more successful (Wellbourne & Grant 2016), we chose to explore a range of styles with various student hosts. The fact that all of the videos were not equally effective or successful is a characteristic of this type of enterprise.

Hardware and Software

Tools like iMovie and inexpensive, ubiquitous cell phone cameras have democratised video production to a large extent. However, to be a highly regarded channel that attracts loyal viewers on YouTube, it is necessary to meet a certain minimum level of requirements for video and audio quality. At the very least, videos should be recorded and edited at a resolution of 720p, although it is common for most modern videos to be recorded at a 1080p. resolution. This takes up a significant amount of storage space, and it takes a while to export a final video, but the high-quality final product is worth the space and effort. To keep pace with improving technology, video producers should consider purchasing a 4K camera. For our project, we bought a Canon 80D DSLR camera, which has video capabilities. This camera has a large sensor and uses high-quality photographic lenses.

In addition to the camera, a basic audio setup is recommended. A shotgun microphone can be used for voice-over work if the budget does not allow for multiple microphones. USB microphones are also available, but a traditional XLR microphone and digital recorder setup is more versatile and modular than on-camera audio or

	Minimum Required	Preferred	Our Solution
Video	720p video camera.	4K digital video camera or DSLR.	Canon 80D DSLR camera.
Audio	On-camera audio.	Digital audio recorder with 4–6 channels. Shotgun microphone. Lavalier microphones.	Tascam DR-70D 4-channel audio recorder. Rode NTG-2 shotgun. Shure Lavalier microphone.
Lighting	None.	Three fully adjustable (colour, temperature and brightness) LED studio lights.	Cowboy Studio kit including three softbox lights with 5500K fluorescent bulbs.
Other Equipment	None.	C-stands. Green screen. Backdrops for interviews.	Tripod with collapsible reversible green/blue and black/white screen.

Table 1. *A description of the minimum and preferred video, audio, lighting, and supplementary equipment as well as a list of the items we purchased for this project.*

Figure 3. *An example of one of the videos from Active Galactic Videos. This video was created using the process described in Box 1. Credit: Active Galactic Videos*

Box 1. Process for Active Galactic Video episode featured in Figure 3.

Carmen from Active Galactic Videos visits a radiotelescope on Kitt Peak that is part of a network of radiotelescopes called the Very Long Baseline Array (VLBA).

The VLBA consists of ten dishes that are each 25 m in diameter and stretches from St. Croix in the Caribbean to Mauna Kea in Hawaii.

Carmen takes us on a tour of the facility, talks to experts and climbs to the top of the telescope where she gets to walk on the dish and explain how it works to focus and amplify radio signals so that astronomers can study the Universe.

a USB microphone. Lavalier wireless mics are also recommended for high-quality sound and location filming. Video and sound equipment is evolving and the merits of different types of hardware are hotly debated; in Table 1, we present our suggestions for the minimum level of equipment, the preferred level and our solution. Other equipment that we purchased and used extensively are a portable green screen and a small lighting kit. Although we ordered an inexpensive Cowboy Studio brand lighting kit with fluorescent lights, the recommendation is to buy an LED lighting kit with adjustable brightness and colour balance.

We did not have access to a dedicated studio space for filming, so we often filmed in our team office or on location. If you have a place to set up a permanent sound- and lighting-controlled studio environment, it is highly recommended. This is beneficial for a variety of reasons. In particular, if you want to use a green screen, colour keying is easier when you have bright, even lightning. Additionally, if you want to produce videos quickly, a dedicated studio space means that you do not have to repeatedly set up and take down your equipment.

Finally, for editing video, we purchased an Apple Mac Pro and a professional level video editing package. We started with Final Cut Pro X and found it to be easy to learn and use, particularly for new students. It has some advanced features, like key-frame animation capabilities and colour keying for green/blue screen removal. More recently, however, we moved to Adobe Premiere and After-Effects. Although not considered as high end as Avid Pro Tools, Premiere is still a professional level editing program and is used widely by YouTube video creators and industry professionals. It has more options and controls than Final Cut Pro X does but is not as easy to learn for new editors. The University of Arizona also has an Adobe site license, so Premiere, After Effects and the rest of the Adobe Creative Suite are all available to us and to all the students; thus, we do not have to restrict their use to a single computer. It may not be necessary to have the most advanced video editing hardware, but an old computer would be a significant bottleneck in the process of editing and exporting videos, so be sure to test out the computer you are planning to use for editing. We also recommend using a computer that can support one or two external monitors to improve workflow.

