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Phys FilmMakers: teaching science students how to make YouTube-style videos

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Abstract

Phys FilmMakers (PFM) is a new type of course in which a science expert and science communicator partner teach physics students how to make YouTube-style videos on cutting-edge scientific research within the university department. Here, we describe this new course, outline its key components and provide recommendations for others considering implementing a similar FilmMakers-style course using feedback from course tutors and students. We discuss successful and less successful teaching techniques as well as use our experience to identify areas that science students in particular often have difficulties: finding an interesting 'hook' for the video, imagining creative B-roll and making a succinct video by removing extraneous (though usually correct and often interesting) material. The course has two major components: workshop sessions in which students learn the key elements of film-making and independent video production where PFM students partner with senior PhD or post-doc researchers to produce a video on their research. This partnership with the department means that the videos produced serve not only as interesting 'edutainment' to encourage teenagers and young adults into Science, Technology, Engineering and Maths subjects, but also provide valuable outreach for the academic department.

Supplementary material for this article is available online

Keywords: film-making, transferable skills, communication, outreach, project work, research-based education

1. Introduction

In the development of a well-rounded graduate physicist, it is increasingly recognised (e.g. [1–4]) that we need to provide training beyond the traditional physicist skills of, e.g. problem solving, scientific knowledge and experimental design: employers are increasingly valuing the communication and group work ability of graduates.

Phys FilmMakers (PFM) is an experimental course in which undergraduate physics students learn how to produce YouTube-style videos about the current research within their department to serve as education and outreach tools. In McKemmish *et al* [5], we discuss the benefits of the PFM course to students, department research staff and the university as a whole. Here, we focus on the process of setting up and running the PFM course, and on the experience of the course from the student and staff perspectives.

This paper is aimed towards those considering running this type of course in their higher education institution; this may be faculty members, post-doctoral researchers, teaching fellows etc. This paper makes no assumptions about the background knowledge of the reader on science education or physics. In particular, this paper describes what is involved in running an extra-curricular PFM course and provides significant practical advice and recommendations to those considering implementing a FilmMakers-type course in their degree programme. Note that a FilmMakers-type course can be applied across broad academic disciplines; however, we feel it is particularly appropriate in the Science, Technology, Engineering and Maths (STEM) subjects to encourage the expression of student's creativity, an aspect often under-utilised in exam-focused secondary school and undergraduate coursework, but vital in practical settings [6–8]. The PFM program represents an innovative way of learning, both for the students producing the videos, and the much wider number of students viewing the videos.

One of the major motivations leading to the creation of the PFM program was the view that scientists should be telling the story of scientific research, rather than non-specialist journalists. However, to train students in making high quality YouTube-style videos, we need the expertise of those trained in media. This led us to creating a teaching team with both a science expert and science communicator with expertise in the type of short films typically seen on YouTube.

Our particular course was voluntary rather than a for-credit module. We have run variations of this course for second year undergraduates, a mixed class of second year undergraduates and PhD students, as well as for 13–15 year old high school students. Focus group data and quotes come from the first program, though the subsequent courses are taken into account in the implementation description and the analysis of the course.

2. Context

Trailblazers have long argued about the importance of science outreach [9], but it is becoming a much more mainstream activity, performed in tandem with scientific research [10] by many esteemed academics and professionals, not just a select few [11]. Outreach fulfils a number of complementary and overlapping purposes [12]: encouraging children and adolescence to

Table 1. Data is accurate as of 25 January 2017. Sorted by total video views. Credit to socialblade.com (accessed 25 January 2017).

Channel name	Subscriber count	Video views	Uploads	Av. views in our/upload	Based	Created
Vsauce	11 479 150	1 121 550 025	332	3 378 163	UK	July 2007
AsapScience	6 068 888	690 617 325	205	3 368 865	Canada	May 2012
BBC Earth	1 021 791	373 882 366	1215	307 722	UK	February 2009
Veritasium	3 904 221	316 536 248	216	1 465 446	USA	July 2010
MinutePhysics	3 668 357	302 897 843	187	1 619 775	USA	June 2011
Numberphile	1 916 599	240 902 711	402	599 260	UK	September 2011
Periodic Videos	883 338	149 259 353	609	245 089	UK	June 2008
Physics Girl	692 443	43 062 824	97	443 947	USA	October 2011

Table 2. Age demographic for MinutePhysics. Credit to channelpages.com (accessed 25 January 2017).

