



# Beyond Entertainment: Unpacking Danmaku and Comments' Role of Information Sharing and Sentiment Expression in Online Crisis Videos

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Online videos are playing an increasingly important role in timely information dissemination especially during public crises. Video commentary, synchronous or asynchronous, is indispensable in viewers' engagement and participation, and may in turn contribute to video with additional information and emotions. Yet, the roles of video commentary in crisis communications are largely unexplored, which we believe that an investigation not only provides timely feedback but also offers concrete guidelines for better information dissemination. In this work, we study two distinct commentary features of online videos: traditional asynchronous comments and emerging synchronous danmaku. We investigate how users utilize these two features to express their emotions and share information during a public health crisis. Through qualitative analysis and applying machine learning techniques on a large-scale danmaku and comment dataset of Chinese COVID-19-related videos, we uncover the distinctive roles of danmaku and comments in crisis communication, and propose comprehensive taxonomies for information themes and emotion categories of commentary. We also discover the unique patterns of crisis communications presented by danmaku, such as collective emotional resonance and style-based highlighting for emphasizing critical information. Our study captures the unique values and salient features of the emerging commentary interfaces, in particular danmaku, in the context of crisis videos, and further provides several design implications to enable more effective communications through online videos to engage and empower users during crises.

CCS Concepts: • **Human-centered computing** → **Collaborative and social computing**.

Additional Key Words and Phrases: Video Commentary Interface; Danmaku and Comments; Crisis Communication; Information Sharing; Sentiment Expression

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Fig. 1. Interface of Danmaku Commenting on Bilibili. Viewers contribute to video content synchronously through danmaku and directly influence what others may see in the video, which brings potential values in crisis communication. For example, the danmaku in the white box corrects the misbehavior of the video character by pointing out "You should cover your nose when wearing the mask".

## 1 INTRODUCTION

In recent years, we have witnessed the increasing popularity of online video websites as an information source to engage the general public in creating and disseminating video information. Online video websites are distinctive from traditional social media platforms such as Twitter and Facebook by exclusively using audio and video content for information dissemination, and generally more accessible to all demographic backgrounds [28]. During crises when timely, accurate, and situated information is crucial for a wide audience, online crisis videos are increasingly used in addition to traditional social media platforms due to their high interactivity and the ability in providing richer and real-time information dissemination. For instance, during the H1N1 influenza pandemic, Centers for Disease Control and Prevention (CDC) in the United States adopted a strategic use of videos posted on YouTube to deliver information to the public, garnering millions of views on YouTube [66].

Video commentary interface<sup>1</sup> is an indispensable component in online video platforms for viewers to communicate with others, share relevant information [42], express emotions [53], and build connections [27]. Conventional video commentary interface is often placed in a comment box under videos, making watching videos and accessing video comments two separate and asynchronous procedures. As such, the immediacy of communications through commentary is limited, which might lead to a decline in users' sharing intention and the ignorance of other viewers' responses [38]. Recently, new synchronous commentary features are emerging. Among them, danmaku has gained increasing popularity especially in Japan and China and received growing attention in the HCI and CSCW community [10, 29, 31, 38, 67]. Unlike traditional video comments, danmaku floats above videos and flies by from right to left for several seconds. It has two distinct features: (1) anonymous posting [67] and (2) fixed showing period on the video timeline assigned by the commenter regardless of the actual post time [38]. Such a design allows viewers to synchronously contribute to video content and directly influence how others may view and perceive the video, as shown in Figure 1.

With live and synchronized danmaku, the video content that viewers see is collectively composed by the original video creator(s) and collaborative contributions of danmaku posts. Most prior works on danmaku examined its role in engaging and entertaining viewers, while how viewers

<sup>1</sup>In this paper, we use "commentary" to represent all forms of user commenting during or after watching the video, instead of the narrow sense of commenting box below the video.

contribute to videos through danmaku and what influence it imposes on information dissemination largely remain unknown. Such video content "co-creation" by viewers, beyond entertainment, have significant implications on the timely information dissemination as well as viewer perception in crisis videos, where accurate, timely and situational information is required while misinformation is rampant [28, 43]. A rich stream of research in HCI and CSCW has examined crisis communication in traditional social media like Facebook and Twitter (e.g., [19, 23, 24, 46, 58]). Such crisis communication is characterized by the collaborative work in creating and disseminating situational information [39, 65, 72] and offering emotional support [13, 48, 49]. On the other hand, though online crisis videos have received increasingly more attention in crisis informatics and communication [4, 5, 44, 66], the existing literature generally considers the video creators as the sole source of information and disregards the viewers' participation. No previous work, to the best of our knowledge, has examined the collaborative contributions of viewers to crisis videos through commentary especially danmaku, which directly influence what others may view and perceive in watching the video. The unique features of danmaku compared to traditional comments, such as anonymity, synchronicity and diverse styles, may further characterize crisis communication in danmaku with special patterns.

This work is the first attempt to explore how users utilize danmaku and comments to contribute to crisis videos. We investigate users' contribution from the perspectives of **information sharing** and **sentiment expression**, which are two core components in crisis communication [22, 48, 49] and two dominant aspects that capture all the danmaku and comments as revealed in our iterative qualitative data coding. We aim to understand how different commentary designs influence such behaviors, and how to better design commentary interface to support public collaborative contribution to videos. Specifically, we propose the following research questions:

- **RQ1:** How prevalent is information sharing and sentiment expression in danmaku compared to comments in crisis videos?
- **RQ2:** What emotions and information themes have emerged in danmaku and comments of crisis videos?
- **RQ3:** What are the unique patterns of danmaku-based and comment-based information sharing and sentiment expression in crisis videos?

To answer these questions, we collect 777,865 danmaku and 1,539,629 reviews from top 1,000 viewed COVID-19-related videos on bilibili.com, the largest danmaku video websites in China, and apply a mixed-methods approach to analyze the data by leveraging natural language processing techniques and qualitative analysis. We discover that sentiment expression is more prevalent in danmaku, while information sharing is more common in video comments. By building taxonomies of hierarchical information themes and fine-grained emotion categories, we reveal that video viewers rely on danmaku more to collectively express positive emotions (e.g., admiration and encouragement), and utilize comments more to individually vent their negative emotions such as criticisms. In addition, we find that viewers share more domain knowledge as well as information that is specifically related to certain sections of videos through danmaku, while information on the major topic of video is more commonly observed in comments. Several unique sentiment expression and information sharing patterns emerge in danmaku, such as *interactive emotion communication* and *style-based highlighting* to emphasize critical crisis information. Based on the findings, we further discuss the potential of synchronous commentary in crisis videos to more effectively engage and empower the public.

In conclusion, this work contributes to the HCI and CSCW community mainly by: (1) understanding viewers' contributions to crisis videos through commentary instead of only being engaged; (2)

proposing comprehensive taxonomies for information themes and emotion categories of commentary in crisis videos; (3) discovering unique hypertext patterns of crisis communication in danmaku and comments; and (4) highlighting design implications for video commentary to facilitate crisis communication. Our study reveals the unique benefits of synchronous commentary interface in crisis videos, and sheds light on richer and more intelligent commentary interfaces that satisfy variant sentiment expression and information sharing needs of viewers during crises.

## 2 RELATED WORK

### 2.1 Crisis Communication on Social Media

A burgeoning body of research in the fields of crisis communication and informatics has demonstrated the importance of using social media platforms in response to crisis events as well as the corresponding positive and negative effects [19, 23, 24, 46, 58, 59]. A consistent feature of such platforms under different crises is the "crowdsourcing" way of information creation and dissemination to increase situational awareness [39, 65, 72]. For instance, Vieweg et al. showed that stakeholders collectively shared and spread situational information (e.g., message with geo-location) on Twitter to enhance public situational awareness in crises [65]. Such crowdsourced information further facilitates collective sense-making [23] and risk assessment for decision-making [19]. In addition, sentiment expression [30, 48, 49] is another typical practice of social media crisis communication. For instance, Qu et al. revealed that people expressed depression, anger and sadness, sought for emotional help and mutually provided emotional support in crisis [48]. The crowdsourced situational information, and the community-based emotional disclosure and support, characterize crisis communication on social media and influence millions' crisis response.

Public health crises, characterized by enormous uncertainties and risks [19], present unique needs for crisis communication through social media [25]. First, scientific knowledge and authoritative guidance during public health crises evolve constantly [20] (e.g., mask-wearing policies in COVID-19 [21]). Also, public health crises typically affect a relatively large area, and the conditions and measures vary across different regions [16]. Consequently, collaborative work in communicating timely and situational information through social media can be particularly crucial during public health crisis.

