Understanding Communication Strategies and Viewer Engagement with Science Knowledge Videos on Bilibili

Yu Zhang
City University of Hong Kong
Hong Kong, China
yui.zhang@my.cityu.edu.hk

Changyang He
Hong Kong University of Science and Technology
Hong Kong, China
cheai@cse.ust.hk

Huanchen Wang
City University of Hong Kong
Hong Kong, China
Southern University of Science and Technology
Shenzhen, China
huancwang2-c@my.cityu.edu.hk

Zhicong Lu
City University of Hong Kong
Hong Kong, China
zhicong.lu@cityu.edu.hk

ABSTRACT

As a popular form of online media, videos have been widely used to communicate scientific knowledge on video-sharing platforms. These *science knowledge videos* take advantage of rich and multi-modality information which has the potential to provoke public engagement with science knowledge and promote self-learning. However, how communicators strategically make science knowledge videos to engage viewers, and how specific communication strategies correlate with viewer engagement remain under-explored. In this paper, we first established a taxonomy of communication strategies currently used in science knowledge videos on Bilibili and then examined the correlations between communication strategies and viewers' behavioral, emotional, and cognitive engagements measured by post-video comments. Our findings revealed the landscape of rich science communication strategies in science knowledge videos and further uncovered the correlations between these strategies and viewer engagements. We situated our results within prior research on science communication and HCI, and provided design implications for video-sharing platforms to support effective science communication.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in collaborative and social computing**.

KEYWORDS

Science communication, Online video platforms

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1 INTRODUCTION

Over the last century, scientists were believed to be responsible to instill scientific knowledge to the general public who usually lacked exposure to science and behaved passively in science communication practices [29, 50, 68]. With the rise of the Internet and online media, however, ordinary people with curiosity and enthusiasm towards science now have the chance to actively join in various forms of online science communication practices [9, 21], fostering several related online communities on different platforms [16, 41]. With the help of digital technologies, the active engagement of the general public in science communication eventually back-feeds and benefits the development of scientific research [33].

Online videos are consumed by billions of people around the world every day [15] and are increasingly used for involving the general public in science communication [52, 72, 77]. Unlike other forms of online media that can also be used to communicate science knowledge (e.g., blog [46, 62], forum [4, 41], and social media such as Twitter [16, 36]), videos provide rich, dynamic, and multi-modality information simultaneously. These video-specific features further empower science communicators to utilize cinematic filmmaking techniques and engaging narratives to produce high-quality content on different scientific topics that can effectively attract the attention of the general public [40, 52].

More importantly, video-sharing platforms enable viewers to post comments on videos so that they can engage with the video-based science communication by sharing their own thoughts about video content and discussing with the video creator and other viewers. The commentary mechanism also supports video creators with timely feedback, fosters video-centered discussions, and motivates crowd-sourced knowledge contributions [76]. For researchers, those comments provide a lens to observe and understand how viewers engage with video-based science communication practices [28].

Previous research revealed the correlations between content-related factors and the popularity of online science knowledge videos on YouTube [40, 66, 72]. However, how viewer engagement (i.e., behavioral, emotional, and cognitive engagement [28, 44]) with science knowledge videos correlates with the communication strategies used by the video creators (i.e., communicators) remains an under-explored topic. A deeper understanding of how science knowledge videos drive viewer engagement could inform the design of user interfaces of video-sharing platforms to support effective video-based science communication.

To fill these research gaps, this research explored the communication strategies commonly used in science knowledge videos on Bilibili (i.e., a popular video-sharing website in China [7]), and then investigated viewers' comments to show how they engage with and respond to online science knowledge videos. Finally we examined the correlations between communication strategies and viewer engagement. Specifically, we are interested in the following research questions:

- **RQ1**: What communication strategies are used in online science knowledge videos to transmit scientific knowledge?
- **RQ2**: How do videos with different communication strategies differ in viewer engagement inferred by comments?

To answer the questions, we initially collected a large-scale dataset of 440,547 science knowledge videos uploaded from August 2021 to February 2022 on Bilibili. Then we implemented a heuristic classification approach to categorize the videos to appropriate scientific topics using the hashtags of each video. This allowed us to have an overview of the science knowledge videos on Bilibili.

For RQ1, we randomly selected 330 videos through stratified sampling from 11 scientific topics. Two authors conducted a qualitative content analysis [45] and created a taxonomy of communication strategies. In the taxonomy, we considered both newly identified features in our own sample videos and existing research outcomes [32, 40, 52, 66, 72] about science knowledge videos regarding the visual and narrative features. For RQ2, two authors coded 2,000 randomly sampled comments from the 330 sampled science knowledge videos, and also created a taxonomy for the comments. The taxonomy categorized comments in consideration of their semantics and meanings for science communication. A neural network classifier based on the BERT language model [17, 25] was built to generalize our taxonomy to all the comments of the sample videos. To investigate the correlations between communication strategies and viewer engagement, we used categorized comments as proxies to build three regression models for behavioral engagement, emotional engagement, and cognitive engagement respectively.

Overall, we found that various visual and narrative strategies were used in online science knowledge videos. Several visual and narrative features (e.g., dramatic questions) were significantly correlated with different types of viewer engagement. In the end, we situated our results within a theoretical framework for evaluating science knowledge videos [32] and demonstrated the challenges of video-based science communication under current community norms. Furthermore, we discussed the participatory culture of online-video-based science communication on Bilibili, and provided design implications for leveraging the commentary mechanism to facilitate dialogues among the participants.

This research makes the following contributions to science communication and HCI: (i) We created a comprehensive taxonomy of the communication strategies that were commonly used in online science knowledge videos; (ii) We categorized comments of online science knowledge videos and captured how comments reflected diverse types of viewer engagement; (iii) We found the correlations between communication strategies and particular types of viewer engagement; (iv) We extended the literature of science communication in HCI and provided design implications for supporting video-based online science communication.

2 RELATED WORK

We first reviewed previous research about science communication related theories and current science communication practices on online digital media. We then focused on reviewing video-based science communication and corresponding viewer engagement. Finally, we reviewed prior work in HCI that explored science communication and related topics.

2.1 Science Communication and Related Theories

Science communication as a research field focuses on the delivering and sharing of scientific knowledge among human society. As defined by Burns et al., science communication is "*the use of appropriate skills, media, activities, and dialogue [to produce] personal responses to science*", including Awareness of science, Enjoyment of science, Interest in science, Opinion-forming, and Understanding of science (the "*vowel (AEIOU) analogy*") [11]. The major stakeholders of science communication include scientists and laypeople (i.e., members of the general public) [21]. This distinguishes science communication from a similar term, scientific communication, which specially focuses on the communication activities within the community of scientific workers or experts [56]. With the wide range of participants, the ultimate goal of science communication is to enhance the public's awareness, understanding, and literacy of science so that human society could eventually benefit from the various science communication practices [11].

Different theoretic models were developed to interpret science communication activities in the real world. The *deficit* model suggests that the general public is interested in science, but they usually do not have sufficient scientific knowledge [29, 50, 67]. Thus, the scientists, as the knowledge group, should take the responsibility to be the starting point of science communication sharing their knowledge to the public. The *deficit* model implied a one-way communication channel in which scientific knowledge is always transmitted from the scientists to the general public.

However, later studies criticized the *deficit* model for being inadequate to explain the complexity and interactions between scientists and laypeople in real-world science communication practices [50, 57, 63, 68]. These studies highlighted that the public's attitudes and understanding of scientific knowledge could be affected by other factors such as political knowledge [68], and the public's response to science is multi-dimensional and crucial to the success of science communication [43]. Therefore, the *dialogue* model [50, 57] and the *public engagement* model [14] were proposed and they indicated the bi-directional information flows in science communication. Both of the two models took the public's participation into consideration and emphasized the benefits of involving laypeople in science communication activities.

These theories shed light on further studies about the real-world science communication practices and inspire our research to investigate online science knowledge videos through the lens of viewer engagement which is a crucial perspective for both science communication research and HCI.

2.2 Science Communication on Online Digital Media

At present, online digital media have overtaken paper-based media as the primary information source for billions of people around the world [65]. This trend also affected science communication. An increasing number of science communicators have learned to leverage the unique affordances of online digital media (e.g., social media and video-sharing platforms) to reach broader audiences and promote scientific literacy [10, 16, 20, 41, 72–74].

Online digital media brings unprecedented opportunities for science communicators to reach a wide range of audiences from the general public and share knowledge with rich and dynamic multimedia content. In the early days of Web 2.0, blog was a popular form for scientists or scientific institutions to share their knowledge and facilitated dialogues by posting articles and replying to the underneath comments [46, 62, 73]. Later on, online forums such as Reddit [30, 37, 41], and social platforms such as Twitter [16, 47] also fostered online communities in which scientists and laypeople could gather together to discuss research progress, argue with scientific topics, and build connections with others. Besides these text-rich forms, online video is another commonly used approach for science communication and becomes popular in recent years [52, 72].

Additionally, online digital media afford users to actively communicate with content creators or other consumers by different mechanisms. Commentary is such a common mechanism that can be used for different types of online content (e.g., posts, articles, videos, etc.) that fosters asynchronous communication [38, 70, 76]. Previous research found that the commentary mechanism of science news served to provide a channel for collective sensemaking and assessment of the scientific content [73].

However, it is still unclear how science communicators strategically utilize online media, especially videos, to create high-quality science knowledge content and engage viewers. Thus, in this paper, we focused on online-video-based science communication, explored the communication strategies and aimed to investigate the correlations between the strategies and viewer engagement.

2.3 Online Science Knowledge Videos and Viewer Engagement

With the popularization of video-sharing platforms (e.g., YouTube), videos have also become a popular medium for science communication [52, 72]. Unlike texts or static pictures, videos take advantage of delivering science knowledge in a richer and more vivid way. From video content perspective, Finkler et al. proposed a framework named "SUCCESS" that highlighted six crucial aspects of science-related short-form videos: *simplicity*, *unexpectedness*, *concreteness*, *credibility*, *emotions*, and *science storytelling* [32].

Previous research found that visual representations are crucial for effective science communication because they could condense complex scientific information into an accessible short form for ordinary audiences while keeping a moderate level of scientific rigor [55, 71]. Rich visual components (diagram, animation, etc.) and narrative techniques (e.g., storytelling) were found to be effective stimuli that provoke viewer engagement during the watching experiences of science knowledge videos [12, 18, 32, 42, 52]. Popular online science videos usually used more narrative techniques to tell their stories than other nameless videos [40, 77], and proper narrative strategies were revealed to be positively correlated with viewer perceptions (e.g., trustworthiness) [66].

In the context of online digital media, user engagement refers to a series of actions that a user actively takes to interact with the media with intrinsic motivations [8, 39, 78]. Particularly for the case of video viewers on YouTube, previous studies categorized user engagement into three types: behavioral engagement, emotional engagement, and cognitive engagement corresponding to viewers' actions, thoughts, and feelings [28, 44, 78]. Previous work also examined that the commentary mechanism of online videos can be used to infer viewer engagement [28, 78] as viewers usually engage with the knowledge content by posting comments and utilize commentary mechanism to start communications and discussions [28, 76, 78]. Therefore, in this paper, we adopted a similar approach to infer viewer engagement by analysing video comments.

