

Millions and Billions of Views: Understanding Popular Science and Knowledge Communication on Video-Sharing Platforms

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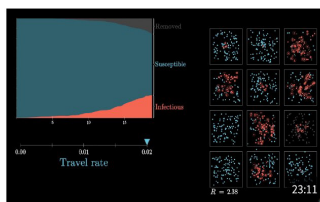
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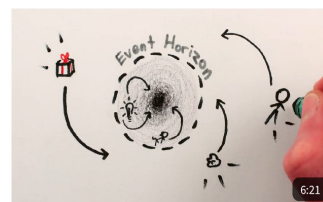
Why are 96,000,000 Black Balls on this Reservoir?
74,601,960 views · May 10, 2019 by Veritasium (10M subscribers)



The surprising pattern behind color names ...
5,844,469 views · May 16, 2017 by Vox (9.89M subscribers)



Simulating an epidemic
4,643,163 views · Mar 27, 2020 by 3Blue1Brown (3.91M subscribers)



The Unreasonable Efficiency of Black Holes
3,580,256 views · Dec 31, 2017 by minutephysics (5.37M subscribers)

Figure 1 Popular online science and knowledge communication videos explain knowledge to a general audience in a highly engaging manner, influencing millions, or billions, of viewers.

ABSTRACT

Science and knowledge communication is the process of informing and engaging the public about a diverse array of topics, such as science, health, philosophy, and history. Effective science and knowledge communication is challenging because communicators need to balance several factors, such as the complexity of topics, viewers' diverse backgrounds, and the characteristics of the medium. With the widespread availability of design tools and platforms to create and share content, laypeople can disseminate knowledge widely through online platforms. Popular science and knowledge communication video channels on YouTube, for example, have millions or tens of millions of subscribers, as well as millions or billions of accumulated views. Even with the growing popularity of science and knowledge communication videos, there is little understanding of the practices the creators use to make and increase the reach of their videos, the challenges they encounter while doing so, and how these videos impact viewers. This paper reports on interviews conducted with 27 creators of popular science and knowledge communication videos on YouTube and 13 viewers of these creators' videos. We present the motivations of creators and viewers, the practices creators use for broad science and knowledge communication, and the challenges encountered by members of the community.

CCS CONCEPTS

- Human-centered computing • Collaborative and social computing
- Empirical studies in collaborative and social computing



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KEYWORDS

Science communication, Science and knowledge communication, Informal learning, Online learning, Video-based learning

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1 INTRODUCTION

Scientific communication is the practice of sharing scientific knowledge with the public, raising awareness and interest in scientific domains, facilitating public discussions on important societal issues, as well as influencing people's opinions, behaviors, and policy preferences. The effective communication of scientific knowledge has had significant social and cultural impact [20][21][50][56]. It has stimulated public interest [50], generated support for research [20], and improved scientific literacy to better inform discussions about important societal issues such as climate change and global public health [37].

However, effective science communication is challenging due to the complexity of scientific methodologies and knowledge and the communication skills required to reach and engage audiences of diverse backgrounds [29][50]. Successful communicators are often domain experts (e.g., scientists) who communicate to the public in a captivating manner or professional information disseminators (e.g., journalists) who have sufficient knowledge about a topic. Carl Sagan, Richard Dawkins, and Bill Nye are popular science communicators who have used books [15][16], TV shows [53], and public lectures [27][70] to communicate with, and impact, billions of people around the world.

In recent years, new groups of communicators have arisen on online-video sharing platforms to share their understanding of domains beyond traditional scientific fields including the philosophy [57], film making [19], and politics [78], and more. With these emerging topics that do not fall within the traditional scope of science, it is pertinent to expand the notion of science communication to *science and knowledge communication* (SKC).

In this work, we study a genre of SKC videos which is often referred to as explainers [41][78] or video essays [19][62][80], represented by YouTube channels such as Vsauce [79], Kurzgesagt [41], Vertisum [77], Vox [78], 3Blue1Brown [1] (Figure 1). Despite their diverse topics and styles, creators of these channels utilize various techniques including storytelling and metaphors as well as exploit different types of multimedia to craft videos that describe, explain, and discuss knowledge of different domains in a highly comprehensible and engaging manner. Popular SKC video creators on YouTube, such as Veritasium [77] and Vsauce [79] have millions or tens of millions of subscribers as well as millions or billions of accumulated views, demonstrating their capability to reach and influence audiences around the world.

Yet, with the growing impact of SKC videos on video-sharing platforms, little is known about the unique practices, challenges, and opportunities of this emerging and rapidly evolving medium. This raises important research questions about:

- Who is this emerging group of SKC video creators and what motivates them to engage in SKC activities?
- What practices do these creators employ to reach and engage with millions and billions of viewers?
- How are SKC videos consumed and perceived by viewers?
- What are the challenges and opportunities in this emerging ecology of SKC on online video-sharing platform?

To address these questions, we conducted an interview-based study with 27 creators of popular SKC videos on YouTube and 13 viewers of SKC videos. The results helped identify characteristics of SKC videos that differentiate them from other types of science communication and online learning content, as well as common communication practices that creators use to intrigue and engage audiences on YouTube. Specifically, we found that the majority of SKC creators are neither domain experts nor professional information disseminators, but rather enthusiastic learners motivated by their intrinsic desire to learn and share. Effective SKC videos were also found to have a low floor due to the attention they require viewers to devote to understanding the content they present, yet a high ceiling due to the education and entertainment value that they offer. As a result, SKC videos enable viewers to obtain a desired mix of intellectual satisfaction and entertainment based on the amount of attention viewers can devote in different contexts, thus enabling audiences from diverse backgrounds to consume videos in a variety of ways. In addition, our work not only confirmed previous findings of the disproportional number of female science communicators on YouTube, but also uncovered concerning female viewership trends for SKC videos on YouTube, ranging from as low as 1% to as high as only 20% for channels with millions of subscribers and tens of millions, and even billions, of views.