In addition to traditional social media like Twitter and Facebook, online video platforms, with enormous popularity and easy accessibility [47], are playing an increasingly important role in communicating information during crises. For example, during the COVID-19 pandemic, many COVID-19-related videos emerged in different languages [5, 43, 74], and millions across the globe have turned to those online videos for information and support [5]. However, most existing work on crisis videos treats online videos as single-source media contributed only by video creators, while the collaborative work of users, which is typical in traditional social media, is largely neglected. In reality, viewers could not only actively engage in online video, but also collaboratively contribute to video content through commentary, especially the emerging danmaku, with additional timely and situated crisis information as well as emotional support. This work aims to fill this gap by investigating how users contribute to videos by sharing information and expressing emotions through commentary interfaces, how commentary designs influence such crisis communication, and how to better design commentary interface to support the collaborative contribution to videos.

### 2.2 Danmaku: An Interaction Channel Featured in Synchronization and Anonymity

Danmaku is a novel interaction feature that has gained increasing attention from video and live streaming researchers in the HCI and CSCW community [11, 29, 34, 35, 38, 67]. First introduced by Nico Nico Douga in 2007 for fans of anime, comics and games (ACG), Danmaku has gained wide

popularity in Japan and China and overwhelmed videos beyond ACG such as movies, TV series and video blogs (vlogs). *Bilibili.com* [7], the largest danmaku video website in China, has retained 172 million monthly users in the first quarter of 2020 and ranked 3<sup>th</sup> of Arts and Entertainment Websites globally after *youtube.com* and *netflix.com* [55].

Danmaku distinguishes itself from traditional video comments in two unique characteristics: (1) synchronization, with a fixed showing period on the video timeline regardless of the actual posting time. It builds a strong tie between danmaku and instantaneous video content, creates a co-watching atmosphere [10], and empowers viewers to contribute to video synchronously; (2) anonymity, with only text "flying" over the screen and no visible user identity information [67]. Users can also adjust the displaying styles of danmaku including font size, color and displaying mode (*fixed at the top*, *fixed at the bottom*, or normal "*flying*"). Special interpersonal and hyperpersonal interaction behaviors have emerged and developed based on danmaku's features. For instance, at some specific emotional triggers during videos, a large amount of danmaku similar in syntactic and semantic features appear concurrently [10, 38], leading to a "screen-flooding" phenomenon. In addition, location, color, or content-based referencing instead of direct reply is used to identify communication addressees because of anonymity [38]. Diverse roles such as caption providers, plotters, and norm regulators also appear in this special video-viewing community [67].

With those unique features, the benefits and challenges of danmaku usages have been explored in different types of videos such as live streaming [29, 34], political videos [71] and online learning [69]. Yet, to our best knowledge, there is still a dearth of research on how danmaku involves in crisis communication in crisis videos, where danmaku not only captures viewer engagement, but also actively contributes to video content with user-generated emotions and additional situated information. To address this gap, we systematically investigate danmaku's role in information sharing and sentiment expression in crisis videos as well as its characteristics compared to traditional comments, in order to explore the full potential of danmaku in facilitating crisis communication.

### 2.3 Information Sharing and Sentiment Expression in Commentary: A Potentially Valuable Resource in Crisis

It is intuitive and a common practice for viewers to comment during or after video watching [27]. The user-generated video commentary, saturated with user specific information and emotions, is of great research and practice value beyond being a venting channel during crises. First, video commentary serves as a valuable resource for viewers to seek additional video-related information [12]. An empirical analysis on Youtube science channel revealed that the discussion through video comments helped to reach a higher level of knowledge construction than the knowledge in the video itself [14]. The significance of such collaborative knowledge construction is amplified in crisis videos where reliable information is crucial yet misinformation is prevalent [28]. More evidently, with the rapid temporal evolvement and the huge regional disparities of crisis situations [6, 26, 64], the recent and situated information in video commentary could help viewers to better digest crisis video content for personal needs. Second, viewers commonly express emotions sparked by video content through video commentary [1, 53]. In the context of crises characterized by feelings of uncertainties, viewers may further use video commentary to disclose concerns and criticisms, empathize with others and mutually express emotional comforts. The emotions in crisis video commentary provide timely feedback for government agencies to learn about civic attitudes and concerns during crisis [2, 62], and also help researchers understand video-based crisis psychology [51].

As an emerging synchronous commentary feature, danmaku has been proven to be an effective information sharing and emotion venting channel [38]. The distinctive characteristics of danmaku results in a different commenting behavior pattern in information sharing and sentiment expression compared to conventional video comments. For example, Wu et al. revealed that more negative

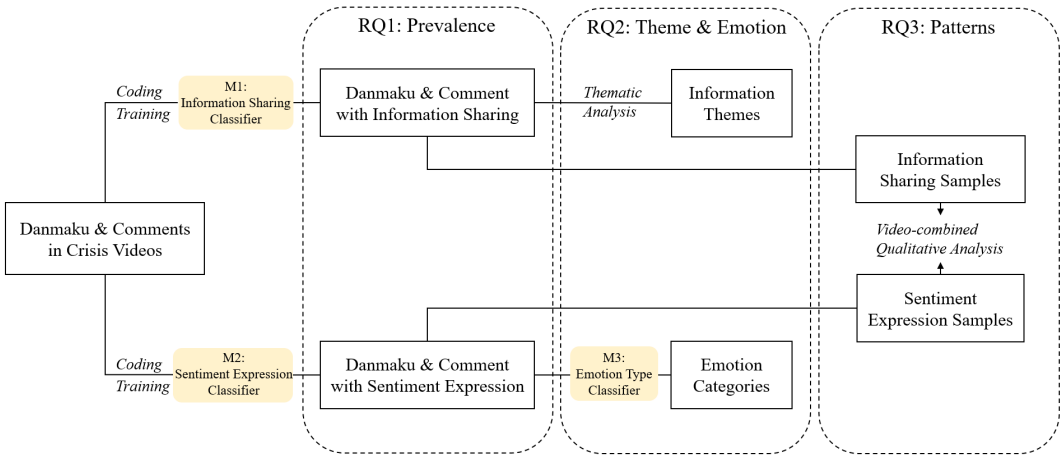


Fig. 2. Overall Analytical Flow

emotions were expressed in danmaku compared to video comments, and danmaku had more explicit knowledge sharing instead of tacit knowledge sharing [67]. Another qualitative analysis on danmaku in political videos found that danmaku encouraged users to leave more playful comments compared to the serious reflection on the political content in video comment [71].

These works provided initial insights into the different user behaviors in the two commentary channels. Nonetheless, there lacks a comprehensive understanding of danmaku and comments' different roles of information sharing and sentiment expression in crisis videos, which would be significant to comprehend the full potential of the two commentary designs in supporting crisis communication. This work fills this gap, and contributes to CSCW and HCI community by revealing respective roles of danmaku and comments and providing design implications for video commentary in facilitating effective and engaging crisis communication.

### 3 METHOD

This paper reports an in-depth investigation into danmaku and comments' role of information sharing and sentiment expression in crisis videos. We adopted a mixed-methods approach, incorporating natural language processing and qualitative analysis. To answer RQ1, We built two machine learning classifiers to quantify the prevalence of information sharing and sentiment expression in danmaku and comments. To address RQ2, we applied qualitative thematic analysis to uncover information themes and built a quantitative emotion classifier to identify the emotion categories. To solve RQ3, we systematically reviewed danmaku and comments in 50 crisis video samples across different topics combined with corresponding video context, and assisted with quantitative analysis to validate the empirical findings. The overall analytical flow is illustrated in Figure 2. Based on this framework, we seek to unpack the information sharing and sentiment expression behavior in danmaku and comments in crisis videos, and understand the potential of them as building blocks within online video platforms to facilitate crisis communication.

#### 3.1 Data Collection and Processing

Among all video websites with the danmaku feature, we collected data from bilibili.com, the largest danmaku video website in China, because it included a large number of COVID-19-related videos created by both the government and the general public, and had received numerous user-generated

danmaku and video comments. Using the Bilibili official API, we crawled the top 1,000 most-viewed potentially COVID-19-related videos as the initial dataset through keyword search "新冠肺炎" (Chinese expression for "COVID-19") on bilibili. The data collection was conducted on March 14, 2020, one week after new cases in China per day dropped below 100 [45]. Consequently, the collected dataset was representative to cover nearly all significant COVID-19-related events from outbreak, peak to gradual control of COVID-19 in China, and combined videos generated by both government and civic video uploaders.

To eliminate irrelevant data and get a deeper understanding of the context of danmaku and comments, we manually viewed, filtered, and coded the themes of the 1,000 videos. Two coders whose native language is Chinese separately watched 100 video clips first and determined whether the videos were related to COVID-19. Videos whose titles or descriptions contained COVID-19 yet with irrelevant content, e.g., videos unrelated to COVID-19 but claiming "all proceeds will be donated to COVID-19" in the video description, were excluded. The agreement ratio was 0.95, indicating substantial agreement. The disagreement was resolved with the help of a third coder following the majority rule. Then, the two annotators used grounded theory [8] to generate a codebook of video themes. Using the 100 video samples, they assessed the video content, referenced the video titles and descriptions, separately developed theme codes and finally confirmed the codebook together through several rounds of discussion. Based on the codebook, each of the two authors further coded 450 remaining videos on relevance and themes, through which all videos in the dataset were assigned with relevance and theme labels. No new theme code appeared in this process. This step excluded 121 unrelated videos, leaving 879 COVID-19-related videos categorized into five themes.