	Total	15–17	18–24	25–34	35–44	45–54	55–64	65+
Female	9.5%	1.6%	4.1%	2.1%	0.8%	0.5%	0.2%	0.2%
Male	90.4%	9.5%	38.7%	29.1%	7.1%	3.1%	1.2%	1.7%

pursue STEM subjects and careers [13], heightening the scientific literacy of the public [14] and creating awareness of the science produced by publicly funded research and its importance [15]. Appropriate and well-managed communication led by scientists to inform non-scientists can enrich public dialogue and improve policy making [16].

The recent study by Besley and Nisbet [12] explores the way scientists view the public's understanding and interest in science, concluding that 'almost universally ... scientists believe the public is inadequately informed about science topics'. When reflecting on the reasons for this in the Mori/Wellcome Trust study [17], 53% of scientists blamed lack of education, 22% suggested lack of interest, while 20% attributed the lack of communication skills displayed by scientists. The PFM course aims to provide students with the communication skills necessary to present science in an interesting, engaging and informative manner.

Bobroff [18] stresses the importance of using the 'amazing new tools' created in the 21st century, specifically the 'internet and new media' and challenges scientists to 'profoundly rethink its ways of engaging the public!' Many have taken up this challenge. YouTube is undoubtedly one of the quintessential 21st century tools that has been taken up by many for science communication [19–25]. One of the most successful series of scientific videos (and most relevant to our course) are those produced at Nottingham University by Brady Haran, including Sixty Symbols (Physics Videos) and the Periodic Table Video series (Chemistry), discussed by Haran and Poliakoff [26]. Brady's videos are notable for containing scientists and current science. Other notable science YouTubers include Vsauce, AsapSCIENCE, Veritasium, and Physics Girl. One can see choice illustrative data regarding the reach of such channels in table 1. The majority of the presenters in this table are male; this is in line with the unfortunate reality [22] that a substantial majority of YouTube science communicator presenters are male, particularly for user-generated content (more than 80%). Reference [22] suggests that this correlates with fewer female viewers. Though an in-depth analysis is beyond the scope of this paper, we examined viewer demographics for MinutePhysics using http://channelpages.com to find representative figures; see table 2. The low female viewership is probably part of the wider issue of female under-representation in STEM subjects [27–29], though lacking appropriate role models in the presenters cannot be increasing interest.

The Technology, Entertainment and Design (TED) conference and its associated videos are another interesting example; these videos, often on science topics, are extremely popular, with over one billion views [30]. Unfortunately, we again see lack of female representation with the majority of academic presenters being senior faculty, male and from United States-based institutions [31]. More broadly, YouTube videos have been used for recording and disseminating course lectures; Kousha *et al* [32] summarises this research. However, while both the TED talk videos and recording of lectures allow increased dissemination of science, neither take substantial advantage of the video medium and of video editing techniques.

In terms of inclusion of outreach into physics course, we highlight Bobroff and Bouquet [33], who describe a project-based course involving production of outreach material. Students emphasised the gain in communication skills (42%), pedagogy (31%) and group work (10%).

The course was seen as quite time-consuming by 29% of students, a common issue with project-based courses.

3. Course description

3.1. Overview

The core of PFM is the production of YouTube-style videos that connect students with the world-leading scientific research at UCL.

In the first half of the PFM course, we introduce students to film-making in a series of workshop classes where they produce a short first video. These workshop sessions introduce each of the key parts of filming, though not in sequential order: pre-production (preparation and planning), production (actual filming including both narration and B-roll material), editing and dissemination of the final product.

Then in the second half of the course, students make their own independent video. For undergraduate students, we pair groups with a senior PhD or post-doc who acts as scientific film consultant and whose research forms the basis of the undergraduate's independent film. This connection between researchers and students is one of the major benefits of the PFM approach [5].

