# User-Collaborative Construction of Informal Learning Spaces on Bilibili: A Study of Danmu and Comment Interactions

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**Abstract.** With digital technology development, online video platforms have become key informal learning spaces. This study examines Bilibili's high school physics content, analyzing how danmu and comments shape this space through content and topic analysis. Results show the space aligns with the school cycle: danmu fosters emotional interaction, while comments deepen knowledge. Discussions reflect community identity, with highly upvoted comments focusing on summaries, reflections, and resource sharing. User collaboration enhances learning and emotional support but may cause disturbances from danmu overload, misinformation, or off-topic content. Recommendations for platform optimization and user engagement are provided.

**Keywords:** Online education, Content analysis method, Informal learning, BERtopic model.

## 1 Introduction

As learning extends to informal spaces, video platforms represented by Bilibili have become important informal learning venues. The number of online education users in China has reached 327 million, accounting for 29.1% of the total number of internet users [1]. Bilibili's knowledge content is particularly popular among teenagers. In 2021, about 183 million users watched videos in the knowledge section on Bilibili [2]; by 2023, this figure had grown to 243 million, equivalent to 5.5 times the number of college students in China that year. "Bilibili is a learning platform" has also transformed from an internet meme into a common perception [3].

As a comprehensive video platform, Bilibili features a highly interactive culture built around danmu and comments. Users actively interpret and recreate content through these channels, integrating the video, real-time danmu, and asynchronous comments into a dynamic, evolving, video-linked resource with the potential to become an informal learning space.

Based on the aforementioned background and characteristics, this study focuses on the knowledge area courses on Bilibili, aiming to explore how user collaboration in the danmu and comment section constructs an informal learning space.

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# 2 Literature review

## 2.1 The Evolution and Digital Development of Informal Learning

Traditionally, learning has been defined as organized and structured activities with explicit instructional objectives within formal educational institutions. Since the mid-20th century, scholars have recognized that substantial learning occurs outside the classroom, a view traceable to Dewey's "learning by doing" [4]. In 1950, Knowles introduced the concept of "non-formal education," referring to learning emerging from everyday experiences and environmental interactions [5]. In the 1970s, the UNESCO report Learning to Be proposed a tripartite framework of formal, non-formal, and informal education, formally establishing informal learning as an academic concept [6].

With the rise of Web 2.0, informal learning has become increasingly integrated with digital technologies, driving research forward. In terms of platform classification, Zhang Jianping classified online collective intelligence into four types: knowledge repositories, open learning platforms, online communities, and user behavior databases [7]. At the group level, studies highlight intergenerational differences among teachers [8] and benefits such as enhanced concentration and curiosity in children [9]. In terms of outcomes, digital media positively influences learners' behavior and emotions [10]. However, challenges like information overload and echo chambers persist, requiring stronger digital literacy [11][12]. Overall, research has moved from value recognition to examining mechanisms and optimization in digital contexts.

## 2.2 Research on Online Learning via Video Platforms

Online video platforms such as Bilibili and YouTube, through features like danmu and comments, create socially interactive environments and have become key venues for informal learning. Research has become increasingly multidimensional. From a spatial perspective, Tian Yuan, drawing on affinity space theory, showed that Bilibili "learning strongholds" emerge through interactions among platforms, creators, and youth communities [13]. Technologically, Zheng Lanqin et al. proposed cross-domain knowledge graphs based on interactive text for real-time analysis and personalized feedback [14].In terms of user behavior, Zhang Yuteng found that both hedonic and utilitarian values enhance learning motivation and persistence [15]. Regarding content quality and strategies, Khalil showed that large language models can help identify high-quality medical information on YouTube, though human oversight remains necessary [16], and Dong Jingfeng et al. highlighted the role of social software in supporting informal learning through resource organization and interaction [17]. Overall, these studies examine video-based informal learning across spatial, technological, behavioral, and strategic dimensions.

As a representative danmu platform, Bilibili has been studied from multiple perspectives. Fu Ruolan found that interactive videos and danmu increase Generation Z engagement, though fragmentation may hinder knowledge internalization [18]. Qiu Xinyou et al. introduced "virtual presence," arguing that danmu and comments recon-

struct spatiotemporal perception and enhance immersion, but may also cause distraction [19]. Zhang Lu et al. showed that danmu supports real-time interaction, while comments enable deeper exchange, and their combination improves engagement and cognition [20]. Using grounded theory, Liu Ruoqi found that danmu–comment interactions among high school students form a dynamic, self-evolving learning system [21]. These studies reveal both advantages (enhanced participation and presence) and limitations (fragmentation and superficiality) of Bilibili's learning ecosystem.