According to the video IDs of the 879 COVID-related video clips, we obtained the corresponding danmaku and comments data. The metadata of danmaku included *text*, *the timestamp of posting*, *time of the appearance in the video*, *font size*, *font color*, *scrolling mode*, *category*, and *virtual user ID* (hashed to keep the anonymity of danmaku). The metadata of comments included *text*, *user ID*, *poster ID*, *the timestamp of posting*, *the number of likes and replies*, and *the top 3 hot-replies*.

### 3.2 RQ1: Predicting the Prevalence of Information Sharing and Sentiment Expression

To answer RQ1 (the prevalence of sentiment expression and information sharing), codes of whether a danmaku or comment expressed emotion and/or shared information were to be assigned. Therefore, we first generated a training dataset through manually annotating the corpus as illustrated in Section 3.2.1, and then built reliable information sharing and sentiment expression text classifiers to generalize the human-assigned codes to the whole dataset as described in Section 3.2.2.

**3.2.1 Corpus Annotation.** Initially, two annotators read 100 danmaku and 100 comment samples to get a general sense of the data, and annotated them separately on (1) whether the post shared information, and (2) whether the post expressed sentiment. Though there are several definitions of "information" with similar core concepts, we followed Losee's definition of information as "statements or facts that are received by a human and that have some form of worth to the recipient" [32]. The posts identified with emotion sharing can be either sharing explicit sentiment (e.g., "I feel relaxed after watching this video.") or implicit sentiment inferred from statements (e.g., "Come on, Wuhan!"). Two coder's agreement ratio of annotation was high (0.91 on average), and the differences were resolved through discussion. Then, the two annotators continued to code another 400 danmaku and 400 comments, yielding an annotated dataset with 500 danmaku and 500 comments in total.

**3.2.2 Machine Learning Model Building.** Using the manual annotations of 1,000 danmaku and comments, we built machine learning models to predict whether a danmaku or comment post shared information or expressed sentiments (*M1: Information Sharing Classifier* and *M2: Sentiment*

*Expression Classifier* in Figure 2). Note that we developed two independent models for information sharing and sentiment expression instead of building a 4-class classifier. The major reason is that we aimed to reveal the prevalence of each variable and make comparisons between danmaku and comments instead of investigating the correlation between information sharing and sentiment expression. Also, the performance of a combined classifier was not good (f1 score < 65%).

We first processed the danmaku and comments text data in preparation for text classification. Before normal text preprocessing procedures, we designed several extra processing steps for danmaku that accounted for the unique characteristics of danmaku, including: (1) normalizing the reduplicated characters that had special meaning in danmaku (e.g., "hhhhhhh" for laughing) [67] by only keeping 3 characters as the length did not influence the meaning; (2) transferring emoticons (e.g., "(-\_-;)" for "nervous") to corresponding meaning by referencing *Bilibili Danmaku Emoticon Set*<sup>2</sup>; (3) replacing pointers such as "←", which were used to reference addressees in communication [38], with the corresponding directions in words. As emoticons and pointers rarely occurred in video comments, we normalized reduplicated characters and translated emoji with their corresponding meaning for video comments instead.

The following steps transferred the processed text into the vector representation. We first conducted text segmentation using Jieba, a widely-adopted Chinese word segmentation module in python [60]. Stopwords were removed based on HIT Chinese stopwords table [18]. Then, we trained Word2Vec word embedding model with 300 dimensions for danmaku and comments separately [40], and adopted average word vectors to represent document-level vectors, which have been adopted in a wide range of tasks and proved to be effective for short text [61, 68].

Taking the 300-dimension danmaku / comment vector as the input feature, we compared multiple classification algorithms such as SVM, KNN and Logistic Regression, aiming to find the model with the best performance. We finally selected XGBoost [9] for its highest F1 score among all algorithms. We tuned two hyperparameters to optimize classifiers, which were maximum depth of trees and minimum sum of instance weights in a child.

### 3.3 RQ2: Generating Information Themes and Emotion Categories

To explore what information themes and emotion categories emerged in danmaku and comments in crisis videos, we first read 100 danmaku and 100 comment posts to get a general sense of the data. We noticed that the emotions in the posts were semantically intuitive, while information themes were more complicated with much hidden information beyond text feature, especially for danmaku data. As an interactive communication channel, demonstrative and personal pronouns were commonly used and represented part of the information, e.g., "You (*refer to the video character*) wear the mask improperly", or "This (*refer to the link given in the video*) is not reliable". Further, given the co-watching simulation, danmaku-based information sharing often required prior knowledge given by video context, e.g., "(*The mechanism introduced in the video that the coronavirus developed a membrane outside their protein*) helps the virus enter cells more easily". As such, though video watchers could easily get the meaning of danmaku under the specific context, it was hard to identify information themes directly from plain text without joint analysis of video content. This challenge was much less observed in sentiment expression. Consequently, we designed different processing strategies, using qualitative thematic analysis to identify information themes and quantitative emotion type classifier to predict emotion categories.

**3.3.1 Qualitative Thematic Analysis.** We randomly sampled 500 danmaku and 500 comments from those predicted with information sharing in Section 3.2 for qualitative thematic analysis. Two investigators separately identified the information themes, and merged the codes through discussion.

<sup>2</sup><https://www.bilibili.com/read/cv3312482/>



We used grounded theory [8] to code the data. For each danmaku post, we assigned theme codes through joint analysis of video context by locating the timestamp of the danmaku's appearance in the video and watching a short period to get the context of the post. For each comment post, we also read the video title and description, referenced the video topic codebook and watched a short period of video to get the sense of commenting context before assigning theme codes.

**3.3.2 Building Emotion Classifiers.** To identify the emotion types, two researchers read 100 danmaku and 100 reviews which were identified with sentiment expression in Section 3.2 and generated a set of initial codes independently. After discussion of the disagreement, establishment of the uniform criteria and re-coding, we finally built the codebook of sentiment types which emerged naturally to describe the content. During the coding, we noticed that very few viewers conveyed mixed-type emotions in a single post. Therefore, we assigned a single sentiment label to each danmaku or comment. Based on the codebook, two coders continued to annotate and generated 1,000 label-assigned posts (500 reviews and 500 danmaku) for sentiment types. Same processing steps, text features and machine learning models were adopted as Section 3.2.2 except for adapting the task as a multi-class classification problem, building *M3: Emotion Type Classifier* in Figure 2. After testing its performance, we utilized it to generalize the emotion category to all danmaku and comments which were identified with sentiment expression.

### 3.4 RQ3: Unpacking the Unique Patterns of Information Sharing and Sentiment Expression in Danmaku and Comments

With danmaku's nature of anchoring at a specific video timestamp and different appearing styles (e.g., positions, colors and scrolling modes), the patterns of information sharing and sentiment expression in danmaku were far beyond the semantic meaning. As such, to systematically unpack the hypertext unique patterns of information sharing and sentiment expression in danmaku and comments, we conducted novel video-combined qualitative analysis on danmaku and comment posts. Specifically, instead of only reading the post text, two authors first separately viewed 50 videos samples (5 video topics  $\times$  10 videos per topic). Then, they interpreted the displayed danmaku, evaluated top-100 voted comments and their replies for each video, and focused on the following features of information sharing and sentiment expression in danmaku and comment posts:

- **Commentary-Video Association:** How the information shared in comments and danmaku was associated with video content, and how the sentiment expression in commentary was triggered by the video?
- **Inter-Commentary Interaction:** The information and emotions conveyed by referring to, augmenting, or refuting other danmaku and comments. Such interaction was explicitly supported through the reply interface for video comment and achieved through the use of colors, positions and content reference for danmaku [38].
- **Style-Communication Relationship (danmaku only):** The relationship between the behavior of information sharing and sentiment expression and danmaku displaying styles (i.e., font size, color and the display mode)

To validate the empirical findings obtained from qualitative analysis, we also assisted with quantitative analysis, e.g., investigating the proportion of information sharing in danmaku of different displaying styles.

## 4 FINDINGS

Our findings provided insights into the role of danmaku and comments in supporting information sharing and sentiment expression in crisis videos. First, we comprehensively reported the descriptive statistics of COVID-19-related videos as well as danmaku and comments in Section 4.1. In Section 4.2,

we described the prevalence of information sharing and sentiment expression in danmaku compared to conventional comments in crisis videos. In Section 4.3, we unpacked rich and multifaceted information themes and emotion categories conveyed through danmaku and comments under crisis videos, and compared their differences. In Section 4.4, we revealed the unique hypertext patterns of danmaku-based/comment-based information sharing and sentiment expression through qualitative video-combined analysis.