3.2. Objectives

(i) To increase the transferable employability skills of physics students, particularly communication, teamwork, time management and computer skills
(ii) To give the students an appreciation of the connections between science and art
(iii) To give opportunities for students to interact with physics and physicists at UCL, and to see scientists in their working environment
(iv) To encourage creativity and ambition in students
(v) To teach students the basics of film-making, including both the technical and artistic aspects of the medium
(vi) To consolidate and deepen the students' scientific understanding
(vii) To produce easily accessed short videos that can assist in promoting and widening participation in physics worldwide
(viii) To produce promotional material on the research done within the UCL Physics and Astronomy department, assisting in the department's outreach

Scientific

- Relate the physics they are taught to modern physics research
- Recognise the importance of mathematics, computer skills, experimental skills and research skills in modern physics

Practice of science

- Appreciate that communication, verbally and in written form, is an important part of the job of a modern physicist
- Understand that science exists within a wider societal context, which both influences and is influenced by scientific research
- Appreciate the important soft skills associated with science research, including independence, curiosity, dedication and passion

Film-making

- Understand the four main stages of film-making: pre-production, production, post-production and dissemination/publicity
- Understand the aspects of pre-production and their importance, including planning locations, people, props, equipment, writing interview questions, scripting, and storyboarding
- Understand the elements of production: camera work, interview, narration (including voice-overs) and B-roll
- Understand basic artistic aspects of filming, particularly the ‘rule of thirds’ and different camera shots
- Understand the importance and variety of B-roll
- Understand the elements of post-production: logging footage, finalising the storyboard, editing and selecting accompanying music
- Understand the importance of selecting very short, focused clips and cutting all extraneous details
- Understand the basics of editing and appreciate that it is a very time-consuming, technical and important process
- Understand the importance of good audio quality, and learn basic techniques to maximise this, the most successful of which is reducing background noise during the original filming
- Understand that accompanying music greatly enhances the video’s artistic quality
- Understand that the dissemination and publicity is important to maximise impact

3.4. Dual expertise teaching team

The teaching team consisted of one physicist, who acted as course coordinator and science expert, and one science communicator, who acted as course lecturer and film-making expert. This combination proved valuable as each could ask the ‘dumb’ questions on the other topic, thereby encouraging students to ask questions. The multi-disciplinary teaching team is reasonably unique in a university context, but commonplace in modern research and work environments.

There were some interesting interactions when one expert was not present at a session. For example, in one B-roll session, the science expert was away and so students needed to figure out by themselves the relationship between absorption of light by molecules and refraction of light in a prism. Unable to ‘appeal to authority’, students were forced to use peer discussion and reasoning based on existing scientific knowledge and internet searches. Similarly, in a latter session without the editing expert, the science expert guided students in ‘Googling’ the answer to technical issues. Of course, this must be carefully balanced with ensuring that both experts are reasonably familiar with the other area and, most importantly, know when to double check details remotely.

3.5. Suggested structure and timetable

We have run two pilot extended courses for groups of around 10–15 students that helped us to refine the course structure and timetable. We also ran an intensive one-week program that was more prescriptive for secondary school students in which only one video was made; this assisted us in refining our recommendations for teaching pre-production, interviews and editing.

The suggested structure and timetable for the course is given in table 3. Our notes on table 3 are:

Table 3. Suggested ideal timetable for course with four groups of three students each. The lecturer here is the science communicator with YouTube expertise while the coordinator is the science expert. Notes on some of these classes are given in the text.