Based on this context, this study focuses on typical courses in Bilibili's Knowledge Zone to examine how users construct informal learning spaces through danmu and comments. It addresses four questions: (1) functional differences between danmu and comments; (2) thematic content characteristics; (3) features of highly upvoted comments; and (4) how collaborative behaviors enhance or disrupt learning.

# 3 Materials and methods

## 3.1 Data Sources and Preprocessing

This study examines the Bilibili Knowledge Zone course "High School Physics First-Round Review Compilation" by HuangFuRen as a case. Using purposive sampling, three lectures—Kinematics, Gravitation, and Electromagnetic Induction—were selected to analyze learner interaction at different stages (Table 1). Data were collected via Bilibili's public API using BV numbers: AID was used to retrieve full comment data (e.g., user ID, content, timestamp, likes, length), and CID to obtain danmu through URL requests and decompression. All data were cleaned with Python's 're' module to remove noise such as symbols, emojis, and ads, using consistent rules for both comments and danmu.

**Table 1.** Video details

| Course videos | Views | Number of likes | Number of comments | Number of danmu displayed |
|---|---|---|---|---|
| Approach to Solving Single-Degree-of-Freedom Kinematics Problems | 25.591 million | 407thousand | 16543 | 6000 |
| Law of Universal Gravitation | 7.191 million | 166thousand | 5934 | 6000 |
| Basic Concepts of Lenz's Law | 8.607 million | 157thousand | 5597 | 6000 |

## 3.2 Data Analysis Methods

**Content Sampling.** This study used purposive sampling. For danmu, a stratified and weighted random method was applied: videos were divided into 5-minute intervals, with samples allocated proportionally (total 1,000), then weighted by keywords related to questioning or collaboration to guide random selection. For comments, those

with over 100 likes were first selected, followed by random sampling to reach 1,000 per video, totaling 3,000 comments.

**Design and Coding.** Content was classified into two dimensions—emotional and rational communication—with separate coding frameworks for comments and danmu (Tables 2 and 3). Each item was treated as a unit of analysis, and two trained coders achieved an inter-rater reliability of 0.8 after pilot testing.

**Table 2.** List of Comment Encoding Categories

| Category | Encode | Introduction | Example |
|---|---|---|---|
| Emotional communication | Check-in | Mark the start or completion. | "362 days until graduation for the Class of 2023" |
| | Interaction | Interactions with lecture and other learners. | "Thank you, Teacher! You saved my physics!" "Teacher, I know all the problems in this chapter. If you have any questions, feel free to ask me." |
| | Goals & Achievements | State goals, report progress. | "Off to the China Criminal Police College next year!!!" |
| | Emotional Expression | Express personal feelings related to learning. | "Good luck on the 2026 college entrance exam!" |
| | Find Study Partners | Seek out study partners. | "Class of 2025 students looking for study partners" |
| | Off-topic Content | Content completely unrelated to the video's topic or the learning material. | "Students who scored a perfect score in Physics on the 2026 Gaokao, give me a like" |
| Rational communication | Question&Answer | Ask and answer questions about the subject matter. | "Why can't we use the method of successive differences for the last question?" |
| | Summary & Reflection | Summarize knowledge, methods, and experiences. | "For this type of problem, using a V-T graph is the best approach!" |
| | Symbolic Interaction | Use community-specific "memes" or symbols. | "Pi times the square root of 3 equals 4πππ!" |
| | Resource Sharing | Share learning videos, materials, notes, etc. | "How do I get the lecture notes…" |
| | Real-world Connections | Discuss learning strategies in the context of personal real-life situations. | "The Gaokao is coming up soon—is it better to work through these accompanying lecture notes or practice with past exam questions?" |
| | Highlighting Key Points | Mark important timestamps or content within the video. | "[Video Timestamp 14:28]" |
| | AI Assistance | Invoke AI tools to summarize the video content. | "@AI Video Assistant" |
| | Questioning & Correction | Question explanations or answers and provide your own interpretation. | "At 11:43 in Episode 12, they factored out a square" |
| | Course Feedback | Evaluate or offer suggestions regarding course quality and experience. | "The teacher's explanation is very detailed and thorough" |
| | Extension & Expansion | Make interdisciplinary connections or associations that extend beyond the scope of the current course. | "Why does this problem feel exactly like the electric field problem?" |