#### 4.1 Descriptive Statistics

The preprocessed dataset included 879 COVID-19-related videos. The average length of videos was 4.4 minutes ( $SD=5.5$ ), and the average viewed times were 851163.9 ( $SD=1042845.0$ ). There were 9 videos disabling both danmaku and comments, and 8 videos disabling danmaku only. A number of 296 videos (33.7%) were published by government accounts, and the remaining were published by civic accounts held by individuals or non-state agencies. Generally, the videos published by government accounts were shorter (~3 minutes compared to ~5 minutes of civic-generated videos) and viewed less (~672k viewers compared to ~942k viewers in civic-generated videos) on average. The average danmaku volume was 4828.6 ( $SD=13070.5$ ), and the average comment volume was 2538.4 ( $SD=3069.5$ ).

Through manual annotation of 879 COVID-19-related videos in our dataset, we identified five video themes naturally describing the video data including **Social Events**, **Entertainment**, **Record in Severely Afflicted Areas**, **Knowledge Popularization**, and **Authoritative Guidance**, whose definitions, examples and proportions are exhibited in Table 1. Among them, videos about Social Events were most frequent (52.2%), followed by Entertainment (15.5%), Recording in Severely Afflicted Areas (14.9%), Knowledge Popularization (9.3%) and Authoritative Guidance (8.1%). Most of videos on Authoritative Guidance (77.5%) were contributed by government accounts, while most of Entertainment videos (90.4%) were posted by civic accounts, which reflected the nature of the two types of video uploaders.

As Figure 3 (a) shows, Videos on Entertainment and Knowledge Popularization were most viewed with more than 1 million viewed times on average, while videos about Social Events and Authoritative Guidance had relatively fewer viewed times. Figure 3 (b) illustrates the volume of danmaku and comments in crisis videos of different themes. The volume of danmaku was larger than the volume of comments in crisis videos of all themes, indicating the wide usage of the danmaku feature. Such volume differences between danmaku and comments reached the highest in Entertainment videos, where the average number of danmaku was 3.89 times higher than the average number of comments, while the volumes of danmaku and comments were nearly the same in the more formal Authoritative Guidance videos.

777,865 danmaku posted by 449,729 unique users and 1,539,629 video comments posted by 950,896 unique users were collected from 879 COVID-19-related videos. The volume of collected danmaku was smaller than the volume of comments because of the upper limit of 1,000 danmaku for each video based on Bilibili official API. The average length by Chinese characters was 8.0 for danmaku ( $SD=7.9$ ) and 24.3 for video comment ( $SD=49.1$ ), which validated the short length nature of danmaku [38].

#### 4.2 RQ1: How prevalent is information sharing and sentiment expression in danmaku compared to comments in crisis videos?

Among 500 annotated danmaku and 500 annotated comments in the training dataset, 190 (38.0%) danmaku and 201 (40.2%) comments were identified with having sentiment expression, and 124 (24.8%) danmaku and 221 (44.2%) comments were labeled with having information sharing. Through training on the annotated data, the F1 scores of Information Sharing Classifier (M1) and Sentiment

Table 1. Content Themes of COVID-19-related Videos on Bilibili

Theme	Definition	Example	Proportion
Social Events	Videos focusing on social events triggered by or related to COVID-19 (e.g., donation, discrimination and mask production)	<i>A young man dropped 500 masks in the police office and ran away, the police said: your "escape" looks really handsome!</i>	52.2%
Entertainment	Videos exhibiting COVID-19 related issues in recreational forms (e.g., animation, music video and auto-tune remix-themed content)	<i>Understand attitudes towards coronavirus in different provinces in the way of Tom and Jerry</i>	15.5%
Record in Severely Afflicted Areas	On-spot record showing the epidemic situation in severely afflicted areas	<i>The seventh day of the lockdown in Wuhan by Wuhanese video uploader: The status of fever clinics in Wuhan</i>	14.9%
Knowledge Popularization	Videos Popularizing scientific knowledge related to COVID-19 (e.g., transmission mechanism of virus)	<i>What is the coronavirus? How does it make people sick in Wuhan?</i>	9.3%
Authoritative Guidance	Videos on epidemic-related information released by authoritative organizations or persons	<i>Epidemiologist Zhong Nanshan: The inflection point of the epidemic has not come yet. Early detection and early isolation is the key</i>	8.1%

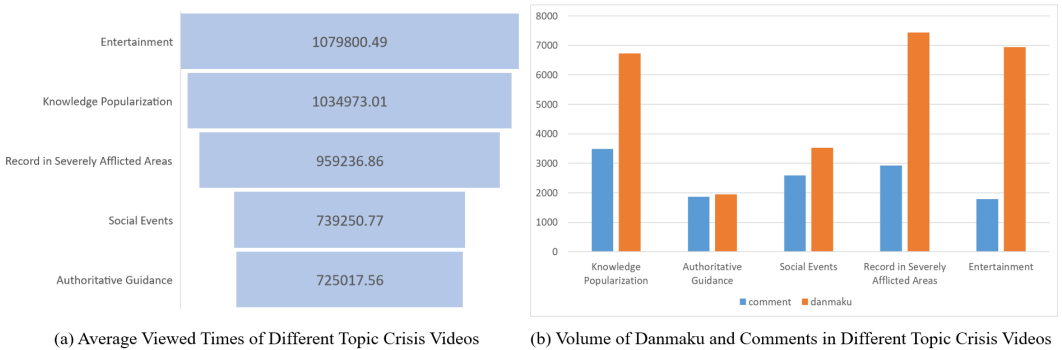


Fig. 3. Descriptive Statistics on (a) Average Viewed Times and (b) Volume of Danmaku and Comments in Different Topic Crisis Videos

Expression Classifier (M2) both achieved higher than 80% under 10-fold cross-validation as shown in Table 2, which was substantially good to generalize the annotated codes to the whole danmaku and comment datasets.

According to the codes assigned by the text classification model, the proportion of sentiment expression was 38.6% (N=300,053) for danmaku and 32.7% (N=503,734) for video comments. For information sharing, only 24.8% (N=192,865) danmaku were predicted as sharing information, while the percentage in video comments reached 60.1% (N=925,691). The differences of danmaku and

Table 2. F1 Scores and Parameters (MD: Maximum Depth; MWC: Minimum Weights in a Child) of Machine Learning Models. There is only one model for M3, as it achieved better performance when merging danmaku and comment training dataset in training the multi-class emotion type classifier.

	M1: Information Sharing Classifier (Binary)	M2: Sentiment Expression Classifier (Binary)	M3: Emotion Type Classifier (Multi-class)
Danmaku	81.1% (MD=3, MWC=1)	87.8% (MD=7, MWC=3)	69.3% (MD=1, MWC=3)
Comments	86.3% (MD=7, MWC=1)	83.7% (MD=4, MWC=1)	

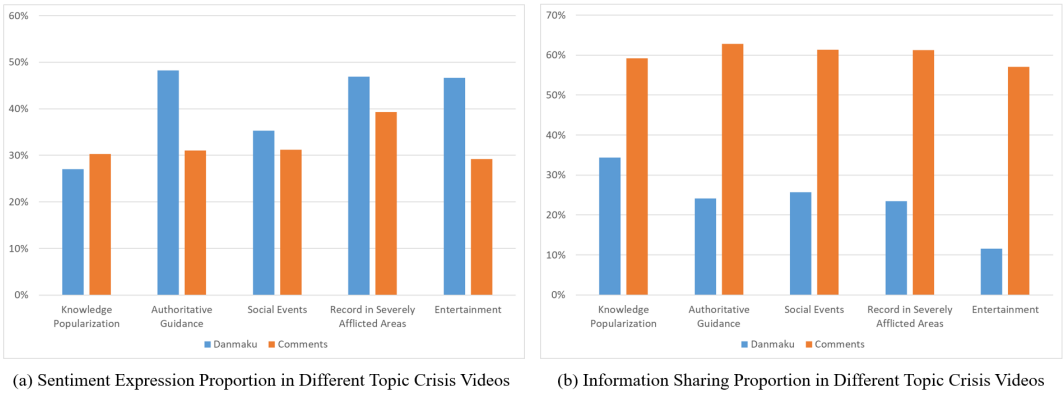


Fig. 4. The proportion of (a) Sentiment Expression and (b) Information Sharing of Danmaku and Comments in Different Topic Crisis Videos

comments were both statistically significant for sentiment expression ( $p < 0.001$ ) and information sharing ( $p < 0.001$ ) under chi-square test, which was applicable for binary variable with large volume. The results indicated that **sentiment expression was more prevalent in danmaku, while information sharing was much more prevailing in video comments.**

Figure 4 illustrates the proportion of sentiment expression and information sharing of danmaku and video comments in crisis videos with different topics. The differences between danmaku and comments of all video topics were statistically significant ( $p < 0.001$ ) under chi-square test. The results indicated that danmaku generally had a higher sentiment expression proportion and a lower information sharing proportion compared to video comments across different video topics, except for Knowledge Popularization videos in which comments had a slightly higher sentiment expression proportion. Besides, there were significant disparities in information sharing and sentiment expression proportions of danmaku between different topic videos, while such inter-topic differences were much smaller for video comments.