Week	Lecturer		Coordinator		Student		Description	
	Contact	*Other*	*Contact*	*Other*	*Contact*	*Other*		
Workshop sessions								
Wk 1	6 h	2 h	2 h	6 h	3 h	1 h	Filming of narration, interviews	(Interview/Narration)
Wk 2	3 h	3 h	3 h	0 h	3 h	1 h	B-roll 1: people and props	(B-roll)
Wk 3	3 h	3 h	3 h	0 h	3 h	1 h	B-roll 2: drawing and experiments	(B-roll)
Wk 4	3 h	6 h	1.5 h	0 h	3 h	2 h	Editing 1: logging footage and storyboarding	
Wk 5	3 h	6 h	1.5 h	0 h	3 h	2 h	Editing 2: trimming and adding clips	
Wk 6	3 h	6 h	1.5 h	0 h	3 h	2 h	Editing 3: audio and music	
Screening of first film								
Independent video								
Wk 7	0 h	0 h	0 h	3 h	2 h	3 h	Meeting researcher	
Wk 8	0 h	1 h	0 h	0 h	2 h	3 h	storyboard, interview Qs and scripts	(Pre-production)
Wk 9	2 h	1 h	2 h	1 h	2 h	3 h	Group discussion of first draft storyboards	(Pre-production)
Wk 10	0 h	1 h	0 h	0 h	2 h	3 h	Conducting interviews, recording narration	
Wk 11	0 h	1 h	0 h	0 h	2 h	3 h	Preparing B-roll, logging A-roll footage	
Wk 12	4 h	1 h	4 h	1 h	1 h	3 h	B-roll discussions	
Wk 13	0 h	1 h	0 h	0 h	3 h	2 h	Producing B-roll	
Wk 14	0 h	1 h	0 h	0 h	3 h	2 h	Final storyboarding, logging B-roll footage	(Supporting B-roll)
Wk 15	1 h	1 h	0 h	0 h	3 h	2 h	Editing	(Supporting editing)
Wk 16	1 h	1 h	0 h	0 h	3 h	2 h	Finalise editing	(Supporting editing)
Wk 17	2 h	1 h	2 h	2 h	2 h	3 h	Preliminary screening of films	
Wk 18	0 h	2 h	0 h	2 h	2 h	3 h	Final videos completed and exported	
Screening of final films								
Total	31 h	38 h	20.5 h	15 h	42 h	41 h		

(*Interview/Narration*) A lecture-style explanation and physical demonstration was much less successful than just starting students filming immediately. We recommend three-hour filming sessions with two groups of three students each session. Students are given an approximately 500-word script. Students rotate roles between narrator, director/camera person and lightning/audio. Each narrator is given two sentences at a time to narrate. They should finish one sentence looking into the camera, then look down to recall the next sentence before looking up and speaking the sentence into the camera. This is important as it provides the ability to edit/ cut at the end of the first sentence.

Interviews proved very important in the independent videos. Students can practice by interviewing the science expert.

Summary hand-outs can support the learning outcomes from the class (e.g. camera angles, rule of thirds, lighting etc).

(*Editing*) We recommend focusing on basic skills:

(i) Import clips into the video editing software media library
(ii) Drag and drop clips onto timeline
(iii) Trim the length of clips in both the timeline and the media library
(iv) Cut a clip into two or more separate clips
(v) Add B-roll on top of A-roll footage in a overlayed video stream (note that this increases the file size compared to removing the underlying A-roll; however, we feel the increased simplicity is more important, especially given the short video lengths)
(vi) Add titles/words to the video
(vii) Add open-source music as a quiet background to the video

(*B-roll*) B-roll is, broadly, the supplementary footage put into a video in order to enhance the main story. The variety of B-roll is limited only by the imagination, but we choose in the workshop sessions to focus on four techniques:

(i) Hand-drawn animations (of the style of ASAPScience [34])
(ii) Filming a simple science experiment
(iii) Illustrating concepts through props
(iv) Illustrating concepts through moving groups of people

It is also useful if each involves students learning new camera settings or techniques, for example, panning shots and face-down overhead shots.

(*Pre-production*) A pre-production pack was useful, but it was far more productive to actually go through the student's initial ideas, scripts and storyboards and identify problems, suggest solutions and, most importantly, encourage more creative and tight story-telling.

(*Supporting B-roll*) In previous films, B-roll was the weakest component; therefore, we recommend each group discuss B-roll with the lecturer and coordinator in a specific session.

(*Supporting editing*) We have included two one-hour office hours, intended for students struggling with editing (another difficult task) to seek help.

Note, we have given estimated lecturer preparation times for the second and subsequent times of delivering the course; the first time will of course require significantly higher time commitment. During the independent video production, we have included an hour of lecturer time per week for answering emails, updating Facebook resources etc. During the independent video production, we have included group work in the estimated contact time for students.

3.6. Organisation and communication

As a voluntary, formative assessment course involving students with different schedules, we ran into significant timetabling difficulties. A ‘drop-in, drop-out’ format for the workshop sessions was adopted with moderate success, where students attended when available.