One innovation we have used in certain videos is the use of a drone for aerial views and to add drama to the visual presentation. The drone used is a DJI Mavic Pro. Because of the drone's mass, it must be registered with the FAA for recreational operation as a U.S. commercial flight and requires a strict, Part 107 license. The drone's camera can shoot at many different resolutions and framerates, including raw (D-LOG) footage up to 4K at 30 frames per second. It has a maximum range of up to seven miles, but the law requires that the pilot or spotter always be within visual contact of the drone, which limits the practical radius to less than one mile. In addition to adding drama, flying cameras provide previously unseen perspectives on remote locations such as observatories, thus improving film quality (Figure 3).

Professional Development

Students play a central role in the project, from pitching ideas in team meetings to forming groups with the appropriate skill sets to create a video and filming and editing the videos. To illustrate this, Box 2 shows quotes from some of the undergraduate participants on the benefits they experienced by working on AGV. Early in the project, we determined that everyone on the team would benefit from specific and purposeful professional development, with the goal of improving our videos in the following areas: sound quality, visual quality, storytelling and presentation and acting.

Each week, we had a one-hour meeting to specifically talk about video projects. In general, at least half of this meeting was dedicated to professional development. To address this aim, two exercises were undertaken: in the first exercise, two students signed up to present to the group and lead a discussion each week. The Education Program Manager always presented at the beginning of the semester to set expectations for the students. Prior to the meeting, the presenters chose a topic and found a variety of videos that illustrated the point they were trying to make. For example, if we wanted to talk about the

Figure 4. *A drone shot of the MMT Observatory at the Fred Lawrence Whipple Observatory on Mount Hopkins, in southern Arizona. This research facility was the subject of an Active Galactic Videos tour. Credit: Active Galactic Videos*

use of animations in videos to show scientific concepts, the presenters found two or three videos that illustrated best practices and a few that did it poorly. The presenters wrote several guiding questions for a discussion about the topic. These were meant to stimulate the conversation and were usually framed in the context of "Which of these worked best?" or "How did the creator use this well and what could have been improved?" Video links and questions were sent out ahead of time and everyone was expected to have watched the videos and prepared to participate in the discussion. Ultimately, the goal was to incorporate the lessons learnt into our own videos.

The second professional development exercise that proved effective was to go back and critique old videos from our own channel. We began by watching the video and then each participant was asked to make at least one comment (positive or negative) about the video. After we went around the room, we opened up the discussion to comments or additional critiques that people want to bring up. One of the most important ways to improve video quality is just to make a lot of videos and reflect on them, making slow, incremental improvements. This can be particularly challenging with a constantly rotating group of undergraduate students, but given the wide range of ages and experience levels, there is often enough continuity to pass on the lessons learned to the next group of incoming students. It also helped that there was a consistent staff manager who could carry these lessons forward and review important information with incoming students that the existing team might have taken for granted.

Filming Issues

At the beginning of the project, we filmed most of our videos with a presenter standing in front of a green screen. Because our equipment was limited, this allowed us to exert some control over the video and sound quality. Unfortunately, this gave our videos an amateur look and feel. As we progressed, we started filming on location, or at least outside of our small office-based studio. While this made filming more of a challenge (with regard to sound, in particular), we simultaneously brought

Box 2. Students' views on the project

Why Students Joined the Project

"Any student interested in science and education can benefit from being a part of the AGV project. If they have this interest, almost any major and skillset can find a place in the project. Our team has artists, journalists, filmmakers and scientists, and all of them can find a way to grow with AGV".
Aidan Gibbs, Astronomy and Physics major

"I joined the AGV team to further my science writing skills. I was interested because I had taken a few astronomy classes prior and was interested in learning more. It ended up being a great fit because I learned a lot and advanced my science writing skills".
Jessica Blackburn, Journalism major, Spanish minor