2.4 Science Communication in HCI

Public engagement in science communication has increasingly attracted HCI researchers' attention [41, 73, 74]. In the past few years, science communication-related research in HCI initially focused on citizen science and public participation in scientific research. Pandey et al. found that public participation could promote the creation of scientific hypotheses [60, 61]. Their results demonstrated the success and positive potential of online-media-based science communication. Other studies explored the design perspective of digital-media-based science communication. Rodríguez Estrada et al. claimed that appropriate designs and novel interaction techniques could improve the overall effectiveness of science communication on digital media [64]. Novel media forms such as video games were experimentally applied to enhance user engagement in particular contexts of science communication [31, 53].

For science communication on online media, HCI researchers have mainly explored text-based science communication online. Jones et al. studied "r/science" (a subreddit on Reddit) and found that it could be seen as an ecosystem in which scientific knowledge was shared and continually discussed by the online community members including both experts and laypeople [41]. August et al. revealed a significant language idiom gap between scientific and non-scientific members of "r/science"[4]. The gap hindered the participation and engagement of ordinary people in in-depth discussions about scientific topics [4]. On Twitter, Gero et al. found that "Tweetorials" (i.e., a genre of Twitter posts that are usually written by experts to deliver structural knowledge) with appropriate writing strategies managed to engage broad audiences and effectively deliver science knowledge [36].

However, video-based science communication is still underexplored in HCI and CSCW. In this research, we seek to first investigate the communication strategies of science knowledge videos, and then explore viewers' behavioral, emotional, and cognitive engagement with science knowledge videos in depth. Our research would deepen the understanding of video-based science communication on video-sharing platforms and contribute to both science communication and HCI research fields.

3 STUDYING BILIBILI

Bilibili is a popular video-sharing platform in China that hosts billions of user-generated videos (e.g., from September 2020 to August 2021, there were more than 450 billion videos uploaded to Bilibili [6]). The number of monthly active users on Bilibili was 272 million in the fourth quarter of 2021, with 86% of users being younger than 35 years old [7], making Bilibili one of the most influential video platforms in mainland China [22, 26], where YouTube is currently banned. In June 2020, Bilibili launched a section named "Knowledge Zone (知识区)" to organize the science knowledge videos that were uploaded. Since its introduction, the number of video uploaders who have contributed at least one video to this section has increased by 92%. Currently, 45% of videos on Bilibili are claimed to be related to knowledge sharing [6].

Studying Bilibili is complementary to the existing body of literature on science communication. While prior studies primarily focused on YouTube [24, 28, 52, 72, 77, 78], Bilibili offers an opportunity to probe online-video-based science communication within a non-Western cultural background.

3.1 Data

In this research, we focused on science knowledge videos on Bilibili and collected publicly accessible data of a large number of videos using automation techniques. In the beginning, we scraped the meta-information of 440,547 videos on Bilibili by scanning their web pages using self-implemented Python scripts. This allowed us to cover all videos that were uploaded from August 2021 to February 2022 in the "Science and Science Popularization (科学科普)" sub-section of the "Knowledge Zone" on Bilibili. For each video, the meta-information contained title, description, hashtags, upload time, duration, the number of views, and the number of favorites (i.e., likes) (Table 1). Before directly answering the research questions, we mainly used the hashtags to identify the common topics of the observed science knowledge videos on Bilibili. To answer RQ1, 330 videos were sampled from 11 scientific topics for qualitative analysis (section 5). To answer RQ2, we further implemented a web crawler to retrieve the comments of the 330 sample videos (section 6).

4 SCIENTIFIC TOPICS OF THE SCIENCE KNOWLEDGE VIDEOS ON BILIBILI

To understand the landscape of science knowledge videos on Bilibili so that we could have a standpoint for further analysis, we followed the ideas of previous research [24, 41] to first categorize the videos by scientific topics.

4.1 Method: Hashtag-based Classification

Unlike YouTube, Bilibili did not provide detailed category information for videos, so we had to infer the scientific topic(s) by video metadata. Particularly, we used hashtags (Figure 1). Each video on Bilibili had a list of hashtags. A hashtag is a single word or a short phrase that commonly describes video-related information. A prior study categorized the hashtags of Bilibili videos into two types: interior (i.e., content-related), and exterior (i.e., non-content-related, such as uploader information) [79]. For our purpose, only the interior hashtags were analyzed. Additionally, Bilibili afforded a moderation mechanism to maintain the overall quality of the video hashtags [13] making them reliable indicators of video content.

We manually reviewed each hashtag to map it to its most-related scientific topic. For example, the hashtag "diabetes (糖尿病)" referred to medical science and healthcare, whereas the hashtag "solar system (太阳系)" referred to astronomy. To accurately map the hashtags to scientific topics, we referred to the definition of scientific disciplines provided by Web of Science [58] and searched through the hashtags found in our own dataset to identify common scientific topics.

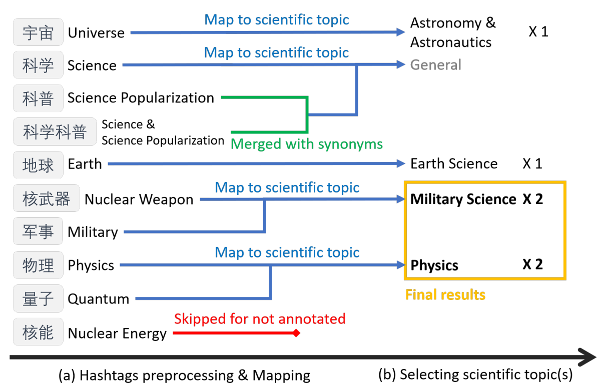


Figure 1: An Example of How to Use Hashtags to Identify the Most relevant Scientific Topics of a Science Knowledge Video. Showing from left to right in this figure, we (a) preprocessed and mapped a list of hashtags of a video into scientific topics, and (b) determined the scientific topics of the video by selecting the most frequent topics inferred from the hashtags.

Specially, we purposefully merged highly-relevant topics into their commonly-rooted scientific disciplines to maintain proper granularity for the subsequent classification task. For example, Geography, Geology, Meteorology, and Oceanography were merged into one class named *Earth Science*. We also incorporated all social-science-related topics (e.g., Economics, Linguistics, Design) into one class named *Social Science and Arts* because videos of these topics were rare in our dataset. If keeping these topics distinct, we would have a massive number of classes while some of them might not have a moderate number of videos to support further analysis. Besides scientific topics, we introduced another special class named

Table 1: Video Meta-information. For each video, we collected its title, description, hashtag list, uploaded time, and duration, the number of views, and the number of favorites.

Feature	Definition	Mean	Median	Min	Max	Std.
title	The title of a video	N/A -				
description	Text provided by the uploader that described the video	N/A -				
hashtags	A list of words or short phrases about the video	N/A -				
uploaded time	The timestamp of when the video was uploaded	N/A -				
duration	The duration of the video in seconds	715.61	126	0	539701	5038.33
# of views	The number of times the video was played	12203.19	113	0	16680340	151107.19
# of favorites	The number of times the video was marked as a favorite	104.62	1	0	613072	2469.62

General to annotate hashtags that did not belong to any specific scientific discipline but were still content-related, such as the word "Science" itself.

Once we built the mapping between hashtags and scientific topics, we could determine the topic(s) of a video by counting the numbers of hashtags of the video in each known topic. The video would be assigned to the topic(s) with the most hashtags. Videos that only had *General* hashtags without any scientific-topic-related hashtags were assigned to the *General* class, and videos that only had unknown hashtags (as we could not annotate all the hashtags in practice, details in subsection 4.2) were assigned to another special class named *Unclassified*.

4.2 Classification Results

From the 440,547 science knowledge videos, 146,853 unique hashtags were extracted. Limited to the workload we could not annotate all of them. Fortunately, we found that the 1,000 most frequent hashtags appeared in the metadata of 91.97% of videos, and a significant marginal diminishing trend was displayed on the hashtag-video coverage rate curve Appendix A. This allowed us to classify most of the videos by only annotating 1,000 hashtags.

Additionally, to improve the quality of hashtags for classification, we pre-processed the most-frequent 1,000 hashtag list by excluding useless exterior hashtags [79] and merging synonymous. Specifically, we iteratively conducted removing and merging and then appended the list with subsequent frequent hashtags to keep the size 1,000 until all the hashtags in the list were interior and having distinct meanings. As a result, the pre-processed 1,000 most frequent hashtags came from 372,479 videos (84.55%). The coverage rate dropped because some highly frequent exterior hashtags were excluded but many videos only had such hashtags. However, the number of remaining videos was still huge and enough to support further analysis to answer the research questions.

Eventually, we classified the 440,547 videos into 13 classes including the 11 scientific topic classes and 2 special classes *General* and *Unclassified* (Table 2). The two special classes were single-labeled, whereas the scientific topics could be multi-labeled. Overall, 68.89% of the videos were assigned at least one scientific topic. Within this proportion, 265,448 (87.47%) videos were single-labeled while 31,633 (10.42%) videos related to two scientific topics and only 6,418 (2.11%) videos related to at least three topics. Besides the videos classified by scientific topics, 15.66% of the full set of videos were assigned to the *General* and 15.45% of the videos were assigned to *Unclassified* as they did not have any annotated hashtags.

In summary, science knowledge videos on Bilibili reflected a wide range of scientific topics. However, compared with results of the prior research of science communication on YouTube [24], the distribution of topics of science knowledge videos on Bilibili was highly skewed. *Medical Science and Healthcare*, for example, was the most common topic, comprising 27.41% of the full set of videos while other topics only appeared in less than 15% of the videos.

5 COMMUNICATION STRATEGIES IN SCIENCE KNOWLEDGE VIDEOS (RQ1)

To answer RQ1, we created a communication strategy taxonomy and took the taxonomy as a codebook to further analyze and annotate the 330 sample videos to investigate how communication strategies were used in practice.

5.1 Method: Categorizing the Communication Strategies

We defined a communication strategy of science knowledge videos as *a series of perceptible video-specific features that could be potentially influential to viewers' watching experiences*. The features could either be determined by the video creator who was also considered as science communicator, or be unintentionally introduced by the video creator themselves, e.g., the communicator's gender. Our communication strategy taxonomy considered both newly observed features from Bilibili videos and existing literature on video-based science communication.

Previous research found three important aspects of science knowledge videos namely *Visual* [52, 72], *Narrative* [18, 32, 40], and *Communicator* [66, 72]. *Visual* referred to the visible components and style of a video. *Narrative* included storytelling and linguistic perspectives. *Communicator* described the main characters who deliver the content or demonstrates experiments in science knowledge videos. In this research, we followed the three aspects to further investigate science knowledge videos on Bilibili and integrated newly found features into these three aspects in our communication strategy taxonomy.

To identify potential new features from science knowledge videos on Bilibili, two authors analyzed [45] 330 videos that were selected from 11 scientific topics (i.e., 30 videos per topic) using a stratified sampling approach. The 11 scientific topics come from the

[1] San Nong: a China-specific term refers to agriculture, rural areas, and rural residents

Table 2: Recognized Scientific Topics of Science Knowledge Videos on Bilibili. Overall, eleven scientific topics were recognized. Videos without specific hashtags would be assigned into a special class called *General*. Videos without recognizable hashtags would be assigned into another special class called *Unclassified*. The sum of the proportions of the classes exceeded 100% because one video could be assigned to multiple scientific topics.