This work thus contributes an interview-based study that uncovers 1) the motivations of the emerging group of science and knowledge communicators on the YouTube platform, 2) the unique practices of SKC video creators, and especially how they differ from other forms of SKC content (e.g., science documentary and TV shows) and educational videos (e.g., online courses and instructional videos), 3) viewers' consumption and perceptions of SKC videos on YouTube, and 4) challenges that hinder the sustainable and balanced development of this ecology. We further discuss and provide insights into future research and community actions that can foster thriving, enthusiast-led, large-scale science and knowledge communication.

2 BACKGROUND AND RELATED WORK

This research is informed by prior work on science and knowledge communication, online educational videos, and educational entertainment.

2.1 Science and Knowledge Communication

Communicating scientific knowledge effectively is challenging, as communicators need to consider the complexity of domain knowledge, the diverse backgrounds of their audience, the need to build credibility, as well as the complexity of communication environments [29][50]. Given these challenges, traditional science communication content has been created and curated by scientists and journalists who acted as gatekeepers for such content [67]. Past and popular models of science communication, including the deficit model—transmitting factual scientific information to the public [7][26], the dialogue model—scientists explaining their work in a comprehensible manner [46], and the public engagement model—including the public in scientific activities [46], all focus on relying on scientists and journalists to initiate the communication with the public [23][70][71].

Recently, there is a growing diversity of forms and people who partake in science communication enabled by the internet and digital media, such as blogs [3][52][62], social media sites [61], video platforms [10][33][35][80], and online forums [36]. Jones et al., for example, studied the largest science discussion forum on Reddit (i.e., r/science subreddit) and found that despite the platform's participatory nature, participants were primarily those who were already interested and invested in science and scientific activities [36]. Prior research analyzed several factors of science communication videos on YouTube, such as views and subscriptions, and found that user-generated videos were far more popular than those produced professionally by corporations and institutions [80]. However, the rapidly evolving online media environment has further broadened the practice of communicating knowledge within several domains and reaching millions and billions of viewers [19][82]. The widespread reach these creators have is the primary motivation for this work. We seek to understand what drives these creators to communicate knowledge, how they decide on the domains to communicate, their process of communicating, and how the resulting content is consumed by viewers. Findings to these questions will further promote SKC activities using online video-sharing platforms, fostering scientific literacy and cultural growth within society.

2.2 Online Educational Videos

Online video-sharing platforms, such as YouTube [68], are prominent media that enable millions of creators to create and share educational content with billions of people. A recent survey conducted by Kross et al. found that YouTube has become the most frequently used educational resource for online learning compared to informational articles, how-to guides, and online courses [40]. Significant research in HCI, CSCW, and L@S has examined the unique practices, challenges, and opportunities of promoting educational videos with different forms, styles, and topics [9][45], among which curriculum-oriented and problem-oriented videos have received the most attention.

Curriculum-oriented videos refer to a series of videos that seek to systematically disseminate knowledge from a domain. Formal online courses such as MOOCs [14], Khan Academy [38], and Skillshare [69], as well as user-generated videos that follow a curriculum structure on video-sharing platforms, fall into this category. The subjects and formats of these videos range widely, from recorded lectures in computer science [13][31] to extra-curriculum livestreams for learning second languages [43]. Viewers often consume such content to fulfill their current educational needs, improve job prospects, and satisfy their own curiosity [32][84]. Given the clear educational benefits for viewers and society, research has explored ways to improve the effectiveness such videos. For example, Guo et al. explored production techniques that can increase student engagement [30]. Among the 30 principles that video lectures should follow to facilitate comprehension, identified by Clark and Mayer [12], Oakely and Sejnowski found that presentation styles and instructional methods are key factors contributing to the popularity of MOOCs [54].

Problem-oriented videos refer to videos that cover the necessary knowledge and skills to answer questions viewers have or help them complete a task, such as how-to videos [28], tutorial or instructional videos [49][59]. The subjects and formats of such videos vary widely, ranging from physical tasks with demonstrations to animated presentations to talking heads. In particular, how-to videos were reported having the most attention of any content category on YouTube [28], which is perhaps the reason why significant research in HCI has explored techniques and systems to facilitate the creation [11][49] and consumption of such videos [25][39][41][59].

While SKC videos are educational in nature, they differ from the prior categories as they do not provide immediate practical, economic, or academic benefits to viewers [44][47][79][82]. These videos also exhibit different characteristics compared to the former categories, such as the use of enticing titles rather than descriptive titles used with how-to videos and their focus on curiosity-inducing phenomenon and events rather than on domain-specific knowledge. As our results show, viewers found these videos contain a considerable amount of educational value and spent significantly more time watching these videos than other types of educational videos. Our work seeks to identify the key differences between SKC videos and other types of educational videos from both creators' and viewers' perspectives.

2.3 Educational Entertainment

Educational entertainment (edutainment) refers to the practice of educating people through entertainment [4][55], such as through dramatization [4], gamification [4], TV shows [65], documentary films [48], animations [76], as well as audio and radio [5]. Edutainment can attract learners' attention and reduce the apparent complexity and difficulty of the concepts being conveyed, thus facilitating the educational and learning processes [4][55], making it an effective method for communicating knowledge to the public.

Recent work that studied different forms of online educational videos found that highly engaging educational content can occasionally serve as entertainment for its viewers. Fraser et al. found that viewers of livestreams on music, crafts, or other performing arts learned artistic skills and were entertained [24]. Zheng et al. found that high-quality MOOCs on history, music, and art can be entertaining to viewers when they satisfy learners' personal interests [84]. While edutainment can increase engagement, research also argued that the focus on entertainment can hinder meaningful learning which inevitably requires cognitive effort [55], and further enhance the perception that learning is an unpleasant experience [65].