Professional Development

"AGV helped shape my interest in documentary work and opened my mind to other styles of production I wouldn't have been exposed to. This is true because of my experiences working alongside other people producing content as well as because of our continual evaluation of other YouTube channels and content creators".
Galen McCaw, Music major, Film and Television minor

"AGV has generally broadened my knowledge and interest in science. I came to the project with a keen interest in astronomy and physics, but the specifics were not exactly my thing. It has also provided useful experience when it comes to writing under time pressure, which is a much needed skill for a writer of any kind".
Grant Bowman, Computer Science and Creative Writing major

Interdisciplinary Experience

"AGV is special because of the interdisciplinary nature of the group; I'm constantly learning, whether it be about science or how to be a better filmmaker. The diversity in the AGV team— (astronomers, journalists, geologists, physicists, graphic artists, filmmakers) —allows us to be extremely creative".
Carolyn McKee, Philosophy major, Film and Television major

"AGV shows students like myself that we can make some amazing things when collaborating with people outside our disciplines. I'm a film student and have always been the art kid of my family, but I also really enjoy learning about science and astronomy, despite not having much knowledge on the subject. AGV gives us a space to come together and make content that is leagues better than what we could do on our own, giving us a way to give back to our community through education and enhance our personal skills in the areas that we hope to pursue after graduation. Also, I've become friends with everyone here at AGV, and it's been such a wonderful experience getting to know new people who are so passionate and talented".
Victoria Pereira, Film and Television major, Creative Writing minor

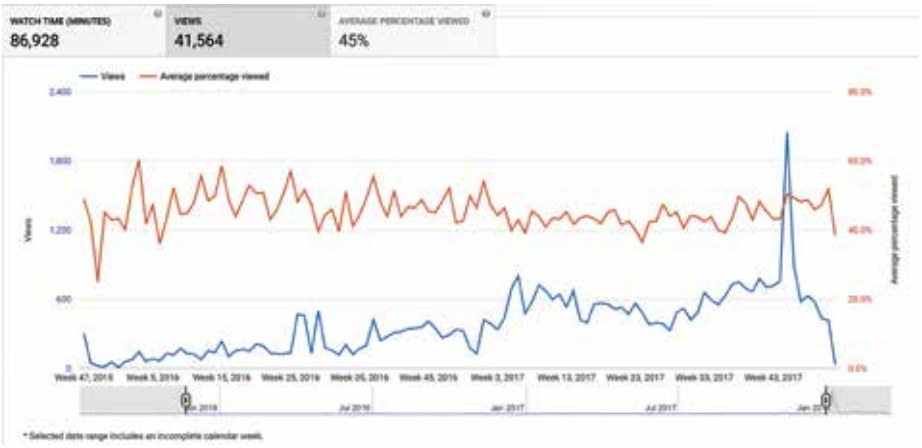

Figure 5. *The classic version of YouTube's analytics enables users to compare various metrics against each other. This graph shows the total channel views (blue) and the view percentage averaged across all videos on the channel (orange), per week. The latter statistic is also known as audience retention and depicts how much of a video the average viewer watches. Credit: Active Galactic Videos*

on students with expertise in sound and videography.

One issue we encountered was obtaining permission to film at certain locations. Although we always work with the staff at the locations where we want to film, large organisations such as observatories can have complex administrative structures. Permission from a collaborator was often insufficient to allow us to film, and permission was required from a high administrative level. We learned to get approval from director-level administrators if possible and to alert as many people as we could about our visit, giving everyone a chance to give their inputs. Major observatories deal with filming requests frequently, and they may have a formal structure in place, with permission forms on their websites. But other facilities have no such structure. It is best to work with an on-site contact and inform an administrator at the highest possible level. We also frequently offered to share our footage with the staff at the locations where we were filming. These organisations may not otherwise have a way to get this footage themselves. It is important to be aware of particular filming concerns and note any special requirements and "off-limit" subjects or areas. For example, filming at Kitt Peak and Mount Graham required sensitivity to the concerns of the Tohono O'odham and San Carlos Apache tribes, respectively. Additionally, many major observatories are on land that is controlled by the U.S. Forest Service, and they may have their own filming requirements, forms and fees. The simple recommendation is to ask lots of questions and be aware that many organisations have these kinds of concerns.