#	Class (Topic)	Top-5 Frequent Hashtags	Count	Proportion (%)
1	Agricultural Science	Agriculture, Liquor, Tea, San Nong (三农) [1], Fruit	7184	1.63
2	Astronomy and Astronautics	Astronomy, Universe, Space, Astronautics, Airplane	34692	7.87
3	Chemistry	Chemistry, Materials, Chemical Reaction, Carbon neutral, New Energy	16876	3.83
4	Computer Science	Artificial Intelligence, Programming, Machine, Robotics, Computer	21034	4.77
5	Earth Science	Earth, Geography, Meteorology, Ocean, Environment	27900	6.33
6	Life Science	Life, Biology, Paleontology, Animal, Plant	64017	14.53
7	Mathematics	Mathematics, Geometry, Calculus, Linear Algebra, Statistics	11198	2.54
8	Medical Science and Healthcare	Health, Medicine, Chinese Traditional Medicine, Gender health, Well-being	120743	27.41
9	Military Science	Military, Weapon, US Army, Navy, War	7453	1.69
10	Physics	Physics, Quantum, Optics, Quantum mechanics, Computational Fluid Dynamics	19817	4.50
11	Social Science and Arts	English, Psychology, History, Humanity, Architecture	18317	4.16
12	General	Science Popularization, Science, Nature, Learning, Experiment	68980	15.66
13	Unclassified	N/A	68068	15.45

hashtag-based classification (section 4) where two classes, *General* and *Unclassified*, were excluded because of their heterogeneity and indeterminacy respectively. For each video that was related to multiple topics, it could be sampled as an instance of any of its topics. However, to ensure that there were no overlaps between the topic groups, one video was only allowed to be selected to represent one topic in the sampling process. Additionally, we only included videos with more than 50 first-level comments to ensure there could be enough comments to be analyzed for answering RQ2.

To create the taxonomy from scratch, two authors collaboratively open coded 66 (20%) videos (i.e., 6 videos per topic). The open coding process was iterative. In the beginning, two coders independently watched the videos and annotated observed the communication strategies, resulting in two independent codebooks. The two coders collaboratively produced a final codebook through three rounds of discussions and iterations. The inter-rater reliability of the open coding process was measured by Cohen's Kappa coefficient for each of the features presented in the taxonomy. On average, the coefficient reached 0.90 (Figure 2). The maximum score was 1.0 on communicator *Gender*, whereas the minimum score was 0.78 on the sub-feature *science experiment* of the *Scientific Feature* in the *Visual* category.

In our taxonomy (Table 3), three new video content features emerged, including two features *Community Culture* and *Scientific Feature* in the *Visual* category, and one feature *Orientation* in the *Narrative* category. Specially, *Scientific Feature* contains four sub-features: *schematic diagram*, *data visualization*, *mathematical proof*, and *science experiment*. All the features and sub-features under *Scientific Feature* were annotated as single-label categorical variables. A special value "N/A" was applied, when there was not sufficient information to determine the most relevant value of a feature. For example, we would assign "N/A" to communicator *Gender* for a video when there was no speech or human presence could be found.

After the taxonomy (i.e., codebook) was finalized, the first author coded the remaining 264 videos (Figure 2).

5.2 Visual Communication Strategies

Under the *Visual* category, we added new possible values to the *Style* feature in our taxonomy based on the Bilibili videos, extending its scope defined by prior works [52, 72]. Altogether, we identified five possibilities: *video clips with voiceovers*, *speaking to the camera*, *animations*, *live recording*, and *non-speaking* (Figure 3). The majority of videos consistently adopted one style, so that we could define this feature with single-labeled values.

5.2.1 Style. Among the five possible styles, *video clips with voiceovers* and *animation* contained fictional visual elements, *speaking to camera* and *live recording* were usually composed of realistic scenes, and *non-speaking* had only visual frames but no speech.

The most popular style is *video clips with voiceovers* across all the scientific topics (138/330, 41.82%). In the videos of this style, video clips were manipulated and orchestrated to match up with the particular themes and knowledge concepts to be discussed. Those clips enriched the video's expressiveness and helped to construct entertaining atmosphere to engage viewers. For example, in a video about obesity (Figure 3 (b) upper) the science communicator purposefully inserted a scene from the British TV series "Sherlock", where Mike (a main character) was surrounded by piles of sweets and could not stop eating. This dramatic short scene was not just amusing, but also implied the key message of the video that "*A main reason for young people getting over-weighted is the unhealthy lifestyle rather than metabolic diseases*". In another case (Figure 3 (b) lower), the video creator cut several clips from the movie "Ready Player One" and reassembled those clips in alternative orders to demonstrate what an instance of metaverse might look like.

Differentiating from the styles featured with fictional content, *speaking to camera* (87/330, 26.36%) and *live recording* (35/330,

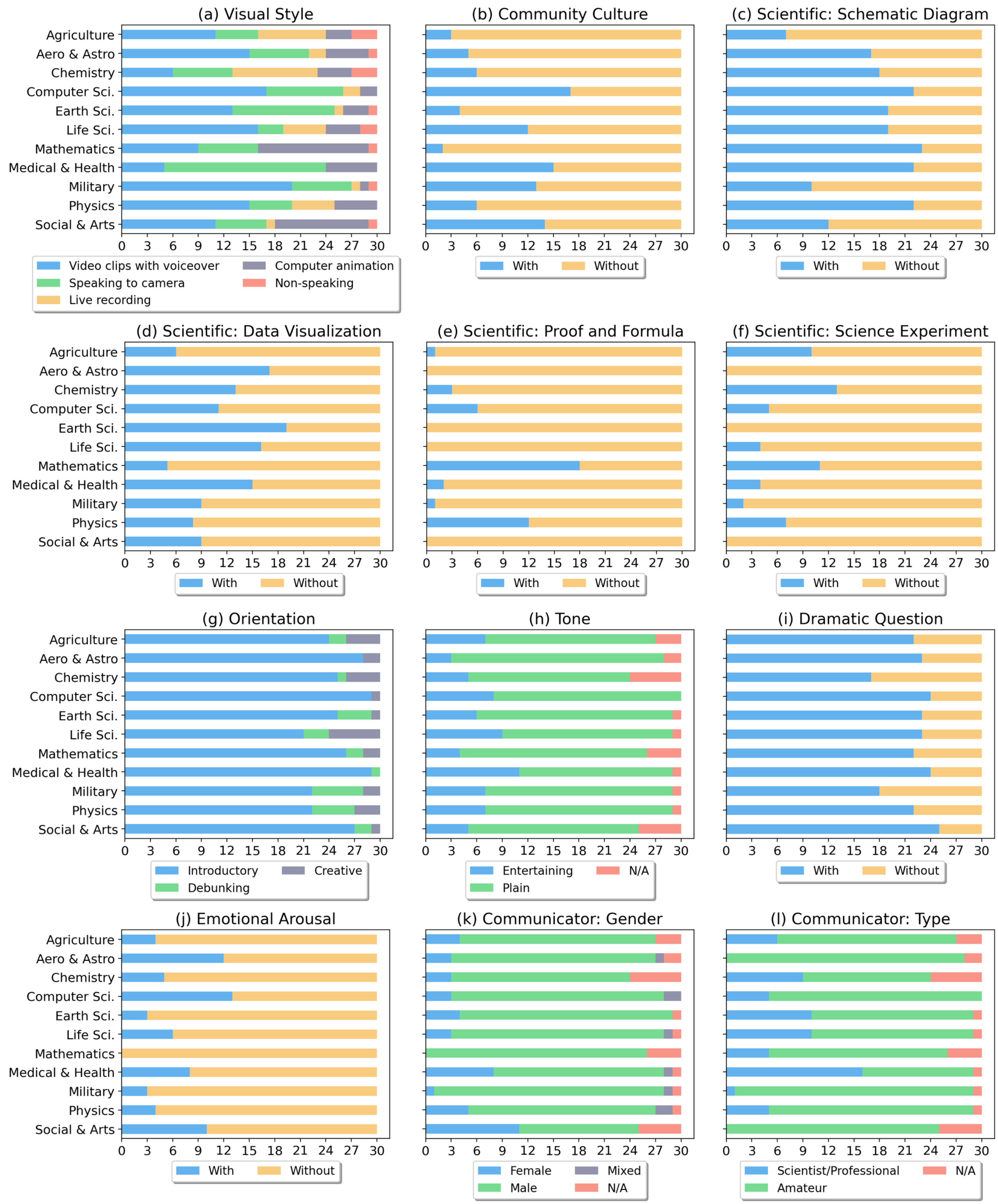


Figure 2: Coding Results of the 330 Science Knowledge Videos. One bar-chart represented a feature of communication strategies. In a bar-chart, the X dimension (horizontal) indicated the number of videos, and the Y dimension (vertical) indicated the 11 scientific topics. The bars with different colors showed the number of videos that had the corresponding categorical value. Bar-charts (a) to (f) are *Visual* strategies, (g) to (j) are *Narrative* strategies, and (k), (l) are *Communicator* strategies.

Table 3: Taxonomy of Communication Strategy in Science Knowledge Videos. In this taxonomy, we categorized science knowledge video communication strategies into three categories (i.e., aspects): *Visual*, *Narrative*, and *Communicator*. *Visual* strategies included style, community culture, and scientific feature. Specially, scientific feature included four sub-feature namely schematic diagram, data visualization, proof and formula, and science experiment. *Narrative* strategies included dramatic question, emotional arousal, tone, and orientation; For *Communicator* aspect, scientific professionalism and gender were included.