Significant research has explored ways to increase the engagement of educational content. Guo et al. found that videos where instructors speak fast with enthusiasm were more engaging [30]. Dixson found that interactions between peer learners and instructors can also increase student engagement [17]. As our results will show, SKC videos on YouTube are highly engaging for viewers and are consumed for their educational and entertainment value. Beyond the identification of common strategies that SKC video creators use to increase viewer engagement, our research seeks to uncover the unique communication practices that SKC video creators employ on a highly competitive media platform to attract and engage millions and billions of viewers, as well as viewers' reception and perception of the highly educational and entertaining content.

3 STUDYING SKC VIDEOS

To understand the growing prevalence of SKC videos on online-video sharing platforms, and specifically answer the research questions mentioned earlier, we conducted semi-structured interviews with creators and viewers of SKC videos on YouTube. These interviews sought to understand the creators' motivations, and communication strategies, as well as viewers' consumption patterns and perceptions of videos and their creators. We were also interested in discovering challenges that hinder the development of this emerging ecology.

3.1 Data Collection with SKC Video Creators

Semi-structured interviews were conducted remotely via Zoom with 27 creators who published SKC videos on YouTube (Table 1; C1-27). Prior to the interviews, creators completed an online form about their demographic data. Each interview lasted approximated 70 mins and probed how the creators started to create YouTube videos, their motivations for creating SKC videos,

their topic, style, and workflow, the steps they have taken to broaden their impact, their career on YouTube, how they interact with their audience, the challenges they have faced, and their views about using YouTube for SKC activities.

To recruit SKC video creators, the research team started by viewing popular SKC channels (i.e., minutephysics [47], Vsauce [79], Physics Girl [58], etc.) and then viewed other channels that

the creators were associated with using the “Channels” tab on their YouTube channels. For example, the “Channel” tab on minutephysics listed 16 similar channels.

Because we wished to gain an understanding of both the successful practices that helped attract a large audience as well as the challenges faced by creators at different stages of their channels, we selected creators with more than 10,000 subscribers (i.e., less than 5% of all YouTube channels [74]) as of January 2021 and more than 2 years of experience. In total, 180 creators were identified and contacted via email, and 27 (Male=24, Female=3; USA = 20, Canada/India = 2, India = 2, Australia/Germany/UK = 1) voluntarily accepted a request to be interviewed. Their channels covered a variety of topics including engineering, film, history, science, politics, culture, and others. Interviews were recorded and transcribed using Descript. We acknowledge that this sampling procedure does not yield a set of representative samples that reflect the entire SKC landscape, which we discuss in detail in the limitation section.

The research team watched 5-10 videos from each creator prior to their interview to become familiar with the creator’s content and inform focused questions about their content, practices, and community. Prior to the interview, some creators also shared videos with the research team about their creation workflow that they had previously published.

Table 1. The demographics and backgrounds of SKC creators. The subscribers and views are presented in millions and current as of September 2021.

ID	Subs (m)	Views (m)	Years	Topic Domain
C1	9.88	2,609.9	8	History, Misc. Facts
C2	0.390	80.0	10+	History, Politics
C3	10.0	1,234.0	10+	Engineering, Science
C4	0.09	1.4	3	Media Theory, Politics
C5	3.03	479.5	9	Culture, Philosophy
C6	2.02	132.4	6	History, Philosophy
C7	0.12	5.2	4	Culture, History
C8 (F)	2.6	363	10+	Science
C9	0.60	156.3	10+	History, Politics
C10	0.13	9.1	7	Culture, Film
C11	0.27	72.1	7	History, Geography
C12	0.87	32.2	10+	Physics
C13	1.39	54.4	5	Culture, Film
C14	2.10	103.3	6	Health, Medicine
C15	0.41	21.0	4	Finance, Investment
C16	0.62	29.5	4	Philosophy
C17	5.37	484.8	10+	Physics
C18	0.14	8.0	7	Neuroscience
C19	0.23	15.6	7	Health, Science
C20	0.02	1.5	7	Health, Science
C21	0.30	16.4	6	Music Theory
C22	0.30	22.0	8	Culture, Film
C23	0.26	16.1	6	Culture, Film
C24	0.22	22.9	9	History
C25	0.06	4.8	8	History
C26 (F)	0.22	6.3	9	Physics
C27 (F)	0.58	35.7	8	Self-development

Table 2. The demographics of SKC viewers.

ID	Education	Age	Consumption	Motivation
V1	College	21	A few times/day	L & E
V2 (F)	Postgraduate	24	A few times/week	L
V3	Postgraduate	26	A few times/day	L & E
V4 (F)	Bachelor’s	23	A few times/week	L & E
V5	College	25	A few times/day	L & E
V6	College	19	A few times/week	L & E
V7	College	21	A few times/month	L & E
V8	College	22	A few times/week	L
V9	College	26	A few times/week	L
V10	College	27	A few times/week	L & E
V11	Bachelor’s	54	A few times/day	L & E
V12	Postgraduate	34	A few times/day	L & E
V13 (F)	Postgraduate	39	A few times/month	L & E

3.2 Data Collection with SKC Video Viewers

Semi-structured interviews were conducted to understand viewers’ goals, consumption patterns, and perceptions of SKC videos. Thirteen viewers (Table 2; V1-13; M=10; F=3; Age: 21-54, Mean = 28 years, Std = 3 years) were recruited through ads posted within a comment or part of the description of a video by a video’s creator, inside Reddit threads associated with the content creators’ channels, and on Discord servers hosted by creators. Interviews were conducted remotely using Zoom. Each interview lasted approximately 50 mins. All interviewees were provided with a \$15 honorarium for their time. All interviews were recorded and transcribed using Descript.

3.3 Data Analysis

Two separate thematic analyses were performed using the interview transcripts from creators and viewers. Two authors began independently open coding the responses to create sets of plausible codes, and through iterative discussion, agreed on a single coding scheme. The themes were conceptualized based on the codes to examine the complex web of factors underlying the process of SKC. A third author then reviewed the codes and the categorized themes, and refined codes and categorization of concepts. In the findings section, ‘C’ denotes creators and ‘V’ denotes viewer interviewees.