Dissemination and Metrics

YouTube was the primary channel for disseminating Active Galactic Videos and soliciting feedback from viewers. Creating a YouTube channel occurs as a by-product of having a Gmail account. The real challenge arises when attempting to cater to a growing audience. Each new release enables creators to fine-tune their content to best-serve their audience, since YouTube provides many metrics, and many dimensions therein, known collectively as analytics. YouTube's analytics includes data on external sources, YouTube search terms and audience retention (Figure 4). From these and other analytics data, the team could decide how long a video should be to hold viewers' attention, which words and phrases to use in a video's title and description and which topics or types of videos draw the most attention. By evaluating metrics like audience retention in contexts such as video type or video duration, it quickly became apparent what kind of content would draw the most attention (Figure 5). There are no fixed good or bad values for audience retention, but analysts tend to agree that a good retention rate is greater than or equal to 65%. If your audience continues to grow and your retention rate either maintains its value or improves, then your content is also likely to be improving.

Managing a YouTube channel is just a small portion of what is required as part of branding and overall outreach. In any context, outreach is about maximising exposure, so each release on YouTube should be accompanied by social media activity such as posting on Twitter, Instagram and Facebook. Potentially engaged users on YouTube often want to know more about the content and its creators, which requires the use of various social media platforms. Although this activity helps to garner new viewers and provides a framework for word-of-mouth propagation, it also adds quite a bit of complexity to the analytics. Posts on

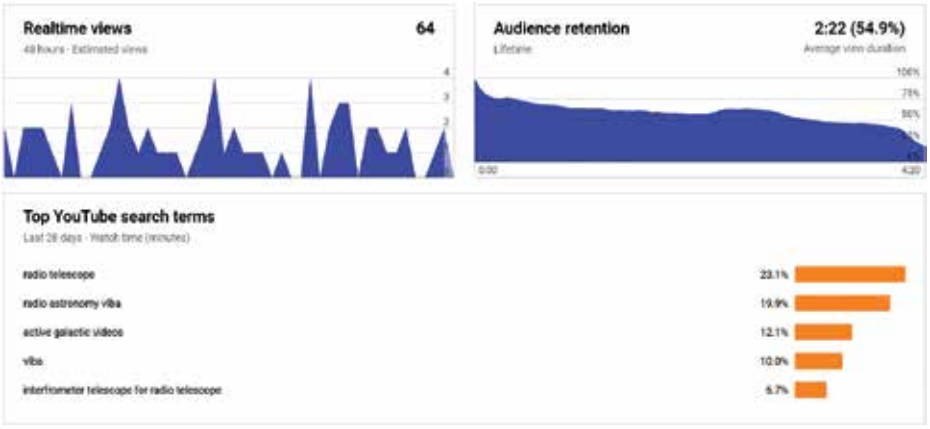

Figure 6. *Part of the YouTube analytics for a single, public video on the channel. The Realtime views graph shows the number of views per hour, including the current hour. The audience retention graph shows the percentage of viewers who made it to any given point in the video. The shape of this plot reflects the anecdotal decline of the average attention span of YouTube viewers. The lower chart shows which search terms people used to find the video. This is the most valuable data, as it can help guide tag and title selection for future videos. Credit: Active Galactic Videos*