Category	Feature	Definition	Possible Values	Related Work
Visual	Style	Overall visual style of science knowledge videos regarding to what visible components were used and how those components were organized	Video clips with voiceovers Speaking to camera Computer animation Live recording Non-speaking	[52, 72]
	Community Culture	Usage of visual elements with ACGN (i.e., Anime, Comic, Game, Novel) themes. ACGN themes were iconic cultural feature of Bilibili user community	With Without	*
	Scientific Feature	Typical visual representations of scientific concepts used in science knowledge videos: *schematic diagram*, *data visualization*, *proof and formula*, *science experiment*	(For each) With Without	[71]
Narrative	Dramatic Question	Curious question(s) or counter-intuitive statements purposefully made by the communicators	With Without	[32, 40]
	Emotional Arousal	Sensational storytelling or exaggerated emotional expressions that were used to arouse viewers' emotional experiences	With Without	[32, 40, 52]
	Tone	The tone of the speech made by communicators as either normal or engaging and entertaining	Entertaining Plain N/A	[52]
	Orientation	The final goal of the storytelling in videos	Introductory Debunking Storytelling	*
Communicator	Professionalism	The scientific professionalism of the communicators in terms of the topics of the science knowledge videos they created	With Without	[51, 66]
	Gender	Observed gender of the communicator(s). The value "mixed" was used for scenarios with multiple communicators in different genders	Female Male Mixed N/A	[2, 51, 72]

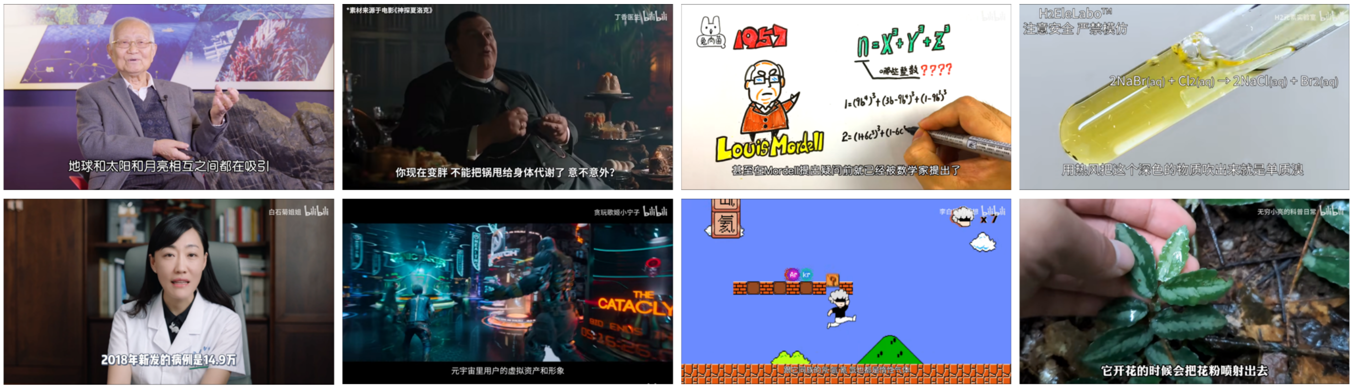
* These features was newly found from the science knowledge videos on Bilibili.

10.61%) were more realistic. *Speaking to camera* referred to the setting in which science communicator looked at the camera pretending to talk to the viewers directly (Figure 3 (a)). This style was used in all the scientific topics and was also discussed in prior works [52, 72] to be one of the most commonly used styles in video-based science communication on video-sharing platforms. *Live recording* described the setting that aimed to show the running process of scientific experiments or the recordings of outdoor expeditions (Figure 3 (d)). This style usually appeared in videos about physics, chemistry, or life science (e.g., botany, zoology, etc.)

5.2.2 Community Culture. Usually, the video clips used in science knowledge videos were obtained from various sources including movies, TV series, anime, video games, and other user-generated videos. This wide adoption of fictional content was reflected by the *Community Culture* feature in our taxonomy.

In our observations, science communicators were skillful in utilizing fictional clips to construct metaphors to present particular science concepts, which was a way to achieve state-of-art balance to introduce science knowledge rigorously while keeping the content comprehensible and entertaining. Besides the existing video clips from external sources, some skillful creators made their own customized graphics or animation clips to enrich the video content, which is also termed *animation* (57/330, 17.27%) in the *Style* feature. In a video made by hand-drawing animations (Figure 3 (c) upper), the communicator designed an anime-style avatar for the mathematician Louis Joel Mordell [1] when mentioning his contributions. Another video (Figure 3 (c) lower) demonstrated a case where the communicator imitated the famous Japanese game Super Mario to illustrate the imaginary instances when humans ate different chemical elements on the periodic table. In this case, each simulated game level corresponded to one chemical element and the communicator replaced the Super Mario character by an avatar of himself. The wide adoption of fictional content like these examples reflected the unique community subculture of ACGN (i.e., anime, comic, game, novel) fans who were the initial target users of Bilibili.

[2]Louis Joel Mordell. https://mathshistory.st-andrews.ac.uk/Biographies/Mordell/



(a) (b) (c) (d)

Figure 3: Examples of Science Knowledge Video Visual Styles. (a) Speaking to camera: the science communicator sat in front of the camera and pretended to speak to the viewers directly, (b) Video clips with voiceovers: a montage of several video clips from various sources with a voice speaking over the frames (upper: a scene from the British TV series "Sherlock"; lower: a scene from the movie "Ready Player One"), (c) Computer animation: hand-drawn or computer-generated graphics or animations with a voice speaking over the frames (upper: hand sketching animation; lower: computer-generated animation), and (d) Live recording: video recordings of realistic situations (upper: a chemical experiment; lower: expedition in a tropical rain forest).

5.2.3 Scientific Feature. Although early research stressed the importance of visual components in communicating science knowledge [55, 71], existing research on online-video-based science communication did not example this perspective in detail. In the taxonomy, we introduced the *Scientific Feature* feature based on the observations of science knowledge videos on Bilibili. This feature contained four typical visual components: *schematic diagram*, *data visualization*, *proof and formula*, and *science experiments* (Figure 4).

Some visual components were observed to appear more frequently in particular scientific topics than others (Figure 2). *Proof and formula* was an iconic scientific visual component of videos of mathematics (18/30) and physics (12/30) since it appeared in more than one-third videos on these two topics. *Science experiment* appeared more frequently in videos of chemistry (13/30), mathematics (11/30), and agricultural science (10/30) than other topics. However, *schematic diagram* and *data visualization* were commonly used in videos of all eleven scientific topics, although the ratios had some variations among different topics.

5.3 Narrative Communication Strategies

Dramatic Question, *Emotional Arousal*, and *Tone* are three features adapted from the literature. In our taxonomy, a new feature *Orientation*, which denoted the standpoint of the communicator to develop the narration, was added.

5.3.1 Dramatic Question. Unexpectedness is one of the dimensions defined in the SUCCESS framework [32] that could arouse viewers' curiosity to science knowledge videos. *Dramatic question* was a common trick to generate unexpectedness. A dramatic question could be explicitly displayed, or implicitly implied by a counter-intuitive point of view in the video title or orally mentioned at the beginning of a video. For all the scientific topics, more than half of the videos had at least one dramatic question (Figure 2). For example, the "metaverse" video (Figure 3 (b) lower) raised a series of dramatic questions in its title asking "*What is metaverse after all? Is it something that can be real in the near future or just a fantasy? Does it relate to us? (*元宇宙到底是什么？近在眼前*OR* 空想未来？和我们有关么？*)*". The three questions related metaverse to viewers' daily life and might induce them to think about "how can this fancy concept affect my real life?". Once the curiosity was aroused, it could motivate the viewers to keep watching the video.

5.3.2 Emotional Arousal. Emotional arousal could make science knowledge videos attractive, believable, and engaging [32, 40]. In the sample videos, we observed that science communicators often integrated the emotional arousal with storytelling to transmit the emotional feelings unconsciously. In the "jungle expedition" video (Figure 3 (d) lower), the science communicator aimed to introduce the animals and plants appearing in his camera view. For each animal or plant, the communicator would begin with a brief introduction about the creature's scientific name and phylogenetic information, and then he would suddenly turn to a jocose tone to express his subjective feelings about the creature, which were usually amusing to viewers. For example, he commented on the leaves of the plant "*It looks beautiful! (But) just a little bit. (*有一点儿好看*)*" using a rhotic accent in the Beijing dialect. The humor and relaxing atmosphere could provide viewers with enjoyable watching experiences.

5.3.3 Orientation. We included *Orientation* as a communication strategy because it determined the overall style of the speech and could also be manipulated by the science communicator. For example, one can choose to introduce an idea directly or raise an idea by debunking another one with a different opinion. Based on the sample videos, we found three possible orientations: *introductory*, *debunking*, and *storytelling*.

Introductory was the most common orientation (278/330, 84.24%), in which the communicator would tell the story straightaway. If there was a pre-presented dramatic question appearing in the title

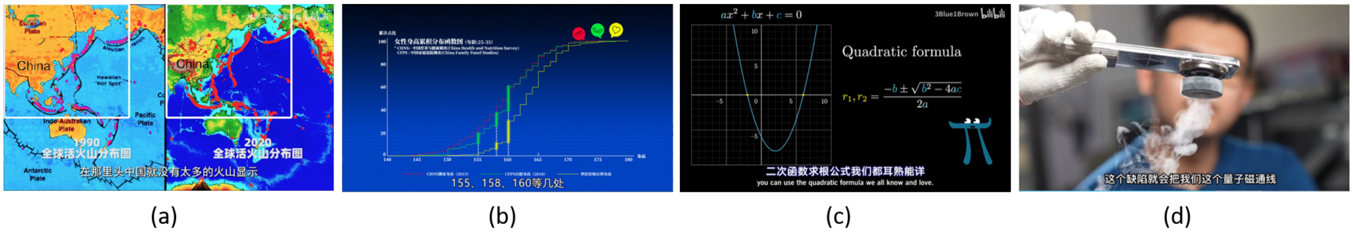


Figure 4: Examples of *Scientific Feature* Strategy. (a) Schematic diagram: manually-made or computer-generated graphics and animations that present particular concepts or support storytelling, (b) Data visualization: scientific or statistical data visualization, (c) Proof and formula: formulas, equations, and mathematical proof, and (d) Science experiment: demonstrations of realistic science experiments or computer-simulated experiments.

or the opening segment in the video, the communicator would start their speech by giving a short answer to the question and then gradually tell their story. *Debunking* videos were made to clarify rumors, to comment on controversial science knowledge videos, or raise strong objections to other opinions. Such videos might have strong and negative emotions than other videos. *Storytelling* distinguished from ordinary introductory or debunking by well-designed storylines, scenarios, and contexts. All the elements in such videos could be deeply customized to serve imaginative storytelling, which made the narrative more complicated than in other videos. For example, the "Super Mario" video (Figure 3 (c) lower) was coded as having *Storytelling* orientation. In this video, not only the visual elements were made to simulate a game interface, but also the communicator pretended to be lively streaming his playing experience to the viewers.

5.4 Communicator Communication Strategies

Although factors of the communicators themselves were unintentionally introduced, these factors were influential to science knowledge videos [66]. Based on the literature, we focused on the *Professionalism* and *Gender* of science communicators [2, 51].

For *Professionalism*, We referred to the communicators' profile page and video content and descriptions to determine their professionalism. Only when recognizable qualification information could be found would we annotate a communicator as "scientist/professional". The open coding results showed that only 67 videos (20.30%) were hosted by professionals, while "amateur" communicators occupied the vast majority (238, 72.12%).

As for *Gender*, we found that male communicators were dominant (252/330, 76.36%), while female communicators were rare (45/330, 13.64%) and distributed mainly in two topics *Medical Science and Health* and *Social Science and Arts* (Figure 2 (g)). The rest few videos either have multiple communicators of different genders (i.e., "mixed") or were not explicitly presented by a communicator (i.e., "N/A"). Our findings echoed prior work about the significant gender gap in video-based science communication on video-sharing platforms [1, 2, 24, 72, 77], and underscore how women's voices are lacking in this context.

6 THE RELATIONSHIPS BETWEEN COMMUNICATION STRATEGIES AND VIEWER ENGAGEMENT (RQ2)

To understand how viewers engage with videos using comments, we first created a taxonomy that categorized comments of science knowledge videos into six classes. With the help of a neural network classifier, we generalized our classification rules to all the comments of the 330 sample videos. Furthermore, three regression models were established to examine the correlations between communication strategies and viewers' behavioral engagement, emotional engagement, and cognitive engagement respectively.