4 FINDINGS

The thematic analysis revealed the main motivations of creators, the practices they employ to attract and engage with their audience, the consumption patterns and perceptions of viewers, as well as the challenges faced by the SKC YouTube community.

4.1 Science and Knowledge Communication

While the first group of channels we used as seeds to identify the channels covered topics on science, engineering, and technology, the scope of topics expanded beyond traditional domains of science communication to domains such as film, philosophy, history, music, and more, when following the connections among the channels. Despite the diverse topics, videos of these channels employ a common communication style that they describe and explain standalone pieces of knowledge of a domain in a highly compact, accessible, and engaging manner.

Burns et al. defined science communication as “*the use of use of appropriate skills, media, activities, and dialogue to produce one or more of the following personal responses to science: awareness, enjoyment, interest, opinion-forming, and understanding*”, and acknowledged that defining the scope of science is challenging in the context of science communication [8]. As our findings will show, the creators shared the goal of traditional science communication in terms of the personal responses they wished to invoke to the knowledge domains that they cover [8].

Therefore, we built upon Burns et al.’s definition and expanded its scope of topics to any knowledge domains, and hence the term Science and Knowledge Communication. We have explored using other terms to refer to the genre of content being studied. For example, while knowledge communication rhymes with science communication, it often created confusion about the practices and goals (e.g., raising awareness and interest vs pedagogical). In contrast, the term Science and Knowledge Communication latches on a familiar term, which facilitates the explanation and understanding of the term itself.

4.2 Motivations of SKC Video Creators

Our results showed that most of the SKC video creators were neither scientists nor domain experts who were invested in their domains. They were also not journalists or news outlets that curated and disseminated content. They are enthusiastic learners motivated by their intrinsic desire to learn knowledge of different domains and share the learned knowledge with the viewers to make positive impacts on their lives. Among the 27 creators we interviewed, 8 had graduate degrees, with 3 of which primarily producing content in the domains they studied. The interviews revealed 3 main motivations for creating SKC videos.

4.2.1 Creators’ Intrinsic Desire for Learning and Sharing their Learned Knowledge Publicly

All creators were initially motivated by an intrinsic interest in a domain and the desire to share the knowledge with a broader audience. Since the creators were not necessarily domain experts, they often communicated knowledge as they learned about it. As C20 described “*the starting of the channel really was for selfish reasons. I am just enamored with learning, so... I thought to myself why not share this with the public?*” For C17, the process of creating videos was tightly connected with their own learning process, i.e., “*I am making [videos] also for myself to understand these [concepts about physics]*”, so that videos “*actually answer my own questions*”.

Sharing the results of what they learned as a video with the public means that the video will be scrutinized by millions of viewers, which motivates creators to fully understand the topic. C26 reported that this is an energizing experience for her, “*when you make a video, you can't hide or pretend that you know things because people are going to ask you questions. If you get something wrong, people are going to comment on it. When you're writing the video you realize very quickly which parts of your understanding are a bit shaky. It's very good for actually being able to understand something well to be thinking I'm going to make a video about it. When I was making videos like that, I found it very energizing*”.

4.2.2 Impacting Viewers’ Wellbeing and Behavior

Disseminating knowledge in a way that can impact an audience’s wellbeing, behavior, and attitude is another source of motivation for creators (N=8). As C19 noted, they consider “*how can [they] give [their] audience something that will be useful in their life or help solve a pressing problem*”. Different from how-to videos that provide immediate solutions and guidance, C19, who covers topics in health, noted that their goal is not to provide knowledge “*with the expectation that you're then going to go and use that knowledge to do something usually. [instead] I'm more just teaching you it so you can apply it to your life and like maybe a more abstract way*”. C24 seeks to “*foster good public history discussion...and public understanding of history ... [as] a methodology*”. C27, who communicates knowledge in psychology, reported that her goal “*is really to bridge the gap between what exists in research and what people know about and how that can impact their everyday lives and wellbeing*”. She focused on creating videos that can “*change attitudes and behavior because knowledge doesn't really have like a huge impact on how people think or act*”.

4.2.3 Helping Viewers Gain Knowledge in a Domain

Creators were also motivated to provide useful knowledge and information to their audience (N=6). To fulfill viewers’ needs for information and knowledge, creators selected topics that they believed would be helpful for viewers, solicited topics from viewers, and found topics that had an existing demand. For example, three creators “*position the videos for topics searched [by the viewers]*” (C16) by using search term research tools such as TubeBuddy. This was mentioned as being also beneficial for creators, as videos that respond to existing demands can often attract more views.

While it is in the financial interest of creators to produce videos that broadly appeal to a general audience, creators whose channels have become extremely popular still create videos about niche topics or that can provide significant benefit for a smaller audience, even if doing so results in poorer YouTube metric performance and thus lower revenue. C7 noted, “*there's a small, dedicated audience that likes those videos. Personally, that is the reason that I started the channel, so I stick with that*”. Creators “*take pride in knowing that their videos are used in classrooms*” or “*are licensed to be used as part of digital textbooks*” (C8).

4.3 Communication Practices of Creators

While the creators enjoy YouTube as a medium for SKC—“it’s so accessible. I mean, people are on their phones, just like scrolling through, and this is a good moment to get them” (C26), it is also challenging for creators in that their content must appeal to a general audience when juxtaposed against other attention-grabbing entertainment content on the platform (e.g., comedy, sports, gaming, drama) and sustain viewers’ attention throughout the video. The interviews revealed several communication practices that are commonly used when designing informative and engaging videos, such as using storytelling techniques [22][35], using an engaging tone [6][30], employing effective visual communication techniques [22][75], and building trust with viewers [17][34]. We report on the unique communication practices SKC video creators employ to enhance video informativeness and engagement.