### 4.3 RQ2: What emotions and information themes have emerged in danmaku and comments of crisis videos?

In this section, we addressed RQ2 by identifying the fine-grained emotions vented in danmaku of crisis-related videos through quantitative sentiment analysis and hierarchical information themes derived from qualitative thematic analysis.

#### 4.3.1 Beyond Positive and Negative: Fine-grained Emotion Types of Danmaku in Crisis Videos.

Fine-grained emotions are regarded with great significance to further understanding of public

reactions and the specific functions that users' emotional states may reflect during crisis [17]. Eleven emotion types across positive and negative categories were identified in the training data, and substantially good performance (macro averaged F1 score=69.3%) of emotion type classifier was achieved through training compared to previous work [3, 41]. The emotions, examples, and the proportions in all danmaku and comment posts after generalization are shown in Table 3. Positive emotions included **Admiration, Encouragement, Gratitude, Joy, Empathy, Moved** and **Relieved**. Negative emotions included **Criticism, Worry, Shocked** and **Recollecting**. Emotions were grouped into positive or negative mainly referring to Robinson's emotion theory [50]. We found that: (1) Compared to video comments, danmaku had higher proportions of positive emotions and lower proportions of negative emotions. (2) Under positive emotions shared in danmaku, **Encouragement**, through which users mutually transmitted courage and confidence, and **Admiration**, through which users expressed the adoration to specialists and staffs aiding in Wuhan, accounted for the highest proportion, both reaching nearly 20% among all danmaku and comment posts with emotion venting. (3) **Criticism** was the dominant negative emotion with a proportion higher than 30%, through which users criticized misbehaviors in crisis. The common target misbehavior included (i) individual behaviors related to the suspected epidemic origin and virus spread such as eating wild animals and refusing mask-wearing; (ii) factories, organizations and agencies failing to perform their duties such as factories that made substandard masks and organizations that embezzled donations; (iii) epidemic-related adverse social phenomena including racial discrimination, regional discrimination and price gouging; (iv) other meaningless, toxic or malicious commentaries.

**4.3.2 Hierarchical Information Themes.** Through qualitative thematic analysis on 1,000 danmaku and video comments with information sharing, we built a hierarchical information topic taxonomy by grouping 17 themes into 5 high-level categories (i.e., domain knowledge, situated knowledge, opinions, video-relevant information, and external sources) as shown in Table 4. **Domain Knowledge** denoted information based on users' expertise. In the crisis videos we studied, the themes of domain knowledge mainly included *the characteristics of virus, personal protection suggestion, COVID-19 pandemic situations and influences, and governmental and social responses*. Some other kinds of domain knowledge, such as the research progress of vaccine, the discussion of effects of traditional Chinese medicine, and knowledge about routine tracking technologies, though rare, were also observed and delivered potentially useful information. We thus grouped them into *other scientific information*. **Situated Knowledge** represented the information based on evidence from users' own experiences. Four typical themes emerged under situated knowledge, which were *Personal and Family Response, Cases and Responses in Community, Daily Live in Pandemic, and Supplies during Pandemic*. Some danmaku and comments shared unproven personal opinions, such as *opinions to individuals' responses, governmental and social responses, as well as crisis-related social events* (e.g., regional and racial discrimination, potential virus origin and mask shortage). We categorized them as **Personal Opinions**, which were subjective yet potentially had values to other viewers for reference. With regards to **Video Information** category, users explicitly or implicitly referenced *Video Characters, Video Sections, or Video Major Topics*, and provided information related to it. In addition, users may also convey information about *Video Meta Information*, which was not directly related to video content but provided additional video information such as the total viewed times, the volume of comments, or the observation that the video was forwarded by authoritative accounts. Finally, **External Sources** denoted information with links to external websites.

The comparison of the danmaku and comment fine-grained information theme proportion yields some interesting findings. First, more domain knowledge was shared in danmaku compared to video comments, indicating the intention of sharers to make the shared domain knowledge co-presented

Table 3. Emotion Types of Commentary in Crisis Videos. The significance of differences between danmaku and comments in emotion proportions was tested through chi-square test (\*\*\*)  $p < 0.001$ ; \*\*  $p < 0.01$ ; \*  $p < 0.05$ ), which was applicable for binary variable with large volume.

Category	Emotion	Example	Danmaku Proportion	Comment Proportion
Positive	Admiration***	<i>Salute to all the staff working in the anti-epidemic front line!</i>	20.94%	19.73%
	Encouragement***	<i>Come on, Wuhan!</i>	19.33%	17.59%
	Gratitude***	<i>Thank you for your hard work and sacrifice!</i>	7.22%	3.21%
	Joy***	<i>Hahahaha. The anti-virus propagation accent is so funny.</i>	5.32%	1.54%
	Empathy***	<i>My dear, protect yourself in the epidemic! It will be fine!</i>	5.51%	5.01%
	Moved***	<i>Moved with tears.</i>	3.46%	2.81%
Negative	Relieved	<i>After hearing uploader's explanation, I feel relieved.</i>	1.05%	1.03%
	Criticism***	<i>Weakness and ignorance are not barriers to survival, but arrogance is.</i>	31.73%	42.11%
	Worry***	<i>The saddest thing is that now we have no solutions to defeat the virus!</i>	2.93%	4.48%
	Shocked***	<i>Oh my god. That is to say, as long as there is no radical cure, school would never reopen.</i>	1.34%	0.27%
	Recollecting***	<i>So Deserted. I miss the days when I can't get on the crowded subway.</i>	1.17%	2.22%

with video content as a synchronous procedure. There was no substantial difference in situated knowledge and personal opinions in proportion between danmaku and video comments. Opinions to social events accounted for a relatively high percentage in both danmaku (14.8%) and video comments (15.8%). Much danmaku-based information sharing focused on video sections (e.g., an event happened in recording or a given URL appearing in a specific section), while comment-based information sharing was more about video major topics as well as video meta information. Also, it is worth noting that external source sharing was only found in video comments. In the following sections, we will validate this empirical finding that external sources were rarely shared in danmaku through a comprehensive comparison in the whole danmaku and video comment dataset.

#### 4.4 RQ3: What are the unique patterns of danmaku-based and comment-based information sharing and sentiment expression in crisis videos?

Previous sections have systematically examined the prevalence of information sharing and sentiment expression (RQ1), emotion types and information themes (RQ2) of danmaku and comments in crisis videos, revealing the distinct roles of danmaku and comments in crisis communication. Yet, as a communication channel featured by collectivity, interactivity, style-diversity and transiency, information sharing and sentiment expression in danmaku is far beyond the semantic value. In this section, through video-combined qualitative analysis, we moved on to the hyper-semantic level and focused on the unique patterns of danmaku-based and comment-based information sharing

Table 4. Information Themes of Commentary in Crisis Videos. The significance of differences between danmaku and comments in theme proportions was tested through Fisher exact test (\*\*\*)  $p < 0.001$ ; \*\*  $p < 0.01$ ; \*  $p < 0.05$ ), which was applicable for relatively small datasets (N=1000).

Category	Theme	Example	Danmaku Proportion	Comment Proportion
Domain Knowledge	the Characteristics of Virus***	<i>This is an RNA virus, so if it doesn't mutate, that would be strange.</i>	6.80%	1.00%
	Personal Protection Suggestion*	<i>Ordinary medical masks would work for general public, Zhong Nanshan has said.</i>	6.20%	3.80%
	COVID-19 Pandemic Situations and Influences***	<i>There have also been confirmed cases in Tibet.</i>	3.40%	0.80%
	Governmental and Social Responses**	<i>Both companies BYD and Foxconn have started making masks.</i>	9.00%	5.20%
	Other Scientific Information*	<i>The accuracy of thermometer is limited.</i>	2.20%	1.00%
Situating Knowledge	Personal and Family Response	<i>I am lucky that my parents will take the initiative to buy masks, ask about the epidemic and learn about the virus.</i>	3.80%	4.40%
	Cases and Responses in Community	<i>There is also a case in my community. Scared.</i>	1.40%	1.80%
	Daily Live in Pandemic	<i>The fifth day in quarantine. If school doesn't reopen soon, I would die.</i>	5.80%	4.40%
	Supplies during Pandemic***	<i>It's cheaper than ours. There are no cases in my city, but the price of masks is still 35 yuan each.</i>	2.40%	5.40%
Personal Opinions	Opinions to Individuals' Responses***	<i>The best way to eliminate fear is to face it!</i>	3.00%	0.60%
	Opinions to Governmental and Social Responses***	<i>In my opinion, Henan Province is making great efforts to control the virus.</i>	9.00%	4.40%
	Opinions to Social Events	<i>Whether the contractors would donate masks is their freedom. No moral kidnapping.</i>	14.80%	15.80%
Video Information	Video Characters	<i>Uploader, are you OK? Your mask seems of no use.</i>	12.00%	11.60%
	Video Sections***	<i>The given URL in the video is invalid???</i>	17.40%	3.60%
	Video Major Topics***	<i>This video is objective and saturated with useful information.</i>	1.60%	17.0%
	Video Meta Information***	<i>This video has been recommended by China Central Television.</i>	1.20%	18.40%
External Sources	External Sources**	<i>You can get the latest epidemic situation from here: URL</i>	0.00%	0.80%

and sentiment expression. Specifically, we introduced two special sentiment expression patterns (*Collective Emotion Resonance* and *Interactive Emotion Communication*) and two information sharing patterns (*Style-Based Highlighting*, *Timely Information Supplement and Regulation*) observed in danmaku. Further, we revealed three unique patterns of comment-based information sharing (*External*