6.1 Method: Categorizing the Video Comments

The post-video commentary mechanism of Bilibili was forum-like. It allowed video viewers to comment on the video as first-level comments and viewers could reply to a piece of first-level comment to form a thread of replies (i.e., second-level comments). Among the raw comments, 291,988 were first-level comments while the rest were all replies. In this paper, we only focused on the first-level comments as they were directly related to the video content.

In data cleaning, comments that only consisted of emojis or stickers (i.e., a kind of customized graphics provided by Bilibili) without any text were excluded from our analysis. The reason was the meanings and interpretations of such pure graphical comments highly depended on the cultural contexts of Bilibili [80], and it would be challenging to interpret them accurately. After removing these comments, 286,313 comments remained. The average length of the remaining comments was 30.21 characters (std err. 51.85), and 98.89% of comments are written in Chinese.

To create the taxonomy, two authors started with 1,000 randomly-selected comments from the 330 videos. Following a similar open coding approach used for communication strategies (section 5), two authors coded the comments independently in the first round obtaining two distinct codebooks, and then discussed and merged their codes to generate the final codebook after two subsequent rounds of iteration. Eventually, we identified six classes of science knowledge video comments from the sample comments Table 4. The inter-rater reliability score of the two coders reached 0.908 (Cohen's Kappa) on the 1,000 sample comments.

Table 4: Taxonomy of Science Knowledge Video Comments. We categorized the comments of the science knowledge videos on Bilibili into six classes. In terms of the content, the four classes: *Discussion*, *Storytelling*, *Question*, and *Critique* were science-knowledge-related, while *Attitude* and *Socialization* were not.

Class	Definition	Examples (translated from Chinese)	Proportion (%) *
Discussion	Opinions, hypotheses, or complementary information about the knowledge-related content presented in videos	"*The silt in the Yellow River does not have much commercial value because it is real dirt rather than grain of sand ...*" (omitted the long subsequent part)	25.40
Storytelling	Personal experiences and self-statement of comment authors.	"*Yesterday when I stayed up late, I suddenly felt uncomfortable on my heart and my body was sweating and hot ... It scared me a lot.*"	12.00
Question	Questions or requests for further information about the video content.	"*Is it true that a bullet can fly over 1,000 meters in only 1 sec. ?*"	8.90
Critique	Strong disagreement with the content or opinions presented in videos. Demonstrations of alternative points of view and counter-evidences.	"*This (video) is nonsense. Everyone knows we should accept the facts, but the key point is how to perceive and make use of (the facts) ...*"	1.30
Attitude	Strong emotional expressions and self-disclosures.	"*(I was) So excited when watching the former half (of the video), but (I) almost cried out in the end.*", "*Can not understand (the content) at all!*"	14.90
Socialization	Courtesy greetings and brief words for thanking	"*Uploader you looks so beautiful!*", "*I'm coming.*"	37.50

* The proportions of each class in the 1,000 co-coded sample comments.

6.2 Science-knowledge-related Comments

In the six classes of comments, we considered *Discussion*, *Storytelling*, *Question*, and *Critique* to be science-knowledge-related comments, because these four types of comments were strongly related to the science knowledge content presented in videos and could reflect viewers' understandings of particular knowledge concepts.

A typical *Discussion* comment could be a short paragraph that demonstrated the comment author's own opinion with corresponding logical deductions and evidences. For example, underneath the "metaverse" video (Figure 3 (b) lower), a *Discussion* comment said "*The debate about metaverse will last for a long time, because the world needs this concept. However, it will not always be a hot spot, though the spiritual needs of people will persistently promote the exploration of metaverse. In the future, there will be a more mature metaverse, but it will take a very long time. ...*". Comprehensive opinion was a major characteristic that distinguished *Discussion* from other classes.

In *Storytelling* comments, the comment authors usually emphasized their personal experiences and devoted to make up a story to tell the situations and feelings. Under the same "Metaverse" video, a *Storytelling* comment said: "*I feel nothing special after using a personal computer for three hours but I would be very tired with conjunctival hyperemia after playing Oculus Quest 2 for just thirty minutes.*" As for *Question* or *Critique* comment, the commenter also had to establish some degrees of understanding of the video content before asking or criticizing.

6.3 Video Comments and Viewer Engagement

Viewer comments were examined to be effective predictors that could reflect viewer engagement in the contexts of science communication on online media [28, 73, 78]. In this paper, we matched different types of viewer comments with *emotional engagement* and *cognitive engagement* [28, 44], and used the number of comments as proxy to infer *behavioral engagement*.

6.3.1 Behavioral Engagement. No matter which theme the comment might contain, the commenting behavior itself represented viewer engagement as it implied that viewers were willing to express while stimulated by the watching experience of either online articles or videos [28, 73]. Therefore, we assumed that all six classes of comments should be accounted for when inferring behavioral engagement.

6.3.2 Emotional Engagement. Based on the definition of *Attitude* comments in the taxonomy Table 4, this type of comment was directly related to emotional engagement. *Attitude* described comments with explicit emotion outpouring and often contained viewer self-disclosure. Viewers made such comments to express strong appreciation, endorsement, or disgust feelings. Most *Attitude* comments were short and often ended with exclamation marks, e.g., "*Hahahahahah!!!*" (laughing loudly).

6.3.3 Cognitive Engagement. Cognitive engagement was inferred from four types of science-knowledge-related comments: *Discussion*, *Storytelling*, *Question*, and *Critique*. Because the content of these types of comments was highly relevant to the video content and exposed the viewers' understanding of the science knowledge delivered by the communicators. To generate such comments, viewers needed to make considerable efforts in thinking and analyzing.

6.4 BERT-based Classifiers for Viewer Comments

To automatically categorize all 286,313 first-level comments from the 330 science knowledge videos, we built a neural network classifier by fine-tuning a Chinese-specialized version [17] of the Bidirectional Encoder Representations from Transformers (BERT) language model [25]. The classifier generalized our comments taxonomy by automatically assigning a given comment to either of the six classes.

6.4.1 Training. Before training, one author (i.e., one of the coders who contribute to the comment taxonomy) annotated 1,000 additional comments to enlarge the size of the dataset for training purpose (i.e., 2,000 annotated comments). Next, we split the dataset into a set of 1800 comments as the training set, and a set of 200 comments as the validation set. During training, we fixed the constant random seed and tried tuning several hyper-parameters including activation function, dropout rate, learning rate, batch size, and the number of epoch. Finally, our model reached a micro-F1 score of 0.77 on the six-class text classification on the validation set, indicating its substantially good performance to classify the video comments.

6.4.2 Predicting. The prediction results (Figure 5) showed that *Socialization* was the most common class accounting for 57.74% of comments in all the 330 sample videos of 11 scientific topics. As predicted, 27.51% of comments belonged to *Discussion* type, and *Discussion* was also the predominated type of science-knowledge-related comments in ten scientific topics expecting *Medical Science and Healthcare*. For videos with medical and healthcare themes, *Storytelling* comments took a greater proportion (25.88% in the topic) than *Discussion* (18.78% in the topic) comments. This finding matched with our observations that viewers preferred reporting their health conditions under the videos of *Medical science and healthcare* topic where science communicators aimed to explain knowledge about diseases and symptoms. The third common class was *Attitude* which took 6.73% of comments on average. As for the other four classes, *Question* (1.40%) and *Critique* (0.34%) were consistently rare among all the scientific topics.

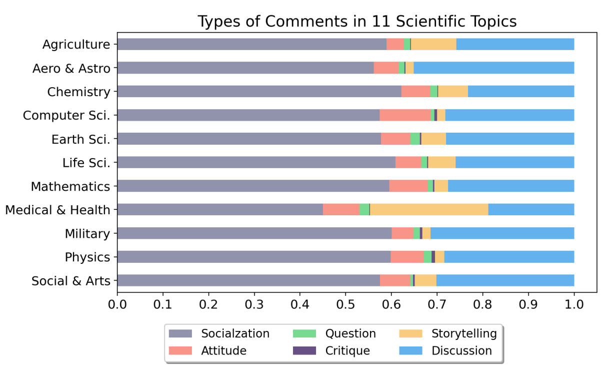


Figure 5: Predictions of the BERT-based Comments Classifier. Among all eleven scientific topics, *Socialization* was the most popular type of comments. In terms of science-knowledge-related comments, *Discussion* was the most popular type in ten topics expect *Medical and healthcare* in which *Storytelling* was the most popular type.

6.5 Method: Regression Analyses of Communication Strategies and Viewer Engagement

Using the quantitative data of the comments and the annotated communication strategies of the 330 sampled science knowledge videos, we conducted a regression analysis to determine whether the communication strategies were correlated to the video comments that served as proxies of the three types of viewer engagement: behavioral engagement, emotional engagement, and cognitive engagement.

6.5.1 Independent Variables. For each regression model, all the features presented in the communication strategy taxonomy (Table 3) were included as independent variables. Before conducting regression analysis, we tested the pair-wise Pearson correlation coefficients among the input variables to address potential multicollinearity issues. The results showed that the pair (*Tone*, *Communicator Type*) had the highest correlation coefficient absolute value of 0.6. The coefficients of all other variable pairs were less than 0.5 (Details in Appendix B). According to previous research, a reasonable threshold can be set to 0.7 [27]. Therefore, no variable was eliminated in our analysis.

Additionally, we converted the variables with categorical values (e.g., *Style*, *Tone*, *Orientation*, and *Communicator Gender*) into dummy variables [19]. This allowed the regression model to fit and report results on each possible value of the categorical variables. For the other boolean variables, we used value 1 for “Yes/With” and value 0 for “No/Without”.

6.5.2 Dependent Variables and Model Selection. For *behavioral engagement*, because all types of comments could be considered as the ways in which viewers engaged with the video, we decided to use the number of first-level comments of the video as the dependent variable. A multivariate negative binomial regression was chosen for behavioral engagement. The reason was that we observed overdispersion in the number of first-level comments of the 330 sample videos, i.e., the standard error (1369.78) was significantly greater than the mean value (867.62) [35].

For *emotional engagement* and *cognitive engagement*, we used the proportion of specific types of comments as the dependent variable. As described in subsection 6.3, cognitive engagement was related to the science-knowledge-related comments. We used the sum of the proportions of the four types of comments to be the dependent variable representing cognitive engagement since proportion reflects the relative magnitude regardless of the video popularity, which varied a lot among different videos in the sample set. Similarly, we used the proportion of *Attitude* comments to represent emotional engagement. Ordinary least squares (OLS) regression (i.e., linear model) was chosen for both kinds of engagement because of the model's simplicity and interpretability [23].

6.6 Results of Regression Analyses

This section reports the results of regression analyses on the correlations between communication strategies and viewer's behavioral, emotional, and cognitive engagements. Although all the communication strategy features were used as independent variables in all three regression models, the tables in this section only displayed independent variables that appeared to have significance.

6.6.1 Communication Strategies and Behavioral Engagement. The results of the negative binomial regression (Table 5) revealed that all three categories of communication strategies correlated with behavioral engagement to some degree. In terms of visual aspects, *Community Culture* significantly positively correlated to the number of first-level comments, while the *schematic diagram* also had a weak positive correlation. *Emotional Arousal* also had a strong positive correlation with behavioral engagement. Combining with the results of the regression analysis on emotional engagement, these findings suggest that *Emotional Arousal* is possible to be an effective communication strategy to leverage viewer engagement. As for the communicator aspect, videos with a *Scientist/Professional* communicator tended to have more post-video comments. However, videos with communicators marked as mixed gender (i.e., had multiple communicators of different genders) got fewer comments.