4.3.1 Spark and Sustain Viewers’ Curiosity

To attract a broad audience, creators reported that one of the most important practices was to spark viewers’ curiosity towards their content (N=20). While some topics have greater intrinsic appeal to general audiences, “people are very passionate about, and wanting to know more” and “are actively searching information on these topics” (C19), many other topics do not naturally attract a large group of viewers. Despite this, creators recognize that “people are curious about things and want to understand things” (C26) so it is important that the creators pose content in an interesting way to viewers. C2 covered topics that were “curiosity-based” so they “come up with ideas that [they] know people will be interested in”. C25 noted that many educational and adjacent channels were also described as “curiosity channels, CGB gray was one of these curiosity channels, Wendover productions, a lot of other similar ones like that”.

Creators in the domain of science and engineering often employ an *inquiry-oriented structure*, often referred to as an explainer, that starts with a “question [that] is gripping enough” (C1) that viewers want it to be answered. The inquiry and explanation process helps “form a narrative” throughout the video, which includes conducting experiments, interviewing domain experts, reviewing literature, and so on. Viewers who watch the video are “rewarded” by the “reveal process” (C1) and the answers to the question serve as “an ‘aha moment’”, which is “intellectually satisfying [for viewers]” (C3).

Creators in the domains of culture, film making, history, music, and philosophy, tend to employ a *commentary-oriented structure*, also often referred to as a video essay. Topics in these domains are more “subjective [than science]” and the interpretation of the content varies from person to person (C21). To make the content broadly appealing to the public, creators often communicate knowledge through a commentary and analysis of other cultural elements such as popular films, TV shows, games, and books. Through the dissection of this content, creators introduce specific domain knowledge to the audience and often go in-depth on certain topics. C21 often brings in “case studies of specific games and what their sound or their soundtrack does

particularly well and then use that to explain some broader concepts about audio or sometimes music theory”. C23, for example, will “sometimes schedule videos [about a film director] to coincide with a new film [from the same director] being released”.

To capture viewers beyond those already interested in their topics, one creator noted that “the thumbnail and title... are so important to the eventual success of the video” (C3). C3 mentioned that they often spend “almost like a literal day or two” on the titling process so that the titles and thumbnails are captivating enough to attract their audience and new viewers. C27 also noted the importance of having a good beginning to their videos to set up the story, as a video “can have the best title and thumbnail in the world, but if you don’t have a good like 30 to 60 second introduction, people are just going to click and watch the first 20 seconds and be like this is weird and then leave”.

The goal of sparking and sustaining curiosity in a broader audience separates SKC content from other types of educational content that people consume based on their own needs and interests such as knowledge-sharing livestreams, online courses, and how-to videos, e.g., “Not because they were curious about that specific topic before, because of the fact that video would just have a catchy topic or title to it. I don’t know if are true, like there’s two different kinds of education. If you think about it” (C19).

4.3.2 Engaging Both Enthusiasts and Neophytes

While one may assume that targeting an audience with no background knowledge can lead to accessible content that can reach many viewers, creators found that videos produced in this fashion often do not attract more views (N=6). For example, C3 “tried to make things for people who are complete neophytes to science and that wasn’t a very successful strategy because the people who were totally neophytes didn’t want to watch a video about science. I was trying to reach an audience that didn’t want to be reached or maybe didn’t even exist”. On the other hand, when videos were designed to “engage science enthusiasts, they often reach a bigger audience and ended up reaching more people who are neophytes than if you targeted them specifically. So, my strategy has almost been to like target the enthusiasts and have that sort of reach bubble over into adjacent communities which would be less engaged with science” (C3).

This strategy conforms with how YouTube recommends content [18]. Since subscribers of a channel are often enthusiasts of a domain and part of the initial audience, videos need to perform well in terms of view metrics (e.g., retention) to be recommended to a broader audience. As such, content that is not intellectually engaging with enthusiasts may not break out of the circle of a creator’s subscribers. On the other hand, creators need to describe complex concepts in a high-level and accessible way such that the content can be appreciated beyond enthusiasts. C17 mentioned that he makes videos that are “accessible to third graders and also interesting to somebody who’s like an expert in the subject...it works in different levels. I find satisfaction in having seen somebody say, oh, this is super entertaining, if they’re like expert in the field, or this is the best explanation of this I’ve ever seen. Or

somebody saying, wow, I never understood this until now. Those two things can happen on the same video.”

As mentioned earlier, creators share the knowledge as they are learning it, and some creators reported that their own learning experiences can help them better engage beginners. C26 who holds a Ph.D. degree in quantum physics and has made educational videos on topics she is an expert in reported that “*actually pretty often it was the videos when I was learning something for the first time that people found it helpful...because I think when you're a beginner yourself and you've just learned this thing, you understand exactly the way to see it that a beginner would understand it, whereas if you know the subjects super well you don't quite understand what it is that people find confusing. I think that actually you're a better teacher when you're only a little bit ahead of the students*”.

4.3.3 Keeping Content Authentic, Casual, and Personal

Creators (N=8) also reported that making content that is authentic, casual, and personal can often lead to increased video popularity and is also the key differentiating factor that separates SKCs videos on YouTube from other forms of SKC videos such as science documentaries and TV shows.

Creators commented that the casual style of SKC videos on YouTube enables viewers to better engage with creators and their content. As C3 noted, “*because YouTubers just have limited production ability ... but the jump cuts and things just give the video a different feel. The shaky footage and things that are out of focus, it's part of like, we were there. You want to feel like you were there and that person you're connected to them. And they're not separated from you either by space or by status or anything like that. It's about having a casual and collegial conversation*”. C26 further pointed out that the difference between SKC videos and common science documentaries and TV shows was that “*when you watch a documentary, the script was written by like 10 people who are working on this for weeks. Everything is manufactured. Every shot is perfect, and everything is planned to the teeth, whereas YouTube is not like that. Often, they just wrote down the script yesterday and now they're like reading it out, and it's really them talking and it's really something that they were interested in, and no one else was involved. It's more a more authentic medium*.”