Organising equipment, meeting times, and communicating logistical information was a challenge. Staff found it very difficult to receive high levels of responses via email; students later said that *‘with emails you can’t really communicate that easily*’, with the reasoning that *‘Sometimes you get them, sometimes you don’t really look at them and you have loads of them coming in.’* The students suggested a Facebook group and this proved more successful. Beyond scheduling, Facebook was used for content delivery, e.g. links to video tutorials on various aspects of film-making. Some material was put on the Facebook page before class, thus utilising a flipped classroom methodology. Students reported that this enabled them to *‘[walk] in with a good visual representation of what we were going to do and ... that places you in the right state of mind to then try and learn about how to actually go about doing it’*. Other times, the material was put on Facebook as revision or in response to a specific question. Focus group feedback says that *‘the Facebook group was useful’*, containing *‘a lot of information’*. Despite these benefits, there are obvious privacy concerns that make Facebook a less than ideal platform for communication and course delivery.

3.7. Resources

As a minimum, the course requires a camera for recording video, large SD memory cards (16 GB for audio, 64 GB+ fast for video), external hard drives and a laptop/PC with pre-installed video and audio editing software. Useful further equipment includes a tripod, light-reflector, a microphone and experimental equipment (depending on the type of video produced). A wide angle lens and/or a GoPro camera in additional to the main camera is extremely beneficial for filming laboratory environments.

We used Canon 600D/750D cameras with 18–55 mm lens and an Olympus LS-14 microphone (which required syncing microphone audio with camera visual) or a lapel microphone (meaning no syncing required, speeding up the editing process). A shot-gun microphone would be a useful addition, as the audio quality is one of the most important aspects of the film and very difficult to correct in post-production. We also had access to a standard four-colour (white, black, gold, silver) reflector and a Manfrotto tripod, as well as a GoPro for some sessions.

For editing, centralised data storage usually offered by universities are inadequate for video editing work; the hard drive of the physical computer or a fast external hard drive are required. We used Adobe Premiere Elements, an affordable video editing package that is a trimmed down version of the popular Adobe Premiere Pro package.

Narration and interviews need to be filmed in a quiet environment to enable good audio quality (this is very difficult to correct later). Staff and students should carefully consider the room chosen and the time of day.

The videos produced in the course will be licensed under the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License. Insurance for the film equipment should be considered. Each individual research group will be responsible for determining the health and safety issues associated with filming in their laboratories.

Some resource management system to manage borrowing of film equipment is required, though this can be quite informal.

3.8. Representation

It is very well known that the number of male physicists far outweighs the number of female physicists, particularly in more senior career stages; for example, the American Institute of Physics data analysis [35] shows only females represented just 14% of US Physics faculty members in 2010, though numbers are trending up. In our course, we actually discuss issues like this with students in humanities-style discussion sessions, described and analysed in McKemmish *et al* [36]. This male dominance can discourage young girls and women from pursuing physics as a career; it is crucial to us that we do not contribute to this with our videos. Unfortunately, from our experience, ensuring female representation in the videos is something that must be actively sought rather than relying on this naturally developing.

We recommend:

- Actively recruiting females as film consultants
- When students determine an interview list, check that this includes at least one female scientist and requiring students to find someone if it does not
- Encourage female scientists to be interviewed; though this is of course a generalisation, many females (including the science expert on this course) feel self-conscious about being interviewed—it is important to support females through this by, for example, offering that they can review the footage and remove anything they dislike, discussing the personal and wider benefits of their participation and, most importantly, listening to the individual and trying to address their concerns
- Include more junior researchers, particularly PhD students and post-docs
- If the particular research area is very male dominated and you cannot find a female in the specific field willing to be interviewed, ask female scientists from related areas to introduce the topic or provide introductory definitions

From the student side, we actually were fortunate enough to not have significant issues. We had generally equal female and males in our course (in the first course, women outnumbered men two to one) and some women were willing to narrate.