Table 5: Negative Binomial Regression: The Number of First Level Comments (Behavioral Engagement)

Category	Feature	Coef.	Std.	z	P>|z|
Visual	community_culture ***	0.2541	0.067	3.776	0.000
	(scientific feature) schematic_diagram *	0.1550	0.071	2.185	0.029
Narrative	emotional_arousal ***	0.2173	0.060	3.632	0.000
Communicator	(type) scientist/professional ***	0.2449	0.066	3.703	0.000
	(gender) mixed *	-0.1254	0.058	-2.177	0.031

* p < 0.05; ** p < 0.01; *** p < 0.001

6.6.2 Communication Strategies and Emotional Engagement. The results (Table 6) showed that both visual and narrative communication strategies have correlations with viewers' emotional engagement. The visual style *Animation* and a scientific feature *Formula and Proof*, which was the iconic feature of videos in mathematics and physics topics (section 5) had significant positive correlations to emotional engagement.

Besides, for narrative communication strategies, the *Emotional Arousal* was positively correlated to the proportion of *Attitude* comments in the video, which intuitively conformed to the definition of the strategysection 5. However, *Dramatic Question* negatively correlated with the proportion of *Attitude* comments. Finally, *Debunking* orientation also weakly correlated to emotional engagement, which indicates that for videos with a debunking orientation, viewers tended to post more comments about their emotional reactions.

6.6.3 Communication Strategies and Cognitive Engagement. The results (Table 7) revealed that three narrative features: *Dramatic Question*, *Orientation*, and *Tone* had significant correlations with the proportion of science-knowledge-related comments. Other categories of communication strategies, especially visual communication strategies, showed no significant correlations with cognitive engagement. This indicates that visual communication strategies might not be effective in increasing the proportion of science-knowledge-related comments for a video.

Dramatic Question had a significant positive correlation indicating that the viewers tend to make more science-knowledge-related comments after watching videos with a dramatic question. While an *entertaining* tone and *storytelling* orientation might lead the comments to non-knowledge directions. Besides *Narrative* features, the model revealed that *live recording* visual style was negatively correlated to the proportion of knowledge-related comments.

Table 6: Linear Regression: Proportion of Attitude Comments (Emotional Engagement)

Category	Feature	Coef.	Std.	t	P>|t|
Visual	(style) computer_animation **	0.0073	0.002	3.430	0.001
	(scientific feature) formula_and_proof **	0.0069	0.002	3.473	0.001
Narrative	dramatic_question **	-0.0054	0.002	-2.717	0.007
	emotional_arousal ***	0.0089	0.002	4.495	0.000
	(orientation) debunking *	0.0039	0.002	1.988	0.048

* p < 0.05; ** p < 0.01; *** p < 0.001

Table 7: Linear Regression: Proportion of Science Knowledge-Related Comments (Cognitive Engagement)

Category	Feature	Coef.	Std.	t	P>|t|
Visual	(style) live_recording *	-0.0216	0.010	-2.104	0.036
Narrative	dramatic_question ***	0.0336	0.008	4.101	0.000
	(orientation) storytelling **	-0.0288	0.009	-3.281	0.001
	(tone) entertaining *	-0.0212	0.009	-2.461	0.014

* p < 0.05; ** p < 0.01; *** p < 0.001

6.6.4 Summary of Regression Analysis. In all three regression models, *Narrative* communication strategies showed significant correlations to all three types of engagement represented by the number or the proportion of viewer comments. *Dramatic Question* was positively correlated to the proportion of science-knowledge-related comments but negatively correlated to the proportion of *Attitude* comments (emotional engagement) at the same time. This was intuitive because a good question might inspire viewers to think and discuss the serious scientific topics mentioned in the video. For videos with *Emotional Arousal*, viewers tend to post more comments among which the relative number of *Attitude* comments was also greater.

Communicator did not show any significant correlations to emotional engagement and cognitive engagement in terms of the proportions of their corresponding types of comments. However, videos with a single *scientist/professional* communicator tended to have more comments indicating a higher level of behavioral engagement. *Community Culture*, as a specialized *Visual* feature of science knowledge videos on Bilibili, was also a significant factor that positively correlated with the total number of first-level comments (i.e., behavioral engagement).

7 DISCUSSION

This research highlighted a series of specialized communication strategies commonly used in online science knowledge videos on Bilibili, and then analyzed video comments to investigate the correlations between communication strategies and viewer engagement which was quantified by several types of comments. In this section, we situate our findings within the prior literature and provide design implications for video-based science communication.

7.1 Communication Strategies for Science Storytelling and Visual Rhetoric

Our research identified diverse communication strategies widely used in practice by a large number of science knowledge communicators on Bilibili, which complement prior research that primarily focused on a single or a small number of popular YouTube channels [32, 40, 72, 78]. Our findings, in general, align with the prior literature on video-based science communication that highlighted storytelling as an important strategy to engage viewers [18, 32, 40, 42, 66]. To unleash the power of storytelling and visual rhetoric, prior work argued that science knowledge videos should be produced as *simple*, *unexpected*, *concrete*, *credible*, *emotional*, and *science storytelling* [32]. Several identified communication strategies in our research draw parallel with these principles. For example, for a science knowledge video, dramatic questions make it *unexpected*, emotional arousal makes it *emotional*, and scientific features (e.g., schematic diagrams, data visualizations, mathematical proofs, and science experiments) make it *concrete* and *credible*. However, some of the identified communication strategies contrasted with the *simple* principle proposed in prior work. For example, videos of video clips narrated by voiceovers, videos with scientific features, and videos of creative orientation tended to be more complicated than ordinary videos shared on Bilibili, but these strategies are still widely used by science communicators. We conjecture that such a tendency to create videos with *complexity* may relate to the community culture of Bilibili users, or even cultural differences of Chinese users, which will be further discussed in subsection 7.4.

7.2 Communication Strategies as Community Norms

Communication strategies and other video-specific features provide a base for science knowledge video viewers to learn and engage with scientific knowledge and interact with science communicators. The clarity and fluency brought by the *Visual Styles* and *Narratives* strategies enable viewers to learn scientific knowledge better from graphics and narration [12, 55]. Besides, learning scientific knowledge is just one possible goal of science communication; through providing feedback and responses to science knowledge videos, viewers can further become communicators to spread scientific knowledge, which is similar to the situation of science communication on blogs [46]. It is, therefore, important for video-sharing platforms to further consider the role of science communication strategies and their effects on viewers.

Our results highlighted that different scientific domains might engage different viewers in various ways with different communication strategies. Viewers' behavioral, emotional, and cognitive engagements with videos of different domains also varied. For example, some science knowledge videos may include many scientific theories with jargon and professional terms to ensure their knowledge rigor, which would increase viewers' cognitive load [48, 69]. This may bring challenges for both science communicators and viewers similar to the situation of r/science [4]. Novice science communicators may not be aware of the appropriate communication strategies to be used to maximize viewer engagement and the effect of science communication within the community. Viewers who are newcomers to the community may also find it hard to navigate a large number of science knowledge videos with so many different communication strategies and visual styles. It may be inefficient for viewers to watch a lot of science knowledge videos before they figure out what types of science knowledge videos they really need.

Therefore, a design suggestion to address these challenges for video-sharing platforms is to make it clearer what communication strategies are effective and welcomed in different scientific domains sub-communities on the platform, even providing a map of the effectiveness of different communication strategies in relation to different scientific domains. Such a standard reference table can be created and validated by designated experts or scientists with expertise in science communication. Based on our taxonomy, we believe video-sharing platforms such as Bilibili could provide practical guidelines about communication strategies for creators. For example, those platforms could provide condensed but memorable tips to inform creators of effective strategies to engage viewers upon uploading their videos. They could also provide tutorials to educate novice communicators about how to make engaging science videos. For viewers, the platform could also categorize science videos with different communication strategies and styles, making it easy for them to find the styles that fit their needs.

7.3 Leveraging Video Comments to Drive Dialogues

Dialogue is a primary goal of science communication [11, 50, 57], and much prior work focused on delineating these roles and activities in dialogue [41]. However, exactly how to promote and regulate the dialogue between science video communicators and viewers is theoretically under-explored. Central to science dialogue, comments on video-sharing platforms provide a space where communicators and viewers communicate their opinions and feedback, and produce new insights [38, 76]. The commentary mechanism enables all participants to incubate science dialogues with different contributions to science communication. Comments provide a channel for information exchange in the form of *Discussion*, which accounted for the largest percentage of engaging comments. Comments construct the dialogue between viewers and communicators and between viewers to aid knowledge learning and to involve these participants missing from the dialogue due to misunderstandings and limitations of viewers or the videos. Therefore, comments become invaluable sources and complement videos for science communication and broaden the viewers' participation. Besides, our analysis indicated that viewers are more likely to express their

Attitudes or participate in *Socialization* via comments. These two classes of comments are more likely to have ungrounded information, which may affect viewer engagement and the construction of effective dialogues in science communication [3, 75]. To promote science dialogues by participants, we derived the following design implications for science communication on video-sharing platforms.

7.3.1 *Facilitating Information Stewardship.*

Comments can not only help explain the science knowledge from videos but also affect the subsequent viewer engagement and dialogue construction [41]. However, fake or malicious information can spread in comments partly due to third-party businesses' attempts to boost video engagement metrics to promote content and increase popularity [49]. Prior work found that uncivil comments can change people's interpretation and understanding of fresh information [3], which can also affect the dialogue between participants of science communication. Therefore, the entire platform, including regulators and community users in science communication videos, should play roles in *information stewardship* to ensure the process and effect of dialogue construction.

For regulators and platforms, they should make efforts to develop a system of detecting and discerning fake engagement activities in science communication videos by spammers from legitimate ones, which is inspired by research on other social networks such as Facebook and Amazon [5, 54]. Besides, they can cooperate with communicators (video creators) to impose careful restrictions on comment styles. The platform should provide interfaces for communicators to specify their commenting preferences when uploading science communication videos. For communicators and viewers, communicators need to balance the accessibility of scientific knowledge with rigor, not only to ensure the precision and correctness of their content, but also to be accessible for viewers, especially the lay public, which can facilitate dialogue with a broader audience [41, 59].

7.3.2 *Integrating Resources to Facilitate Dialogue.*

To facilitate dialogue [50, 63] with rigor and engagement in science communication, some resources need to be re-integrated between the platform and participants (i.e. communicators and viewers). For the platform, they can provide some prerequisite video recommendations related to the science communication videos as a mentor [34] to provide basic knowledge for viewers to better understand the video and engage with the dialogue in comments. Besides, the platform can inspire active participants to play roles in information mining and management. The platform should enable science communicators to regularly update and upload their recommended videos to the platform with descriptions, which can be high-quality videos that viewers may have missed because these videos are less promoted by the platform due to low engagement metrics. By doing this, communicators can drive more dialogues without wasting existing resources. Platforms can also aggregate and connect these videos and construct collaborative science videos for viewers to learn together instead of watching alone, which can further drive dialogues. With more active viewers posting positive comments to drive more on-topic dialogue about scientific knowledge, it is likely to reduce the proportion of negative comments and further reduce the community's load of information stewardship, creating a better space for science communication.