C27 noted that “*a personal question that drives the videos tend to be more popular than ones that are just like explainers*”, as “*the personal drive builds a narrative around a topic that is much more compelling than like a TED-Ed style explainer*”.

4.4 Consumption and Perceptions of SKC Videos

Interviews with viewers found that the main motivations for viewers to consume these videos were for learning and entertainment. The communication practices that creators were using also created a unique category of content for viewers.

4.4.1 SKC's Unique Position in the Landscape of Learning and Entertainment

All viewer interviewees reported that they watch SKC videos for learning purposes and 10 out of 13 reported that they also

consume them for entertainment purposes (Table 2). Viewers thought that SKC videos occupied “*the extreme ends of that spectrum from entertainment to education on both of those extremes*” (V6), in comparison to other types of educational and edutainment content such as documentaries, TV shows, online lectures such as Khan Academy videos, or MOOCs.

While many online course videos, such as Khan Academy videos and MOOCs, are also designed for the public, viewers reported that they watch educational videos when they have an immediate need to look for answers for “*an example or a homework problem*” (V4), “*specific to [their] job*” (V13), or to “*get certificates for [their] resume*” (V3). V4 noted, “*for videos from Khan Academy... I don't watch those for enjoyment*”. On the other hand, viewers perceived SKC videos to be of high educational value. V10 said they “*come out of a video in the same way I come out of a lecture that I really enjoy. I think there's a scale where the most detailed ones are really fulfilling academically. And they are, truly. It is being taught like you would in school, but they just happened to be the best presenters, which is why they're popular*”.

When compared with traditional science communication content such as documentaries and TV shows, viewers found that SKC videos offer more educational value. V7 noted that “*science documentaries don't want to go into too much detail because they have to serve the least common denominator*”, whereas SKC videos “*don't want to dumb things down, so they put some technical stuff in there and the technical stuff can often be what's the most interesting thing*”.

The high educational and entertainment value that SKC videos offer shows that they occupy a unique position in the grand landscape of online education and entertainment medium. V12 quoted media theorist Marshall McLuhan, i.e., “*anyone who draws a distinction between entertainment and education doesn't know the first thing about either*”. This is similar to C17's belief that SKC videos “*can be engaging without just purely being entertaining*”. V4 has two YouTube accounts, a “*causal*” account and an “*educational*” account “*used mostly for when I was in school and I was trying to find extra videos like more lecture style videos to keep track of*”. They reported that “*I just wanted them separate because they were two separate things in my mind*” and “*I'm subscribed to those [SKC videos] on both of my accounts*”.

4.4.2 Flexible Viewing Behaviors Enabled by SKC Videos

In contrast to the common purposes of viewers for consuming SKC videos, they reported a diverse range of viewing behaviors. For example, V1 and V6 reported that they often watch SKC videos as they play video games, i.e., “*it's probably 60% of the time I have the video on one half of my monitor and then a video game on the other half*”. V8 reported that “*sometimes I'm watching the more serious ones, I am probably cleaning dishes, just because I want to have those facts*”. V10, on the other hand, “*usually give my full attention to it. It's something I do when I don't have any work I want to get done, and I can block out time usually before bed*” because “*you don't really end up consuming and processing the information*” so they focus all their attention on the video even they are watching for entertainment.

The different levels of detail that creators provide in their videos, their accessible communication styles, the flexible duration of the videos, and the high educational and entertainment value of videos enable viewers to consume the content in a variety of contexts for educational or entertainment purposes. As V5 noted, *“often I’ve watched videos because I think, oh, that is an entertaining way to spend 10 minutes or an hour of my time”*. The different viewing behaviors demonstrate that SKC videos have a low floor for the attention needed to understand the content and a high ceiling for the educational and entertainment rewards. As a result, viewers can obtain their desired mix of intellectual satisfaction and entertainment with the amount of attention they devote in different contexts. This also aligns with the creators’ expectation of how their content being consumed. 3Blue1Brown, a SKC YouTube channel covering mathematic topics [1], describes the channel as *“some combination of math and entertainment, depending on your [viewers’] disposition.”*

4.4.3 Reception of Knowledge, Enjoyment, and Passion from SKC Videos

All viewers reported SKC videos contributed to their overall level of knowledge, e.g., *“it has made an impact on my overall knowledge of how things work”* (V10). V1 mentioned that the SKC videos he watched served as *“the gateway”* to other types of educational content. While the videos were often viewed for entertainment purposes, the knowledge that a viewer could acquire made the entertainment more justifiable because *“the entertainment is educational”* (V12) and the *“highbrow content [made them] feel more inspired to subscribe”*. V3 mentioned that consuming SKC videos is *“good for people to keep an open mind ... to continue learning and to build their own knowledge. I think that just helps society become better and more educated, because most of the time, any conflict is just because people are uneducated or ignorant about topics”*.

The viewers also reported that they enjoyed the distinctive style each creator has (N=7). When asked about their preference for certain channels over others, viewers reported that creators’ own passion and personality were key factors driving engagement, as viewers can *“feel [the creator’s] passion through it [the video]. And so you can’t help but be engaged in it”* (V9). Similarly, V10 reported that *“these people are just really passionate and you can tell they love it and it’s like spreading to me”*. On the other hand, viewers were not as engaged with channels if the channel used a *“disembodied voice”* or if the content felt *“too scripted”* (V6). Creators’ personality and their communication style form distinctive brands that viewers appreciate, *“even though the channels seem very similar, they have these little intricacies. ChemicalForce you just want to see the pretty reaction, but Explosions&Fire is probably the funniest, while Nile Red is very professional, and his videos are very clean”* (V4). On the contrary, other types of SKC content, such as documentaries and TV shows, despite having high production value, lacked the personal feelings viewers enjoyed. As V7 noted, *“in a documentary there’re thousands of talented people working around the clock to try and get a beautiful piece of content produced but because there are so many hands on the project, it feels like there’s less of a distinctive voice”*.