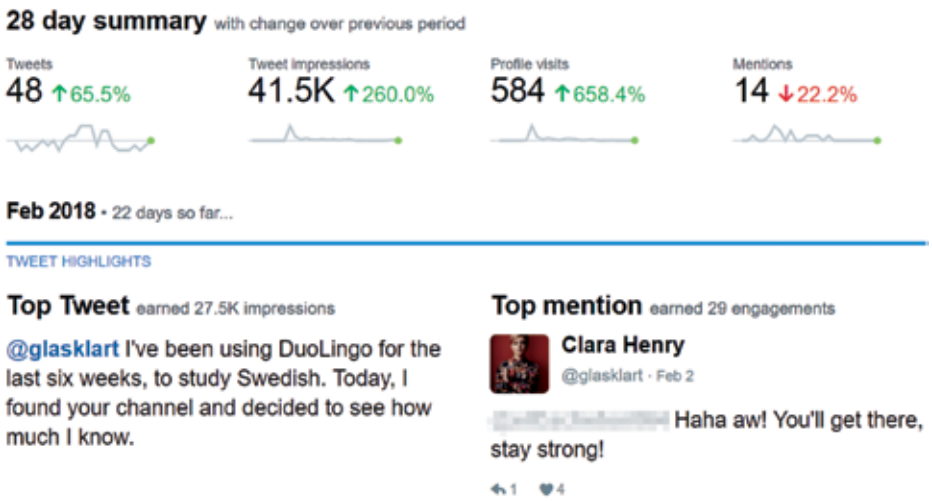

Figure 7. *Twitter analytics page for a single user. The default view is a 28-day breakdown of activity. The Tweet Impressions data along with the Top Tweet/mention fields highlight which words, phrases or topics are considered the most interesting. A Tweet Impression is the number of times a person saw this Tweet on any device for a measurable amount of time. Credit: Active Galactic Videos*

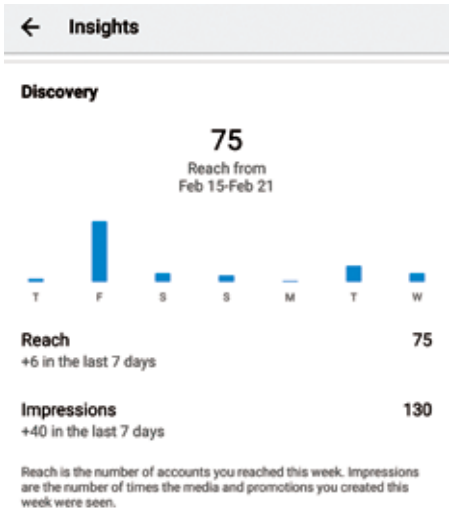

Figure 8. *This is the Instagram Business Analytics viewer. The tool provides sparse information, requiring a manual approach to look for any potential correlation between the posts and impressions data. Credit: Active Galactic Videos*

Twitter and Instagram must be accompanied by hashtags in order to be given an advantage by the algorithms of these platforms. However, words and phrases used to boost viewership on YouTube do not necessarily translate to Twitter and Instagram. As with YouTube, Twitter provides analytics to help determine which hashtags perform the best (Figure 6). Additionally, Twitter makes it clear which networking efforts are the most beneficial.

Instagram also has its own analytical data available only to Instagram Business accounts (Figure 7). Converting an account to Instagram Business is just as easy as creating the account itself. Among the platforms mentioned so far, Instagram has the sparsest analytical data which is the most subject to interpretation. This platform does nothing to inform the user of which hashtags or keywords helped viewership. Additionally, Instagram's analytical data is only viewable on a mobile device, which makes assimilating and using the data very inconvenient.

Facebook provides a thorough, high-level set of analytical data. While it is not evident why one post performs better than another, it is easy to compare among posts (Figure 8). Like with Instagram (a Facebook platform), the analytical data is subject to interpretation and theory. All three major platforms (Twitter, Instagram and Facebook) provide the ability to boost a post. This service costs money and is the equivalent of buying ads. Since this is one major part of Facebook's revenue, they focus their analytics page on boosting posts.

Project Costs

Active Galactic Videos is funded in part by the Department of Astronomy and the College of Science, who pay the salaries of the second and fifth authors, respectively, and by a grant from the Howard Hughes Medical Institute, held by the first author.

The grant supports an array of educational projects, but it is possible to itemize the expenditure that supports the videos. Depending on seniority, students are paid between $10 and $15 per hour. Most have full class loads so they work an average of ten hours per week for the 30 weeks of an academic year. There is flux as new students join the project and senior students graduate, but over the past two years, an average of eight students have been working on the videos. This works out to about $29 000 per year on student stipends. With employee-related expenses at 3.5% and

Figure 9. *Facebook's analytics page for a business or public group. Reach is defined in the same way as on Instagram: the number of accounts who saw any particular post. Engagement shows how many of those accounts interacted with the post by clicking and/or liking it. The task of determining why any post got more engagement than any other posts is up to the user. Credit: Active Galactic Videos*

indirect costs at 54%, the cost to the grant is $45 000 per year. If the portion of staff time supporting this project is included, this number doubles.