7.4 Participatory Community Culture and Science Communication

Some of our findings might be deeply related to the unique participatory community culture of Bilibili [13, 76]. When science communicators consider the purpose of science knowledge video creation, they inevitably consider the community's sub-cultures and norms, which can potentially direct the content, features, and value of videos they want to create. On Bilibili, science communicators have to seriously consider balancing entertainment and scientific rigor so that they could maximize viewer engagement and popularity since enjoyment is a main purpose of viewers to watch science knowledge videos [77]. Our findings showed that many science knowledge videos on Bilibili consisted of several video clips from movies or other fictional videos with voiceovers, which is a unique type of science knowledge video that is hardly seen in prior work. The prevalence of this type of science knowledge videos may result from the fact that Bilibili has been a major hub in China for fan-made videos, audio and video remixes, and pirated video content that users reshared [13, 22, 26]. Compared to its Western counterparts, Bilibili may be less strict about its copyright regulations as well [26], which may be another reason why science communicators leverage professionally-made videos in their science knowledge videos. Many science knowledge videos also directly embed community culture in their storytelling, which could potentially resonate with community members to drive empathy and engagement, because prior work has shown that the relationships between Bilibili users are much more complicated than ordinary online communities and that Bilibili users are keen on providing feedback to content creators [26]. These further highlight the need for science communicators to better know the audience they communicate with, and the need for video-sharing platforms to make it easier for communicators to know their audience [74]. We advocate that future research in science communication should explore more non-mainstream video-sharing platforms and investigate science knowledge communication practices beyond Western platforms, which could bring new insights into online-video-based science communication.

7.5 Limitations

This study has several limitations. First of all, because we focused on the specific platform Bilibili, our findings may not generalize to other platforms or contexts. Secondly, we only took first-level comments into consideration so our analysis did not cover the viewers who do not like posting comments. We also could not capture insightful science-knowledge-centered discussions in the replies of first-level comments, which could also reflect viewers' cognitive engagement. Finally, limited to manpower, our in-depth investigations of online science knowledge videos only covered 330 instances, which was relatively small, especially compared to the number of videos (440,547) uploaded during the six months of our data collection. Future research should consider leveraging automatic approaches for quantitative video analysis.

8 CONCLUSION

In this paper, we presented a mixed-method study about science knowledge videos on Bilibili. We first established a taxonomy of communication strategies, revealing how science communicators strategically create interesting videos to engage viewers. Next, we analyzed the post-video comments of science knowledge videos by categorizing the comments regarding their meaning for science communication. Furthermore, using video comments as the proxy of viewers' behavioral, emotional, and cognitive engagements, we uncovered the correlations between video communication strategies and the three types of viewer engagement. Our findings highlighted the unique affordance of online videos to empower effective science communication practices. We situated this work within existing literature in science communication and HCI, and discussed video-based science communication under current online community norms and the participatory culture of Bilibili. Design implications were made for leveraging the commentary mechanism on video-sharing platforms to facilitate dialogues among the participants to eventually promote public engagement of science.

REFERENCES

[1] Joachim Allgaier. 2019. Science and environmental communication on YouTube: strategically distorted communications in online videos on climate change and climate engineering. *Frontiers in Communication* 4 (2019), 36.

[2] Inoka Amarasekara and Will J Grant. 2019. Exploring the YouTube science communication gender gap: A sentiment analysis. *Public Understanding of Science* 28, 1 (2019), 68–84.

[3] Ashley A Anderson, Dominique E Brossard, Dietram A Scheufele, and Michael A Xenos. 2012. Online talk: how exposure to disagreement in online comments affects beliefs in the promise of contro-versial science. *Citizen voices: Performing public participation in science and environment communication. Bristol: Intellect* (2012), 119–136.

[4] Tal August, Dallas Card, Gary Hsieh, Noah A Smith, and Katharina Reinecke. 2020. Explain like I am a Scientist: The Linguistic Barriers of Entry to r/science. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems.* 1–12.

[5] Alex Beutel, Wanhong Xu, Venkatesan Guruswami, Christopher Palow, and Christos Faloutsos. 2013. Copycatch: stopping group attacks by spotting lockstep behavior in social networks. In *Proceedings of the 22nd international conference on World Wide Web.* 119–130.

[6] Bilibili. 2021. *Report of the Ecological Environment of Content Creators on Bilibili 2021.* Retrieved July 05, 2022 from https://www.bilibili.com/read/cv14332832/

[7] Bilibili. 2022. *About Us - Bilibili.* Retrieved July 04, 2022 from https://www.bilibili.com/blackboard/aboutUs.html

[8] Roderick J Brodie, Ana Ilic, Biljana Juric, and Linda Hollebeek. 2013. Consumer engagement in a virtual brand community: An exploratory analysis. *Journal of business research* 66, 1 (2013), 105–114.

[9] Dominique Brossard. 2013. New media landscapes and the science information consumer. *Proceedings of the National Academy of Sciences* 110, supplement_3 (2013), 14096–14101.

[10] Michael Brüggemann, Ines Lörcher, and Stefanie Walter. 2020. Post-normal science communication: Exploring the blurring boundaries of science and journalism. *Journal of Science Communication* 19, 3 (2020), A02.

[11] Terry W Burns, D John O'Connor, and Susan M Stocklmayer. 2003. Science communication: a contemporary definition. *Public understanding of science* 12, 2 (2003), 183–202.

[12] Hung-Tao M Chen and Megan Thomas. 2020. Effects of lecture video styles on engagement and learning. *Educational Technology Research and Development* 68, 5 (2020), 2147–2164.

[13] Zhaodi Chen and Dali L Yang. 2022. Governing Generation Z in China: Bilibili, bidirectional mediation, and online community governace. *The Information Society* (2022), 1–16.

[14] Jason Chilvers. 2010. Sustainable participation? Mapping out and reflecting on the field of public dialogue on science and technology. (2010).

[15] V Cisco. 2018. Cisco visual networking index: Forecast and trends, 2017–2022. *White paper* 1, 1 (2018).

[16] Isabelle M Côté and Emily S Darling. 2018. Scientists on Twitter: Preaching to the choir or singing from the rooftops? *Facets* 3, 1 (2018), 682–694.

[17] Yiming Cui, Wanxiang Che, Ting Liu, Bing Qin, and Ziqing Yang. 2021. Pre-training with whole word masking for chinese bert. *IEEE/ACM Transactions on Audio, Speech, and Language Processing* 29 (2021), 3504–3514.

[18] Michael F Dahlstrom. 2014. Using narratives and storytelling to communicate science with nonexpert audiences. *Proceedings of the National Academy of Sciences* 111, Supplement 4 (2014), 13614–13620.

[19] GA Darlington. 2005. Dummy variables. *Encyclopedia of biostatistics* 3 (2005).

[20] Sarah R Davies and Noriko Hara. 2017. Public science in a wired world: How online media are shaping science communication. , 563–568 pages.

[21] Sarah R Davies and Maja Horst. 2016. *Science communication: Culture, identity and citizenship.* Springer.

[22] Rebecca Davis. 2020. *China's Streamer Bilibili Aims to Embrace a Wider Audience Without Alienating Its Fans.* Retrieved July 05, 2022 from https://variety.com/2020/digital/features/china-streaming-bilibili-1234617963/

[23] Robyn M Dawes and Bernard Corrigan. 1974. Linear models in decision making. *Psychological bulletin* 81, 2 (1974), 95.

[24] Stéphane Debove, Tobias Füchslin, Tania Louis, and Pierre Masselot. 2021. French Science Communication on YouTube: A Survey of Individual and Institutional Communicators and Their Channel Characteristics. *Frontiers in Communication* 6 (2021).

[25] Jacob Devlin, Ming-Wei Chang, Kenton Lee, and Kristina Toutanova. 2018. Bert: Pre-training of deep bidirectional transformers for language understanding. *arXiv preprint arXiv:1810.04805* (2018).

[26] Xianghua Ding, Yubo Kou, Yiwen Xu, and Peng Zhang. 2022. "As Uploaders, We Have the Responsibility": Individualized Professionalization of Bilibili Uploaders. In *CHI Conference on Human Factors in Computing Systems.* 1–14.

[27] Carsten F Dormann, Jane Elith, Sven Bacher, Carsten Buchmann, Gudrun Carl, Gabriel Carré, Jaime R García Marquéz, Bernd Gruber, Bruno Lafourcade, Pedro J Leitão, et al. 2013. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography* 36, 1 (2013), 27–46.

[28] Ilana Dubovi and Iris Tabak. 2021. Interactions between emotional and cognitive engagement with science on YouTube. *Public Understanding of Science* 30, 6 (2021), 759–776.

[29] John R Durant, Geoffrey A Evans, and Geoffrey P Thomas. 1989. The public understanding of science. *Nature* 340, 6228 (1989), 11–14.

[30] Michelle L Edwards and Caden Ziegler. 2022. Examining science communication on Reddit: From an "Assembled" to a "Disassembling" approach. *Public Understanding of Science* 31, 4 (2022), 473–488.

[31] Daniel Fernández Galeote, Nikoletta-Zampeta Legaki, and Juho Hamari. 2022. Avatar Identities and Climate Change Action in Video Games: Analysis of Mitigation and Adaptation Practices. In *CHI Conference on Human Factors in Computing Systems.* 1–18.

[32] Wiebke Finkler and Bienvenido León-Anguiano. 2019. The power of storytelling and video: a visual rhetoric for science communication. (2019).

[33] Baruch Fischhoff. 2013. The sciences of science communication. *Proceedings of the National Academy of Sciences* 110, supplement_3 (2013), 14033–14039.

[34] Denae Ford, Kristina Lustig, Jeremy Banks, and Chris Parnin. 2018. "We Don't Do That Here": How Collaborative Editing with Mentors Improves Engagement in Social Q&A Communities. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. New York, NY, USA, 1–12. https://doi.org/10.1145/3173574.3174182

[35] William Gardner, Edward P Mulvey, and Esther C Shaw. 1995. Regression analyses of counts and rates: Poisson, overdispersed Poisson, and negative binomial models. *Psychological bulletin* 118, 3 (1995), 392.

[36] Katy Ilonka Gero, Vivian Liu, Sarah Huang, Jennifer Lee, and Lydia B Chilton. 2021. What Makes Tweetorials Tick: How Experts Communicate Complex Topics on Twitter. *Proceedings of the ACM on Human-Computer Interaction* 5, CSCW2 (2021), 1–26.

[37] Noriko Hara, Jessica Abbazio, and Kathryn Perkins. 2019. An emerging form of public engagement with science: Ask Me Anything (AMA) sessions on Reddit r/science. *PloS one* 14, 5 (2019), e0216789.

[38] Changyang He, Lu He, Tun Lu, and Bo Li. 2021. Beyond Entertainment: Unpacking Danmaku and Comments' Role of Information Sharing and Sentiment Expression in Online Crisis Videos. *Proceedings of the ACM on Human-Computer Interaction* 5, CSCW2 (2021), 1–27.