These findings show how SKC videos on YouTube can produce the five categories of personal responses Burns et al. defined for modern science communication, i.e., awareness, enjoyment, interest, opinion-forming, and understanding [8]. However, this does not occur without challenges. As V10 mentioned, the knowledge they acquire *“is very scattered ... it’s like a million little things you’re learning”*. While V7 found SKC videos require *“a little bit more active thing”*, for V3, the high accessibility also has negative effects, *“it’s very difficult to internalize every single piece of content that’s in a video. It’s the content that’s really packaged up and tidy so your brain is really able to process it like very easily and because of that, it’s hard to memorize”*. The high entertainment value may also mask its educational value, which was debated amongst creators. For example, C22 mentioned that *“Mark Robert made a Ninja course for squirrels or whatever. I’m like, I don’t know what I’m supposed to learn here, but I am entertained”*. C27, on the other hand, believed that the video *“speaks to go through the scientific method or the engineering process and in a way that is a lot more fun, which means that people are going to be a lot more engaged and learn that in a better way... than a TED-Ed video.”*

4.5 Challenges for Inclusive, Substantiable SKC

In addition to the creation and consumption of SKC videos, we have identified challenges faced by the SKC community, including the male-dominant creatorship and viewership as well as the financial unsustainability creators face.

4.5.1 Male-Dominant Creatorship and Viewership

While prior research has found an underrepresentation of female science communicators on YouTube [2][83], our interviews found that both creators and viewers were heavily male-dominated in many SKC domains. Creators reported that *“most educational creators are men”* (C25) and although the gender distribution of viewers varied by topic, most SKC channels’ viewers were male. For example, C27, a female creator covering topics on social science and neuroscience reported that her viewership reported by the audience analytics of YouTube is *“between 65 to 70% male, which is actually far less than other channels like Veritasium etc, [where] it’s like 95, 99% male”*.

Creators reported several reasons for this, e.g., *“for science and technology, YouTube as a platform is dominated by male audience members, [even though] YouTube as a whole isn’t”* (C27), *“early science communicators were males and what you find with channels that have a male host is that they will have a higher percentage of male viewership”* (C27), female creators receive *“vastly more harassment than male creators”* (C13), the *“barrier to entry on YouTube that the creators really need to have like a video camera and professional editing software and audio equipment”* (C27), video editing *“has historically been a ‘boys’ club’”* (C13), *“other platforms such as Reddit [are] a driver of audiences on YouTube I think like that contributes to it, which has more of a male audience than female audience”* (C27), and YouTube’s recommendation algorithm may *“amplify small signals”* (C17), which compounded existing biases. C13 believed the underrepresentation was due to the *“continuation of all the friction already found in our society.”*

To appeal to female audiences, creators employed several strategies. C20 noted that they “*make videos about women’s health*”, which helped increase the percentage of female viewers, but their viewership largely remained male. C26, a female creator covering topics on science, mentioned that “*a really big change [of gender distribution of viewership] happened to my channel after I started having my face in videos and in thumbnails*”, after which her viewership changed from “*97-100%*” male viewership to “*around 75%*” for videos where she appeared in the video. C26’s viewership still remained at 95% male on average, but she mentioned “*I don’t really love making videos with my face in it, but I kind of think that maybe it’s important*”. C27 explored other platforms for science communication and found that for “*science communication on TikTok, Facebook, or Instagram, the balance is closer to 50-50*”.

4.5.2 Financial Support and Perception by Viewers

SKC video creators on YouTube can earn income from a variety of sources, such as YouTube ad revenue, sponsorships, and viewer donations, similar to other YouTube channels. However, as SKC content creators, these financial opportunities impose challenges due to the internal conflicts they may have about receiving financial support and concerns those financial motives may harm viewers’ perceptions of them or their channels.

Creators often receive requests from external sponsors who seek to leverage the influence of the creator to advertise their products. However, some creators (N=7) reject these sponsors for reasons other than money. For instance, C16, who covers philosophy and self-development content, rejected sponsorships from gaming companies, as they were “*against the addiction that gaming comes with*” and they “*would rather be focused on promoting companies that are into the same thing ... like Skillshare*”. C19, who covers health related knowledge would “*focus on being trustworthy as possible and not overly like trying to sell an extra 50 bucks of ads*”, because “*the health industry is untrusted in general*”. For these creators, the intrinsic benefits of authentically sharing their knowledge with others outweighed the financial benefits they could obtain.

Viewers were also aware of the unique financial challenges SKC video creators face. V7 noted that “*many scientifically inclined YouTubers are more hesitant to jump onto Patreon because they don’t want to be perpetually selling themselves*”. V12 also added that some creators “*don’t want to do a lot of sponsorships*” because sponsorships “*might compromise their neutrality*” and they want to “*stick to their principles*”. Viewers also recognized, however, that “*if you want to have YouTube be sustainable, I don’t see a better option*” (V7). It thus appears that even though viewers are aware that sponsorships could help creators, they appreciated when creators thought about how these sponsorships would be viewed and valued their independence.

Occasionally, the creator may attract sponsors whose interests were aligned with creators’ motivations. For example, C17 reported that “*the Chief Scientist at the US Census Bureau reached out to me and said, ‘hey, we see that you’re good at explaining really technical things’ and commissioned a video to explain ‘privacy-preserving measures [of the 2020 census] ... to the public*”. As C19

said, “*a gut health test company ... asked me if I would be interested in promoting their product. I wanted to do a video on (stomach) bloating anyway, so I made this connection [to the content of the video]*”. These sponsorships could be a “*natural integration*” (C19) with a creator’s content and were preferred by creators. C27 reported that they have started to receive more opportunities from research scientists about covering their latest research results, as funding agencies have started to focus on broader dissemination of the results of the funded research.