Sources, *Comprehensively Integrated and Summarized Information* and *Information of Particular Users*), discussing how video comments supplemented the information sharing features that were not suitable for danmaku posts.

**4.4.1 Collective Emotion Resonance.** In crisis videos, video commenters leveraged danmaku as a channel of collective emotion resonance especially admiration and encouragement, which cultivated an intense emotional atmosphere of video watching in the way of screen flooding as shown in Figure 5 (a). For instance, in the video "Wuhan Real-time Record: The living conditions of hospitals, doctors and citizens in Wuhan" revealing the situation and response in Wuhan at the early stage of the epidemic, there was screen flooding of encouraging danmaku "*Come on, Wuhan!*"; in the video "Medical aid teams from four best hospitals have arrived in Wuhan: We will win the war against coronavirus!" recording the medical aid to Wuhan, there emerged screen flooding of admiring danmaku "*Salute!*". Such short yet powerful danmaku-based emotion venting, similar to a slogan, was infectious, which effectively communicated courage and positive energy and built public confidence in the video-viewing community during crises. Another typical case was that users utilized different but fixed-formed danmaku to create the screen flooding, e.g., "[Local specialty] (e.g., Peking duck) is supporting Hot Sesame Paste Noodles! (Wuhan specialty)", which appeared in multiple COVID-19-related videos. Such danmaku not only raised viewers' interest in commenting by forming small groups with the same demographics, but also created the collective emotion resonance in the large video-viewing group with the same sentiment expression intention. In contrast, more individual emotion venting appeared in video comments.

**4.4.2 Interactive Emotion Communication.** In danmaku, people interactively expressed emotions, especially empathy and gratitude to: (1) video uploader, e.g., "*Uploader, you must be careful! Remember always wear masks.*" to a vlogger recording Wuhan situation; (2) characters, who could be either a key actor, one anonym showing up transiently or a group, e.g., "*Academician Zhong Nanshan, appreciate your work! Please take care of yourself*" to the Chinese COVID-19 guidance provider Zhong Nanshan, "*Guarding parking lot now must be lonely. Take care.*" to a parking guard in a Wuhan recording video, "*You are really angels. Salute!*" to a medical group aiding in Wuhan; (3) other viewers, e.g., "*Guys watching this video, you don't deserve to have this disease!*". It is worth noting that actually such emotional communication was hard to reach the target objects as the processes of video recording and video watching were asynchronous, yet viewers were still keen to initiate the simulative emotional dialogue, creating the interactive viewing experience.

**4.4.3 Style-Based Highlighting.** Before posting danmaku, users can adjust the display settings including displaying mode, font size, and color, which diversifies danmaku. In our danmaku dataset, there were 95.02% shown in the way of normal "flying", 4.34% fixed at the top of video, 0.61% fixed at the bottom of video, and 0.03% advanced danmaku with specialized style. The majority of danmaku (99.82%) had normal font size, with 0.15% with smaller font size and 0.03% with bigger font size. There were 174 different colors in the danmaku dataset, in which white danmaku accounted for the highest proportion (91.70%), followed by red (5.01%), yellow (1.36%) and blue (0.04%).

We found that danmaku with unique display styles had a higher information sharing proportion. Specifically, normal "flying" danmaku only had 24.3% sharing information, while the percentage was 29.2% and 29.5% for fixed-at-the-top and fixed-at-the-bottom danmaku separately. Danmaku with color had a higher information sharing percentage (27.1%) compared to default white danmaku (24.3%), and yellow danmaku held the highest information sharing proportion (35.3%). Also, larger font size indicated a higher chance of information sharing, with the information sharing proportion of 31.4% for danmaku larger than the normal font size, 24.6% for danmaku with normal size, and 19.7% for danmaku smaller than the normal font size. All aforementioned differences were statistically





(a) Example of Collective Emotion Resonance: Screen flooding of "武汉加油" ("Come on, Wuhan!")

(b) Example of Style-Based Highlighting: Using fixed-at-the-top red danmaku to highlight crisis-related information

Fig. 5. Examples of Unique Patterns in Danmaku-Based Sentiment Expression and Information Sharing: (a) Collective Emotion Resonance; (b) Style-Based Highlighting.

significant ( $p < 0.001$ ) under chi-square test. The combinations of display styles endowed additional displaying information to danmaku in addition to plain text, which elicited the strategic use of the style-based expression, especially highlighting, and thus facilitated crisis-related information sharing. For instance, in Figure 5 (b), under the context in which the vlogger mentioned mask and brought out a heated discussion about mask usage in danmaku, a user posted fixed-at-the-top red danmaku, which was distinct among all danmaku posts in style, to provide an authoritative explanation to mask usage:

*First of all, don't say that masks are useless. There is no doubt that wearing masks is better than no protection, because one function of the mask is to prevent people from transmitting droplets that carry viruses. Another problem is which masks are to be selected. N95 masks are better but not necessary. If you cannot distinguish the differences between different types of masks, just choose a surgical mask if there is no N95. (Appear at 3'30" of video "Real-time record in Wuhan: under the coronavirus, what is the situation of supermarkets, business districts and companies now?")*

Such information highlighted by special danmaku patterns gained the attention of a wide audience and received other users' gratitude in danmaku, e.g., "Thanks to the red words for sharing the information". We also observed that users tended to cite the information source in highlighted danmaku to enhance authority, such as "Nanshan Zhong has confirmed that there is human-to-human transmission of coronavirus".

**4.4.4 Timely Information Supplement and Regulation.** Section 4.3.2 has revealed that danmaku had a much higher proportion of information sharing about video sections (17.4%) compared to comments (3.6%). This section moved a further step about the information sharing about video sections in danmaku and introduced its unique pattern: Timely Information Supplement and Regulation.

With the characteristic of appearing at a fixed time period, information sharing in danmaku exhibited a close correlation on the video context, which might provide detailed explanations and information extensions focusing on a specific video period. As such, danmaku-based information sharing could play the role of furnishing a timely information supplement to the video content. For instance, in a video related to community epidemic control, a section described the scenario that the community staff used an infrared frontal thermometer to measure the temperature of visitors. Danmaku popping up under this section provided further descriptions about the infrared thermometer, such as "the infrared thermometer may not be accurate" and "the accuracy of the infrared thermometer is affected by the environment". In another example, when the vlogger recorded the

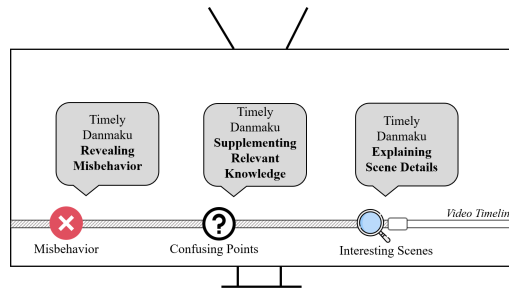


Fig. 6. Timely Information Supplement and Regulation of Danmaku: Danmaku immediately following the corresponding scene could effectively reveal misbehavior in videos, supplement relevant knowledge for confusing points and explain interesting scene details.

real-time situation in Wuhan and interviewed citizens, danmaku reminded that "*uploader wore the mask (nose not covered) in an inappropriate way*", which aimed to timely rectify the misinformation conveyed in the video. Danmaku immediately following the corresponding scene could effectively reveal misbehavior in videos, supplement relevant knowledge for confusing points and explain interesting scene details as shown in Figure 6, which could be substantially beneficial in crisis videos. In comparison, video comments failed to build such a strong correlation to video sections. Recently, some video platforms adopt the clickable timestamp [70] as an additional commentary function. Users could add a timestamp in comments, and others could click the timestamp and jump to the referenced video section. However, such behavior often asynchronously happened after video watching, and users might need to make a second effort to understand the video context, which limits the timely information supplement.