[39] Linda Hollebeek. 2011. Exploring customer brand engagement: definition and themes. *Journal of strategic Marketing* 19, 7 (2011), 555–573.

[40] Tianle Huang and Will J Grant. 2020. A good story well told: Storytelling components that impact science video popularity on YouTube. *Frontiers in Communication* 5 (2020), 86.

[41] Ridley Jones, Lucas Colusso, Katharina Reinecke, and Gary Hsieh. 2019. rscience: Challenges and opportunities in online science communication. In *Proceedings of the 2019 CHI conference on human factors in computing systems.* 1–14.

[42] Marina Joubert, Lloyd Davis, and Jennifer Metcalfe. 2019. Storytelling: the soul of science communication. , E pages.

[43] Dan M Kahan. 2017. 'Ordinary science intelligence': A science-comprehension measure for study of risk and science communication, with notes on evolution and climate change. *Journal of Risk Research* 20, 8 (2017), 995–1016.

[44] M Laeeq Khan. 2017. Social media engagement: What motivates user participation and consumption on YouTube? *Computers in human behavior* 66 (2017), 236–247.

[45] Shahedul Huq Khandkar. 2009. Open coding. *University of Calgary* 23 (2009), 2009.

[46] Inna Kouper. 2010. Science blogs and public engagement with science: Practices, challenges, and opportunities. *Journal of science communication* 9, 1 (2010), A02.

[47] Julie Letierce, Alexandre Passant, John Breslin, and Stefan Decker. 2010. Understanding how Twitter is used to spread scientific messages. (2010).

[48] Petra J Lewis. 2016. Brain friendly teaching—reducing learner's cognitive load. *Academic radiology* 23, 7 (2016), 877–880.

[49] Yixuan Li, Oscar Martinez, Xing Chen, Yi Li, and John E Hopcroft. 2016. In a world that counts: Clustering and detecting fake social engagement at scale. In *Proceedings of the 25th International Conference on World Wide Web*. 111–120.

[50] Steve Miller. 2001. Public understanding of science at the crossroads. *Public understanding of science* 10, 1 (2001), 115–120.

[51] Jesús Muñoz Morcillo, Klemens Czurda, Andrea Geipel, and Caroline Y Trotha. 2019. Producers of Popular Science Web Videos. Between New Professionalism and Old Gender Issues. *arXiv preprint arXiv:1908.05572* (2019).

[52] Jesús Muñoz Morcillo, Klemens Czurda, and Caroline Y Trotha. 2015. Typologies of the popular science web video. *arXiv preprint arXiv:1506.06149* (2015).

[53] Vicki Moulder, Lorna R Boschman, Ron Wakkary, Carman Neustaedter, and Hiroki Hill Kobayashi. 2018. HCI interventions for science communication. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–9.

[54] Arjun Mukherjee, Bing Liu, and Natalie Glance. 2012. Spotting fake reviewer groups in consumer reviews. In *Proceedings of the 21st international conference on World Wide Web*. 191–200.

[55] Sophie A Nicholson-Cole. 2005. Representing climate change futures: a critique on the use of images for visual communication. *Computers, environment and urban systems* 29, 3 (2005), 255–273.

[56] Kristian H Nielsen. 2013. Scientific communication and the nature of science. *Science & Education* 22, 9 (2013), 2067–2086.

[57] Matthew C Nisbet and Dietram A Scheufele. 2009. What's next for science communication? Promising directions and lingering distractions. *American journal of botany* 96, 10 (2009), 1767–1778.

[58] Web of Science. 2022. *Web of Science Core Collection Help*. Retrieved Aug 15, 2022 from https://images.webofknowledge.com/images/help/WOS/hp_subject_category_terms_tasca.html

[59] Nigini Oliveira, Michael Muller, Nazareno Andrade, and Katharina Reinecke. 2018. The exchange in StackExchange: Divergences between Stack Overflow and its culturally diverse participants. *Proceedings of the ACM on Human-Computer Interaction* 2, CSCW (2018), 1–22.

[60] Vineet Pandey, Amnon Amir, Justine Debelius, Embriette R Hyde, Tomasz Kosciolek, Rob Knight, and Scott Klemmer. 2017. Gut instinct: Creating scientific theories with online learners. In *Proceedings of the 2017 CHI conference on human factors in computing systems*. 6825–6836.

[61] Vineet Pandey, Justine Debelius, Embriette R Hyde, Tomasz Kosciolek, Rob Knight, and Scott Klemmer. 2018. Docent: transforming personal intuitions to scientific hypotheses through content learning and process training. In *Proceedings of the Fifth Annual ACM Conference on Learning at Scale*. 1–10.

[62] Mathieu Ranger and Karen Bultitude. 2016. 'The kind of mildly curious sort of science interested person like me': Science bloggers' practices relating to audience recruitment. *Public Understanding of Science* 25, 3 (2016), 361–378.

[63] Cathelijne M Reincke, Annelien L Bredenoord, and Marc HW van Mil. 2020. From deficit to dialogue in science communication: the dialogue communication model requires additional roles from scientists. *EMBO reports* 21, 9 (2020), e51278.

[64] Fabiola Cristina Rodríguez Estrada and Lloyd Spencer Davis. 2015. Improving visual communication of science through the incorporation of graphic design theories and practices into science communication. *Science Communication* 37, 1 (2015), 140–148.

[65] Alexander Romiszowski and Robin Mason. 2013. Computer-mediated communication. In *Handbook of research on educational communications and technology*. Routledge, 402–436.

[66] Selina A Ruzi, Nicole M Lee, and Adrian A Smith. 2021. Testing how different narrative perspectives achieve communication objectives and goals in online natural science videos. *PloS one* 16, 10 (2021), e0257866.

[67] Molly J Simis, Haley Madden, Michael A Cacciatore, and Sara K Yeo. 2016. The lure of rationality: Why does the deficit model persist in science communication? *Public understanding of science* 25, 4 (2016), 400–414.

[68] Patrick Sturgis and Nick Allum. 2004. Science in society: re-evaluating the deficit model of public attitudes. *Public understanding of science* 13, 1 (2004), 55–74.

[69] John Sweller. 1994. Cognitive load theory, learning difficulty, and instructional design. *Learning and instruction* 4, 4 (1994), 295–312.

[70] Mike Thelwall, Pardeep Sud, and Farida Vis. 2012. Commenting on YouTube videos: From Guatemalan rock to el big bang. *Journal of the American society for information science and technology* 63, 3 (2012), 616–629.

[71] Jean Trumbo. 1999. Visual literacy and science communication. *Science communication* 20, 4 (1999), 409–425.

[72] Dustin J Welbourne and Will J Grant. 2016. Science communication on YouTube: Factors that affect channel and video popularity. *Public understanding of science* 25, 6 (2016), 706–718.

[73] Spencer Williams and Gary Hsieh. 2021. The Effects of User Comments on Science News Engagement. *Proceedings of the ACM on Human-Computer Interaction* 5, CSCW1 (2021), 1–29.

[74] Spencer Williams, Ridley Jones, Katharina Reinecke, and Gary Hsieh. 2022. An HCI Research Agenda for Online Science Communication. *Proceedings of the ACM on Human-Computer Interaction* 6, CSCW2 (2022), 1–22.

[75] Stephan Winter and Nicole C. Krämer. 2016. Who's right: The author or the audience? Effects of user comments and ratings on the perception of online science articles. *Communications* 41, 3 (2016), 339–360. https://doi.org/10.1515/commun-2016-0008

[76] Qunfang Wu, Yisi Sang, Shan Zhang, and Yun Huang. 2018. Danmaku vs. forum comments: understanding user participation and knowledge sharing in online videos. In *Proceedings of the 2018 ACM conference on supporting groupwork*. 209–218.

[77] Haijun Xia, Hui Xin Ng, Zhutian Chen, and James Hollan. 2022. Millions and Billions of Views: Understanding Popular Science and Knowledge Communication on Video-Sharing Platforms. In *Proceedings of the Ninth ACM Conference on Learning@ Scale*. 163–174.

[78] Shiyu Yang, Dominique Brossard, Dietram A Scheufele, and Michael A Xenos. 2022. The science of YouTube: What factors influence user engagement with online science videos? *Plos one* 17, 5 (2022), e0267697.

[79] Yang Yuyu and Zhang Pengyi. 2020. Social Tagging of ACG Video Contents and the Entertainment Tagging Trend: A Case Study of Bilibili. com. *Library and Information Service* 64, 8 (2020), 125.

[80] Yiqiong Zhang, Susan Herring, and Suifu Gan. 2022. Graphicon Evolution on the Chinese Social Media Platform BiliBili. In *Proceedings of the The Fifth International Workshop on Emoji Understanding and Applications in Social Media*. 75–85.

A TOP-1000 FREQUENT HASHTAGS AND COVERAGE CURVE

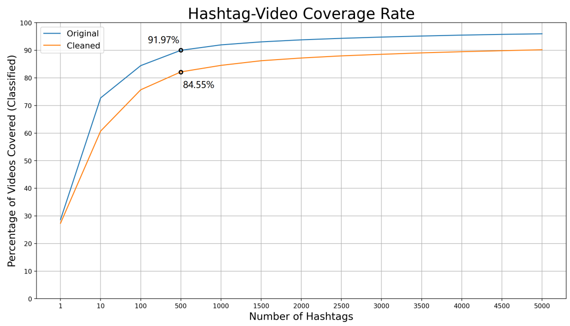


Figure 6: Hashtag-video Coverage Rate Curve. The marginal diminishing trend indicated that increasing the number of annotated hashtags could only reward a small number of videos to be covered. When filtering out exterior (i.e., non-content-related) hashtags, the coverage rate decreased because high-frequent exterior hashtags dropped out and relatively low-frequent interior hashtags were filled in. Eventually, the curve shows 84.55% of the videos can be classified by the 1,000 frequent interior hashtags.

B THE CORRELATION MATRIX OF INDEPENDENT VARIABLE (VIDEO FEATURE) PAIRS

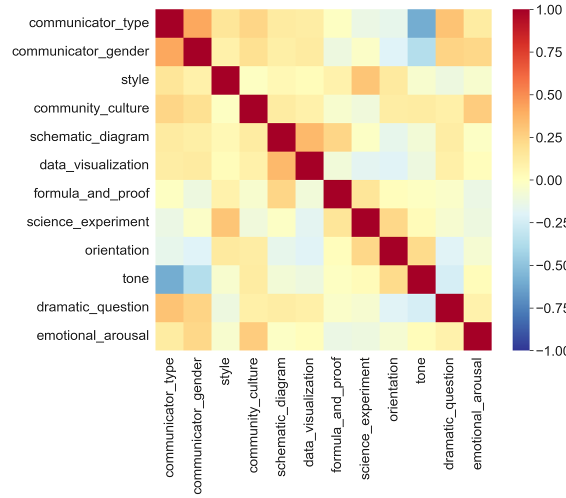


Figure 7: Correlation Matrix of All Independent Variable Pairs. The maximum absolute value of correlation coefficient was generated by (tone, communicator type) as 0.60. The second highest absolute value was generated by (communicator gender, communicator type) as 0.42. For all other variables pairs, the absolute values of correlation coefficient were less than 0.40.