5 DISCUSSION AND FUTURE WORK

A growing body of work has explored various new forms of science communication, such as social media sites [61], online discussion forums [36], and video-sharing platforms [35][80]. However, no prior work has sought to understand its extension to other knowledge domains on YouTube. Our interviews with the SKC video creators and viewers uncovered creators’ motivations and practices, as well as viewers’ perceptions towards, and viewing behaviors of, such content. In what follows, we situate our findings within prior research on science communication and online educational videos as well as discuss the challenges and opportunities to further promote SKC.

5.1 Learning in an Entertainment Environment

Recent work by Kross et al. has found that YouTube has become the top educational resource for online learning within the United States [40]. On the other hand, a research report by Google showed that the top two reasons that viewers watch YouTube videos are to relax and to feel entertained [72]. Our findings reveal the key difference between SKC video and other educational videos on the highly versatile video platform.

To compete with other attention-grabbing content and satisfy the platform’s metrics of video performance, SKC video creators employ a variety of techniques to create highly engaging and accessible content that can intrigue viewers’ curiosity and sustain their attention, even if they are looking for entertainment content. Other forms of educational content, however, rely on the viewers’ own curiosity and interests as well as their academic and practical needs, and thus attract people who are already invested in certain domains. Given the different forms and goals of educational content available on the platform, future work can expand on this present research and Kross et al.’s work [40] to understand how viewers distribute their attention across different types of educational content.

The low attentional demand as well as the high return of intellectual satisfaction and entertainment of SKC videos, enables viewers to engage with content using their preferred amount of attention, thus inviting viewers from diverse backgrounds to consume it in a variety of contexts. However, both viewers and creators expressed concerns that the highly accessible and entertaining communication may hinder retention and active thinking about the content. While it is widely recognized that the outcomes of watching SKC videos, especially the long-term consequences, are difficult to define and measure scientifically due to the in-the-wild nature of SKC [8][21][50], the broad reach and popularity of SKC videos still beg the question of how

effective this communication medium is. As such, future research should explore the different types and degrees of impact that SKC videos have when they are consumed under different contexts.

5.2 Safe and Engaging Environments for Female Creators and Viewers

Our findings extend prior work on the underrepresentation of female science communicators [2][83], showing a similar degree of underrepresentation of both female creators and viewers for domains beyond science. Female viewership varied from as low as 1% to as high as 20% among SKC channels. Creators suggested several social, educational, technical, platform-oriented barriers for this concerning bias of female creatorship and viewership.

Creators suggested strategies, such as for female creators to appear in the videos and thumbnails so that female viewers can identify with creators, can often lead to a higher percentage of female viewers. However, it remains unclear whether the positive change of female viewership is because of an actual influx of female viewers, or a loss of male viewers. Moreover, recommending female creators to appear more in their videos is not without challenges, as female creators tend to receive more hostile comments towards their appearance than male creators [83]. While prior work has discussed the importance and ways to create safe and encouraging environments for female creators [2][72][83], less attention has been devoted to understanding what male creators can do to make their content appeal to female audiences. One important future direction would be to identify the unique styles and strategies employed in videos created by male creators that have substantial female viewership. The recommendation mechanism of the video-sharing platforms can also be adjusted to ensure the highly educational content is equally discoverable and accessible to female audiences.

5.3 Sustainable Development of SKC

Traditional models of science communication such as the deficit, dialog, and public engagement models all seek to encourage knowledge producers, mainly research scientists, to also serve as communicators [8]. However, effective communication to the public effectively in a competitive media environment requires expertise that research scientists may not have. In contrast to traditional science communication models, our study showed that the majority of SKC video creators were neither domain experts nor journalists who are the traditional producers, curators, and disseminators of science communication content. Instead, they are learners who are passionate about learning knowledge in different domains and sharing it with others. While the unique skillset that SKC video creators possess has made them the new, de facto gatekeepers [67], they suffer from unstable financial income when compared with traditional news and publishing agencies.

As funding agencies have growing interests in broadly disseminating the results of sponsored research and are encouraging knowledge producers to allocate resources for such activities [51], this presents an opportunity to systematically bridge knowledge producers with SKC video creators. This could

be beneficial for knowledge producers to leverage the reach of SKC video creators, as well as provide stable and congruent sponsorship opportunities for the creators.

6 LIMITATION

To recruit creator interviewees with sufficient experience, we selected those with more than 10,000 subscribers and 2 years of experience on YouTube. As a result, the findings were distilled from a small percentage of SKC creators who volunteered to participate in our study. A key limitation of this approach is that it may suffer from sampling problems in that the creators we interviewed may not represent the overall demographic of SKC video creators, such as female-male ratio and distribution of creators on different topics. It would be beneficial to expand the data collection in the future to paint a more comprehensive picture of SKC ecosystem. However, a representative sampling of SKC creators may perhaps be technically and ecologically infeasible even if the entire demographics of YouTube creators is accessible. Nevertheless, our interviews with the experienced creators have shed the first light on the practices employed and challenges encountered in the SKC community.

Similarly, the viewers we interviewed were frequent viewers of SKC videos, and therefore may not fully represent the broad audience of SKC videos on YouTube. While frequent viewers can provide unique insights given their viewing experiences, a balanced sampling of viewers that matches the demographics of society could help examine the entire landscape of SKC videos in the wild, which is our immediate next research step.

7 CONCLUSION

This paper contributes an in-depth analysis of SKC videos on YouTube, their creators, and their viewers. It summarizes interviews with both creators and their audiences to understand how this increasingly popular medium is used by nonprofessionals to communicate with the public on a growing and increasingly diverse array of topics. Based on an analysis of interviews with 27 creators and 13 viewers, we identified creators' motivations, the practices they employ to engage audiences, the unique niches they occupy, as well as challenges the SKC community faces within the current media landscape. The insights we gained by examining SKC videos on YouTube, which can reach millions and sometimes billions of viewers, highlighted future research directions that could be taken to address existing challenges to improve SKC practices in general. We hope that the results from this research can foster effective communication of knowledge to the public, and consequently promoting literacy and culture within society.

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