We look to apply similar principles to other under-represented groups, though our sample size thus far is too small to be indicative; it is worth noting that diversity in student narrators was much easier to achieve than diversity in interviewed scientists. Selecting diverse scientists is something we are striving to improve, however. The positive influence of representation can be summed up best by the example of Stephen Hawking, a household name who has done an absolutely phenomenal job of demonstrating that people with disabilities can make an immense contribution to science.

4. Assessing the course

4.1. Methodology

When analysing this course, we used a formal focus group ran by an uninvolved staff member after the first pilot course, classroom observations, course documents, the course Facebook page and emails between the course developers. Further, the course developers, teachers and some participating students from the pilot course are co-authors of this paper; their experiences shape the whole article.

4.2. Narration session

Students highlighted that practical experience of narrating meant they understood the importance of simplifying the science and the dialogue. Students discussed the difference between written and verbal communication: *'when you write something down ... it makes sense to you ... but actually saying it out loud ... it's just completely different. If it's wordy and you can't process [it], you can't get the words out...'*. There was also a discussion around how one can communicate in an engaging, enthusiastic way without seeming ridiculous and over-the-top.

One student remarked that they relished the opportunity to use equipment they otherwise would not have been able to afford. Students gained a greater appreciation for elements of film-making such as lighting and sound, which they did not believe was important before.

4.3. Interviewing

Interviews proved to be a crucial part of the independent videos. Students coped relatively well with the interviewing process, scheduling issues and location difficulties. They gained confidence in asking questions to scientists and learned how to make the interviewee feel comfortable (for many interviewees, this was their first time in front of a camera).

The biggest issue was that the interviews needed to be shortened significantly but students were very reluctant to cut footage, especially from scientists. Students should first cut all the 'umms' and 'errs', then cut full sentences, even answers when they are not necessary for the story being told by the video (even if they are interesting!). Learning how to cut without losing vital information is an important transferable skill to other written and verbal communication mediums. This problem was exacerbated when the student interviewers asked many untargetted questions. There needs to be a balance between promoting student enthusiasm and ensuring students do not become overwhelmed during editing and produce focused videos.

4.4. B-roll sessions

The initial B-roll session was well received, though more time was required than anticipated. In general, it was difficult to encourage physicists to imagine creative B-roll. For example, in the middle of a teaching laboratory, students expressed the belief that they could not do any experiments. Students were generally more confident with hand-drawn animations and had to be encouraged to try the more artistic types of B-roll. This carried on to their independent video, which generally contained limited B-roll. Instructors need to be pro-active in encouraging different types of B-roll—prior research of classroom experiments and bringing props to class can help.

Some examples of B-roll produced by students includes:

- Running footage of a ball going down a ramp backwards to demonstrate a particle trying to escape a potential well
- Colliding billiard balls with coins to illustrate the use of photons to slow down atoms
- Students, representing different coloured photons, moving across a classroom with some 'absorbed' or 'slowed down' by string material in the middle of their route

An interesting and unexpected consequence of the artistic nature of the B-roll session was that it forced students to view the science from a different perspective. For example, when asked to illustrate the sample script using people, students became very involved in a debate over the similarities and differences between absorption of light by molecules and refraction by a prism. They understood each concept individually, but had never been asked to actively illustrate these concepts, let alone side-by-side. This sorts of opportunity demonstrate the benefits of the course in deepening the student's scientific understanding. It is important to allow the flexibility and time for these important teaching moments.

Students were often concerned that by simplifying a concept (particularly via B-roll) they would over-simplifying to the point where there was incorrect physics. This reflects the conflict between the scientific training to look at the details and the needs of clear communication to simplify and get across the main point. These sorts of skills are needed whenever physicists communicate, e.g. at talks and in papers.

4.5. Editing sessions

Editing proved difficult for some students, particularly those less confident with computer skills. Formulating and focusing on a set of basic skills (listed above) helped. Once these basic skills had been taught, students were able to perform more advanced tasks by either (1) looking through software menus, (2) 'Googling', i.e. searching for the answer online or (3) asking the film expert. Students also requested to learn more about animation; this is unfortunately generally a quite substantial course in itself that cannot realistically be included in this type of course.

It is important to teach the basics of copyright law and to direct students to music and images in which the copyright allows reuse with modification for commercial purposes. YouTube Audio Library is a good source of royalty free music and Google Images search now has an option to filter results by usage rights.