In the following three subsections, we revealed three unique patterns of comment-based information sharing that were not suitable for danmaku.

**4.4.5 External Sources.** Sharing external sources is a common behavior in video comments. Users may add external uniform resource locators (URLs) in comments to provide supportive evidence or information extensions that may link to other information hubs, social media sites, relevant videos, news outlets or authoritative guidelines [56], and others could directly click or copy and paste to go to the shared websites if interested. For instance, some video comments shared "*(Here records) the real-time situation of the new coronavirus epidemic in China: URL*", and some introduced "*Here is the paper mentioned in the video which has been published in Lancet: URL*". Such information was particularly valuable during crises in spreading more accurate and reliable information sources. However, URL sharing was seldom observed in danmaku. The major reason was that danmaku could only show for several seconds, and the transitory appearance limited other users to remember or copy the shared URL. In addition, going to other websites would interrupt the video-viewing process. Based on URL regular expression matching, we observed that only 7 (0.0012%) danmaku contained URLs, while 2497 (0.41%) video comments contained URLs.

**4.4.6 Comprehensively Integrated and Summarized Information.** Integrated and summarized information is defined as the combination and summarization of multiple information sources or knowledge points in a single commentary. Such information was prevalent under video comments and gained a large number of likes, spreading to a wide audience. For instance, the following video comment under authoritative guidance video "*Zhong Nanshan: It is certain that the COVID-19*

can be transmitted human-to-human. The virus is most likely from wild animals.", receiving 26,171 likes, concluded the main knowledge points in the video:

*Summary of academician Zhong Nanshan's speech: 1. Confirm the human-to-human transmission 2. The intensity is lower than SARS temporarily 3. The epidemic is currently in a climbing stage 4. The source has not been determined, but it is suspected to be wild animals. 5. Some medical workers have been infected 6. Public should be vigilant that the epidemic has escalated 7. N95 is out of stock, and ordinary masks are effective to some extent 8. Fever is the first suspected symptom 9. Do not go to Wuhan in the near future if unnecessary* (video "Zhong Nanshan: It is certain that the COVID-19 can be transmitted human-to-human. The virus is most likely from wild animals.")

In addition to the integrated video information summary, users may also collect useful external links relevant to the crisis and combined them in one post. For instance, the following video comment integrated external websites including complaint management platform, debunking websites, situation tracking websites, reminder and donation platforms:

*Complaint management platform: URL; Real-time debunking science website: URL; Real-time situation tracking: 1. The spread of the new coronavirus: URL; 2. Baidu version (including migration map, recommended): URL; 3. NetEase version (including detailed news reports): URL; 4. Tencent version (including a list of fever clinics): URL; ... Remind parents to wear mask: URL; Donation: URL.* (video "What is the current situation of the epidemic? Here comes the authoritative analysis!")

This kind of integrated information sharing was also only available in video comments instead of danmaku. As introduced in Section 4.1, The average length by Chinese character was only 8.0 for danmaku. The short-time appearance and the large volume of concurrent danmaku limited the time spent on a single danmaku, leading to its short text-length nature and thus the inappropriateness of integrated and summarized information sharing.

**4.4.7 Information of Particular Users.** Danmaku provides a novel anonymous information sharing channel. However, in some scenarios, user identities of commentary would endow additional reliability, authority or popularity to the shared information, such as comments posted by video content curators, social media influencers or government accounts, which would further influence the broadness and acceptance of such information in crises. For instance, the creator of auto-tune remix-themed video "[Anti-coronavirus] Village head hardcore radio trap: Cheap" commented, "Within 7 days of this video, the incentive proceeds will be donated to Wuhan! Thank you all!", which obtained a high exposure and received more than 80 thousand likes. Another case was the comment posted by government account "Zhejiang Communist Youth League", "Article 330 of the Criminal Law of the People's Republic of China stipulates that whoever, in violation of the provisions of the Law on the Prevention and Treatment of Infectious Diseases, commits any of the following acts, thereby causing the spread of a class infectious diseases or causing serious danger of their spread, shall be sentenced to fixed-term imprisonment of not more than three years or criminal detention...". This government-generated comment also received wide attention, with more than 10,000 likes and more than 100 replies.

## 5 DISCUSSION

Through a mixed-methods approach integrating machine learning and qualitative analysis, this work systematically investigated how users shared information and expressed emotions in danmaku and comments in crisis videos with regard to prevalence (RQ1), information themes and emotion categories (RQ2), and unique patterns (RQ3). In this section, we reflect on the findings, discuss

the potential of synchronous commentary in crisis videos, and propose implications for designing improved commentary interfaces to facilitate effective and engaging crisis communication.

### 5.1 Complementary Role of Danmaku and Comments in Information Sharing and Sentiment Expression

This work largely reveals the complementary roles of danmaku and comments in information sharing and sentiment expression in crisis videos. In general, information sharing was more prevalent in video comments, while sentiment expression was more prevailing in danmaku. For sentiment expression, danmaku was more used to collectively vent the positive emotions, and appeared to be more interactive; in contrast, comments were more used to individually vent the negative criticisms, and appeared to be more dissociated. For information sharing, danmaku provided synchronous information supplement for video sections, while comments initiated asynchronous discussions focusing on video major topics. In addition, video comments supported specific information-sharing functions that were not practically suitable for danmaku, such as external URLs and comprehensively integrated and summarized information.

As Durkheim's theory of "collective effervescence" suggests, synchronization with shared symbols and emotions can increase emotional intensity [15]. The collective positive emotion expression in danmaku, especially the Admiration and Encouragement vented in the form of screen flooding, reflected such emotional valence increase. Also, the prevalence of "Positive Energy" largely echoed with previous findings on crisis response in Chinese social media [36]. The "Positive Energy" dissemination would be beneficial to establish public confidence, but may also influence how people perceive the veracity of information [36]. On the other hand, video comments provided a more calm and rational environment for information sharing, credibility assessment and discussion, which largely complemented the role of danmaku.

With the development of online videos and live streaming, it is a growing trend to support more than one alternative commentary channels for video platforms. For instance, both live comments through Internet Relay Chat (IRC) and retrospective comments through commenting box are available in YouTube Live [37]. Our finding contributes to a large body of research on video commenting interfaces that when two characteristics-distinct commenting channels (e.g., synchronous vs. asynchronous) are concurrently accessible to users, nuanced and complementary roles would develop based on their temporal, spatial, and style nature and collaboratively facilitate interaction by satisfying different aspects of user needs. On this note, unilaterally focusing on one channel would lead to bias and fail to get the full picture of user behavior. Future HCI and CSCW researchers are suggested to critically compare the behavior patterns in different commentary channels and design specialized commenting features to satisfy users' communication needs.

### 5.2 The Particularity of Commentary in Crisis Videos

During time of crisis, online crisis videos typically exhibit an exponential increase within a short period (e.g., "infodemic" in COVID-19 [73]). Such crisis videos often show a varied quality with a not small proportion of misinformation [28], and rapidly evolve as the crisis situation changes [26]. As such, users may spontaneously leverage video commentary to correct misinformation, update the latest information and express emotions in the crisis. The features and uses of commentary in crisis videos are largely distinctive compared to commentary in other video genres such as music, movie and animation, which renews the demands to understand the commentary in this special video genre.

Our findings uncovered comprehensive taxonomies for granular emotion categories and information themes in danmaku and comments of crisis videos, which revealed the particularity of crisis video commentary. *Admiration* and *Encouragement* accounted for the majority of positive

emotions, and *Criticism* was the most prevalent negative emotions. The emotion categories, as well as their proportions, reflected public emotional status during COVID-19 pandemic and were largely different from previous emotion models (e.g., circumplex model [52]). Particularly, the prevalent emotional support towards governmental disposition and collective contributions to pandemic control (e.g., government-led cross-region medical aid), reflected the patriotism and nationalism of specific groups in Chinese social media context [33]. As for user-generated information, a not negligible proportion of danmaku and comments shared situated knowledge such as *Cases and Responses in Community* to increase situational awareness among viewers. Also, numerous video commentary especially danmaku spontaneously shared domain knowledge about the video content, such as the scientific knowledge about the *Characteristics of Virus* and the latest authoritative *Personal Protection Suggestion*. In other words, the commentary in crisis videos was knowledge-intensive focusing on the crisis. Online videos are gradually becoming an irreplaceable information source for public, and government agencies are also increasingly taking online videos to release crisis communication [5, 66]. Mining how public are engaged in crisis videos and how they react to video information through video commentary, e.g., what public concerns are conveyed through negative criticisms and what information (and misinformation) are most widely disseminated in commentary, is of great importance for government agencies to design better crisis communication strategies. Future work will be required to take advantage of the rich data of crisis video commentary to discover public awareness, concerns and reactions in crisis.