Most of the costs of producing videos for education and outreach lie involve salaries and stipends. We have bought, and occasionally upgraded, mid-range video equipment (i.e. not professional level) and have had to purchase consumables like batteries. There are costs for computer peripherals, storage media and video editing software (the latter is available at low costs through licenses to the University of Arizona). Additional costs arise from location filming, including car or van rental, and occasional hotel and meal expenses for longer trips. The sum of all these ancillary costs has averaged about $8000 per year. Therefore, the entire annual cost is around $100 000. If staff support is already provided by the institution or if the student team is small, the costs can be kept below $50 000. There are 67 universities with astronomy majors in the USA, totalling over 1600 juniors and seniors, and all these universities have Liberal Arts students who could be included in such projects (American Institute of Physics, 2017). Thus, we believe this model for the creation of videos for education and outreach could be replicated at many colleges and universities in the USA and elsewhere.

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References

American Institute of Physics, 'Roster of Astronomy Departments with Enrollments and Degree Data, 2016', College Park, MD, AIP Statistical Research Center, 2017

Hoppe, H. U. et al., 'Video versus Domain Concepts in Comments to Learner-Generated Science Videos', in Proceedings of the 24th International Conference on Computers in Education, Mumbai, India, November 28–December 2 2016, Asia–Pacific Society for Computers in Education, 2016, p. 172–181.

Impey, C. D. et al., 'Bringing the Universe to the World', CAP Journal, no. 21, 2016, p. 20–30

Lee, H., N. Park and Y. Hwang, 'A New Dimension of the Digital Divide: Exploring the Relationship between Broadband Connection, Smartphone Use, and Communication Competence', Telematics and Informatics, no. 32, 2015, p. 45–56

Margaryan, A., M. Bianco and A. Littlejohn, 'Instructional Quality of Massive Open Online Classes (MOOCs)', Computers and Education, no. 80, 2015, p. 77–83

Reemer, G., The YouTube Channel Crawler, [website], 2016, www.channelcrawler.com/

Reich, J., 'Rebooting MOOC Research', Science, no. 347, 2015, p. 34–35

Rosenthal, S., 'Motivations to Seek Science Videos on YouTube: Free-Choice Learning in a Connected Society', International Journal of Science Education, Part B, no. 8(1), 2017, p. 22–39

Smith, D. K., 'iTube, YouTube, WeTube: Social Media Videos in Education and Outreach', Journal of Chemical Education, no. 91, 2015, p. 1594–1599

Sugimoto, C. R. and M. Thelwall, 'Scholars on Soap Boxes: Science Communication and Dissemination in TED Videos', Journal for the Association of Information Science and Technology, no. 64, 2013, p. 663–674

Wade, P. D. and A. R. Courtney, 'Using Video Projects in the Science Classroom', in J. L. Drake, Y. Y. Kontar and G. S. Rife (eds.) New Trends in Earth Science Outreach and Engagement, Advances in Natural and Technological Hazards Research, Switzerland, Springer, no. 38, 2013, p. 177–192

Wang, C. and Q. Shao, 'Engaging Students in Learning Science and Technology using Students-Generated Educational Videos', in IEEE 16th International Conference on Advanced Learning Technologies, [online] IEEE, 2016, p. 270–274

Wellbourne, D. J. and W. J. Grant, 'Science Communication on YouTube: Factors that Affect Channel and Video Popularity', Public Understanding of Science, no. 26, 2016, p. 706–718

Yoo, A. and R. Catrambone, 'The influence of situational interest on learning outcomes for science videos, in Proceedings of the Human Factors and Ergonomics Society 2016 Annual Meeting, Washington DC, September 19–23 2016, 2016, p. 1404–1408

Zhou, R. et al., 'How YouTube Videos are Discovered and its Impact on Video Views', Multimedia Tools and Applications, no. 75, 2016, p. 6035–6058

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