Audio quality was one of the most challenging and persistent issues. It is possible to use a separate microphone and sync the microphone audio to the video visual using a clap. However, we found it much easier to use a lapel microphone that feeds directly into the camera. Editing can fix some audio issues, but this is very difficult and usually needs to be done by our film expert. Attempts to teach students how to do this often resulted in more audio issues that were quite difficult for the film expert to correct. The advice we have is two-fold: (1) ensure the room where interviews and narration were filmed is sufficient quiet and (2) add low-level background music to the film—this will cover most minor audio issues and actually improves the video. Some physicists are reluctant to add music; we would recommend encouraging these students to at least try it—most responded with an enthusiastic 'Wow!'.

It is critical teachers are aware that students generally have significant trouble reducing video length and are particularly reluctant to trim (and, as is often needed, slash) interview footage, especially from academics. A preliminary screening, set time-limit and practical demonstration can help.

Students often had difficulties forming a coherent narrative structure, particularly with a large number of clips. Students should be encouraged to start the editing process by removing un-necessary or repeated parts of clips and delete useless files. In general, students then should produce a video skeleton with only narrative, interview clips and key experiments (this cut can be long), check that it makes sense, then cut as much as possible, then finally add the B-roll. Titles could be used to help structure the video during the initial stages. Students can also be encouraged to use physical tools such as storyboarding, sub-headings, post-it notes etc.

It is worth noting that students gain significant skills from the editing process even if they never edit another video again! Most notably, the process by which the video is taken from initial ideas to a skeleton to a finalised product is very similar to the process by which journal articles, lectures and reports are written, with many of the same techniques being useful. Students should be made aware of this relevance, particularly for future job applications.

4.6. Pre-production

Pre-production refers to the planning processes that take place before filming. Pre-production starts by selecting the overarching topic area, then brainstorming ideas to creating an exciting, interesting overall story including an exciting hook. Student then plan and refine the overall structure, write narration, select interviewees and prepare appropriate questions. Next, students must creatively imagine a variety of experiments and B-roll, and determine how to enact these ideas. Students must plan for their shoot, considering booking equipment, finding appropriate rooms and other locations and finding time-slots where all relevant people are available. Finally, students must do all the above collaboratively and iteratively in a team.

It is important that pre-production is treated as a serious component of film-making; good planning both improves the final video and greatly reduces the stress and length of the process. Students will generally need to be actively encouraged to take the necessary time and effort to engage in pre-production activities; creating specific times for review can help.

In our experience, physics students normally are quite good at including the science; the key is making sure there is a good hook and overall interesting story, and that there is creative and useful B-roll. Post-it notes, coloured markers, big sheets of paper, scissor and calendars are all tools that we have used to encourage good pre-production. Google docs or similar were also very useful for facilitating collaborations.

In the focus group, students discuss finding it difficult to produce a script that was *'interesting as well as informative'* and *'not that long'*. They noted that analogies were particularly effective; their best B-roll concepts often followed from these. For example, students compared laser cooling where photons hit an atom to a snooker ball being hit by ping-pong balls, then added B-roll of this.

4.7. Dissemination and publicity

The videos produced by the students are not intended to become simply lost in an archive of assignments; they are put on the Phys FilmMakers YouTube channel and publicised in as many ways as possible via social media and university channels. These same skills are important in research to maximise impact and ensure continued funding.

Dissemination is also important to fulfil another of the course's aims, i.e. to produce 'edutainment' videos that can be used for teaching and inspiration in both university and high school classrooms worldwide.

Locally, an end-of-term screening is the key dissemination activity. In the initial course, the course coordinator took responsibility for organising and publicising this screening. Due mostly to the late date, which clashed with summer holidays and work committments, almost half of the students did not attend. We thus recommend giving students the primary responsibility of organising and publicising this final screening, including selection of dates, publicity (newsletters, departmental calender, posters etc), venue and catering. This should increase the student's sense of ownership and thus participation and enjoyment.