### 5.3 Potential of Synchronous Commentary in Crisis Communication

Section 4.4 revealed the unique patterns of danmaku-based sentiment expression and information sharing, including *Collective Emotion Resonance*, *Interactive Emotion Communication*, *Style-Based Highlighting*, and *Timely Information Supplement and Regulation*. In this section, we critically discuss how these patterns differentiate danmaku from traditional video commentary and how viewers leverage danmaku to contribute to videos, and highlight the potential of synchronous commentary in crisis communication.

**5.3.1 Collaborative Misinformation Correction.** Prevalence of misinformation is a critical problem of crisis communication on social media, including crisis videos. For instance, previous work has identified more than a quarter of top-viewed Youtube videos about COVID-19 contained misinformation such as misleading protective recommendations for the general public [28]. In this light, danmaku provides a potentially effective way to synchronously identify and correct misinformation in crisis videos. This study revealed that danmaku distinguished from video comments for its *Timely Information Supplement and Regulation*. Viewers spontaneously moderated the video content and collaboratively provided correction when noticing misleading information in videos. Recall the example that when the vlogger left the nose outside the mask in a video recorded in Wuhan, a large number of danmaku rectified the improper behavior by pointing out "*Uploader wore the mask in an inappropriate way*" or "*Please cover your nose*". With part of such information assisted with *Style-Based Highlighting*, other viewers could immediately notice the collaborative correction of misinformation. In addition, the crowdsourcing way of information assessment endows danmaku with the ability of self-correction, which somehow inhibits the misinformation dissemination through danmaku. For instance, when a danmaku claimed that "*Don't worry, young people are less likely to be infected*", a following danmaku immediately replied, "*(Reply to) the foregoing danmaku, the authority has said that there is no less vulnerable population*". These observations extend previous research in understanding crisis misinformation correction on social media [57, 63]. Compared to video comments, danmaku-based misinformation correction co-appears with the misleading video section, making it easier to target the content with misinformation and get other viewers' attention.

How to further support such collaborative misinformation correction, e.g., how to better distinguish valuable user-generated correction among danmaku stream, and how to improve the quality of such spontaneous and unproven correction, are the questions that future CSCW researchers and practitioners shall critically think about. Meanwhile, more robust misinformation auto-detection and reporting mechanism should be considered to complement the current crowdsourcing way of self-misinformation-correction, so as to maximally hinder the misinformation creation and dissemination through danmaku.

**5.3.2 Knowledge Co-construction and Augmentation.** Existing literature has revealed that in scientific video clips, video comments reached a higher-level of knowledge construction beyond the information of video content [14]. In this section, we argue that danmaku also facilitates such knowledge co-construction, and achieves synchronous information augmentation in both width and depth. As described in Figure 6, *Timely Information Supplement and Regulation* is a significant feature of danmaku. Such information sharing can either be triggered by video content, providing detailed explanations of different aspects of the corresponding scene, and thus broadening the width of video knowledge system; or triggered by danmaku discussion, correcting other danmaku's mistakes and supplementing relevant information, and thus deepening the depth of video knowledge system. As such, the video knowledge system with danmaku could be analogous to a tree structure with video content as the trunk and viewer-generated information as the branches, though there is no de-facto frameworks such as reply threads in Reddit. Such co-constructed knowledge structure is more robust and comprehensive than traditional crisis videos with the video creator as the only contributor. Besides, though the "trunk" of the video information system (i.e., pure video content) remains static, the "branches" (i.e., information in danmaku) are dynamic, in which danmaku with latest information provided by new viewers would cover old ones that may be out of date. As such, the video knowledge system also evolves with time when scientific information and authoritative guidance changes, which brings great values to crisis videos.

## 5.4 Design Implications

**5.4.1 Optimization of Style-based Highlighting.** Users leveraged unique displaying styles of danmaku (i.e., font, color and displaying mode) to highlight the danmaku, and the findings revealed that information sharing was more prevalent in such danmaku, indicating the strategical use of style-based information highlighting to emphasize critical information. However, we also noticed that some users misused this function to abuse others or transmit misinformation. Though moderation in the community could mitigate the damage of such behaviors to some extent, the misuse of style-based highlighting would still degrade the video-viewing experience and mislead those who seek crisis information. On the other hand, some danmaku which provided high-quality information but had normal styles just "flew away" without getting much attention. This suggests a design implication for optimizing style-based highlighting, which could be either AI-facilitated (i.e., automatically measure the quality of danmaku and modify the styles to highlight those with higher quality), or feedback-facilitated (i.e., allow users to vote for danmaku with useful and high-quality information and highlight those with higher votes in style).

**5.4.2 Design Improvement for Better Section Information Sharing.** In our study, nearly 30% of danmaku-based information sharing focused on events, objects, or characters in particular sections of the video (12.0% for video characters and 17.4% for content in video sections). As introduced in previous sections, such kind of information sharing serves as a timely information supplement and regulation, and might contribute to misinformation correction and knowledge augmentation. However, we noticed difficulties in referencing specific elements in sections when sharing corresponding information. To reference a character or object, viewers usually used position pointers

like “↓” or described the referenced target like “the nurse with short hair”. As such, other viewers took the extra effort to find the referenced target by following pointers or digesting descriptions, which might cause distraction or confusion. Thus, developing advanced referencing interfaces for danmaku is recommended. For instance, users could have the option to fix the danmaku at a specific area with the referenced target.

*5.4.3 User Empowerment in Commentary Interface.* Empowering people through technology is of increasing concern in the HCI community [54]. Online videos have always been considered as the sole products of video creators and uploaders, while the contribution of viewers, who often complement the video content through commenting, is largely ignored. Through danmaku, users are empowered to create a text-based “floating screen” and endow additional user-generated information to the video content, influencing other viewers’ watching experience. Unlike video comments, users can choose to anchor danmaku posts at a specific video period and adapt the displaying styles. As revealed in the results, unique communication patterns were developed and adopted by users such as style-based highlighting, and further provided special benefits to crisis videos, e.g., collaborative misinformation correction. In this light, we propose a general design implication to video commentary designers to broadly empower viewers by providing more choices to tie their comments to video content temporally and spatially, and thus allow users to collaboratively and interactively contribute to videos. Note that the unique communication patterns brought by user empowerment were not limited to crisis videos and might be generalized to other video genres. For example, the collective emotion resonance might help to create a strong emotional atmosphere in some recreational videos, and the timely information supplement and regulation might be applied to other knowledge-intensive videos like scientific and educational videos. On this note, we suggest investigations on how different empowerment designs bring new user behavior patterns, and how they provide unique values to different video genres. On the other hand, viewers shall not only be empowered to co-create “what others could view” through commentary interface, but also have more options to choose “what they are willing to see”. For instance, the collective emotion resonance in a form of screen flooding of danmaku might be appealing to some viewers, but may also be distracting to those who want to watch the pure video content. Consequently, more specialized filter options, e.g., merging similar danmaku, should be designed as compensation.

## 5.5 Limitations and Future Work

Our work has some limitations. First, we only focused on one video platform, bilibili, which might have introduced biases into our analysis. Second, the demographics of viewers are missing because we could only access the virtual hashed user ID of danmaku, which is designed to be anonymous, based on Bilibili official API. Therefore, we are unable to trace back to users’ demographic information through actual user ID. Third, though the text classifiers achieved substantially good performance, a larger annotated sample size and a more detailed feature engineering might lead to a more accurate generalization result. Fourth, though we conducted an in-depth analysis of danmaku and comments in crisis videos, a comparison study on other video genres might help highlight the distinct features of crisis communication through danmaku and comments. Finally, a proof-of-concept interface would be beneficial to get a thorough evaluation of design implications. Future work will need to address these limitations, as well as explore additional opportunities of diverse commenting interfaces in video and live streaming. Also, a further investigation and comparison on the commentary pattern differences in different crisis video types (e.g., videos with different themes and purposes, videos generated by government or individuals), would deepen the understanding of crisis communication through video commentary and shed light on more effective crisis management.

## 6 CONCLUSION

In this paper, we studied the roles of danmaku and video comments in information sharing and sentiment expression in crisis videos through a mixed-method approach incorporating machine learning and qualitative video-combined content analysis. By investigating a large danmaku and comment dataset collected from COVID-19 videos, we revealed that danmaku had a higher proportion of sentiment expression, while comments had a higher proportion of information sharing. Viewers leveraged danmaku more to collectively vent positive emotions, and relied on comments more to individually disclose negative criticisms. In addition, more domain knowledge as well as information focusing on specific video sections was observed in danmaku, while more information on general video topics was found in comments. Several unique sentiment expression and information sharing patterns were identified in danmaku, such as collective emotional resonance and timely information supplement and regulation. Based on the findings, we discussed the potential of synchronous commentary in crisis videos including collaborative misinformation correction and knowledge co-construction and augmentation, and highlighted several design implications for commentary in promoting effective and engaging crisis communication.

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