5. Impact of the course

Participants felt more involved in the department community and experienced a greater sense of belonging. Students recounted they had *'no clue what's going on at UCL in terms of* *research until we actually went in and saw stuff there'*, finding that *'it was quite cool'*. Multiple students expressed their appreciation of the *'excuse'* that film-making gave them to *'to actually talk to people in your department'*, including PhD students, post-docs and eminent scientists. Students felt *'more confident'* and believed researchers would see them as *'pro-active'* and *'probably more interested in their subject than the average student'*.

In terms of scientific content, as many teachers and communicators have found before them, students noted that *'when you are actually communicating it to other people you get to learn a lot more.'*. When asked about how this course fitted into their degree as a whole, students seemed very positive about its complementary qualities: it *'expands on what you've learnt'* and provides an opportunity to engage in current research and *'meet the researchers that are probably making the [future] material for your course'*.

Students report learning about *'the filming and all the skills around that'*, for example, *'editing skills'*, *'how to write a script, how to actually use a good camera'*, how to use the reflector and *'the sound thing'*. Students commented that the course taught them about *'presentation and being able to talk in front of a camera'*.

Students found they developed significant transferable skills that would increase their employability. One student commented that *'I think trying to plan a scientific YouTube video is like trying to plan your life'*. Though it was difficult, students valued the opportunity for independence. *'Organisational skills, like... planning ahead, figuring out what you need to do when'* are a key, and often underrated, element of video production. The planning was deemed extremely important even *'if you don't follow it'*, because *'structure is really really important'*. Many students enthusiastically said that they underestimated the time requirements; computer issues were cited as one contributor, with difficulties with effective internal communication the other major contributor. Fortunately, students reported that they'd *'learnt an awful lot ... about working as a team'*.

Students emphasised their improved skills in visual and verbal communication, feeling that the course had adequately prepared them for using the emerging outreach tools for science communication, a trait valued by employers. They gained the ability to filter a diverse set of information, often quite technical, distill the essential elements and convert this into a hook or story. Some students remarked that this course provided a *'really good introduction'* to careers focused on the *'explaining side'* of science, such as in scientific policy, science journalism, teaching or outreach. These science communication skills saw long-term use with different students producing an additional summer video on researchers, a video instead of a conventional presentation for their final year group project, and a promotional video for a student-led Physics conference.

Perhaps one unexpected benefit of this course is the increased respect of science students to the sheer amount of hard work and skill required to make a video. Students grew to understand that there is *'a lot behind the scenes with filming'*, as well as realising how *'how hard it is to [say a script] word for word'*.

6. Challenges and moving forward

It is well established that a high degree of engagement is essential for the success of this type of active learning course [37]. However, as the course was voluntary and not-for-credit, there were significant motivation and commitment issues that were particularly problematic for the independent group video. Further, there was often competition between the course and assessable coursework, particularly final exams. To minimise these issues for this particular course, we propose:

(i) Careful student selection
(ii) The ability for students to 'drop-out' after the workshops
(iii) A frank up-front discussion of the required time commitment, coupled with a discussion of the course's longer-term benefits, and
(iv) Fitting the schedule around exams

The course could also be a compulsory component of the degree or available as an optional, credit module; this requires careful consideration of existing degree structures. Examination of videos could be difficult and/or subjective, but these issues have been successfully tackled by many (for example, in Science and Technology Studies and Science Communication programmes worldwide). A larger number of scientific consultants would be required; PhD students may be ideal. Making the course for credit may reduce student's desire to take creative risks.

The course can successfully work with students from different year levels, e.g. undergraduates and post-graduates; it is a great mechanism to allow cross-year mixing. We also promote PFM as an ongoing vehicle for staff-student engagement by supporting alumni students in making more videos on Physics, often using the PFM equipment and software. To help create and maintain this identify within the department and more broadly, we have branded the PFM program using clip-art figures.

7. Conclusions

Overall, the two-part PFM course structure outlined here was found to be a successful addition to the usual science degree structure. The independent video in particular was a valuable project that connected students with research and encouraged development of key transferable skills, in particular the ability to develop and communicate ideas concisely and creatively. The course was beneficial more broadly as it created videos that can be used as educational resources, scientific outreach and departmental promotion.

We invite you to check out our PHYS//FILM//MAKERS channel on YouTube. We end with one student's closing statement on the course: *'it was a lot of fun, very worthwhile'*.

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