**Table 3.** List of Danmu Encoding Categories

| Category | Encode | Introduction | Example |
|---|---|---|---|
| Emotional communication | Check-in | Mark the start or completion. | "Come check in this weekend" |
| | Maintaining Discipline | Criticizing behavior in the comment section that disrupts the study atmosphere. | "Everyone, cut the chatter and listen carefully to the teacher explaining the problems" |
| | Whispering | Multiple comments discussing topics unrelated to studying. | "Anyone taking the provincial exam?" |
| | Self-Motivation and Mutual Encouragement | Expressing determination to study or motivating oneself and others. | "Let's all give it our best shot, 2024 Anhui college entrance exam takers!" |
| | Goals & Achievements | Stating specific academic achievements or life goals. | "Guangzhou Medical University, wait for me!" |
| | Expressing Gratitude | Thanking the content creator at the end of the video or after understanding a difficult concept. | "Thanks, I've memorized the formula for the volume of a sphere" |
| | Find Study Partners | Seeking study partners. | "Looking for a study partner for the college entrance exam review" |
| | Off-topic Content | Content completely unrelated to the video's theme or studying. | "I am Qin Shi Huang" |
| Rational communication | Question&Answer | Asking immediate questions about the video's key points. | "Isn't magnetic flux a scalar quantity without direction?" |
| | Explaining Difficult Concepts | Proactively explain or supplement difficult concepts in the video. | "If you didn't get it, look here—the blank part…" |
| | Sharing Perspectives | Share personal insights and judgments regarding knowledge or methods. | "I don't think the new college entrance exam will cover this section; celestial mechanics later on is the focus" |
| | Answer Sharing | Provide direct answers to questions in the video. | "The instantaneous velocity at 5.5 seconds is 4 m/s" |
| | Study Tips | Highlight key points, warn of common pitfalls, or mark specific timestamps. | "The first step in writing physics is to translate it into plain English" |
| | Interacting with Lecturer | Respond to the learning content mentioned by the content creator. | "Neumann" |
| | Questioning and Correction | Question the explanation or answer and provide your own interpretation. | "The mass is wrong" |
| | Course Feedback | Evaluate or offer suggestions regarding the course quality and experience. | "Bad camera—I'm not used to not being able to see my HuangFuRen" |
| | Extension & Expansion | Make interdisciplinary connections or associations that go beyond the scope of the current course. | "Le Chatelier's Principle" |

**BERTopic Topic Analysis.** This study uses the BERTopic model to analyze danmu and comment texts, automatically identifying latent topics from large-scale interactive content. First, a Chinese pre-trained model (moka-ai/m3e-small) converts text into semantic vectors. Then, UMAP reduces dimensionality, and HDBSCAN clusters semantically similar texts into topics. TF-IDF is used to extract keywords and label topics, followed by similarity analysis to track their evolution across key lectures (1,

7, and 13). As an unsupervised method, BERTopic captures core discussion themes and their dynamics, complementing content analysis to build an objective and evolving understanding of this informal learning space.

# 4 Results and discussion

## 4.1 Temporal Distribution: The Regularity of Comments and the Ceremonial Nature of Danmu

Based on the time distribution of course comments (Figure 1), this study found that activity in this informal learning space closely follows the formal educational cycle, functioning as a flexible supplement to school learning. Comment activity peaks during winter and summer vacations (February, July, and August), when students engage in autonomous learning and intensive interaction. During semesters, activity aligns with exam periods, forming secondary peaks in April and January to meet review needs, while interaction declines during the beginning and middle of semesters. This pattern suggests that learning behavior in this physics review course is strongly exam-oriented and mainly serves as a supplementary informal learning tool for high school students preparing for exams and the college entrance examination. This exam-centered motivation is further supported by the subsequent thematic analysis of user discussions.

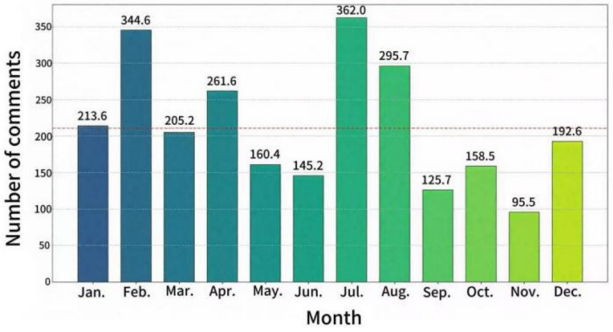


**Fig. 1.** Average comment volume for each month

In terms of interaction patterns, danmu reflect a shared community "etiquette" that fosters a ritualized participatory culture. Interactions typically follow a pattern of "check-ins at the beginning, exchanges in the middle, and acknowledgments at the end." Early "check-in" danmu, such as "120 days until the Class of 2024" function as rituals of identity and belonging, helping reduce the loneliness of online learning. As lessons progress, danmu shift toward knowledge collaboration, with comments like "Is this vector addition or scalar addition?" or "I get it now, thanks, Master," turning individual learning into a shared experience of "progressing together." Unexpected incidents, such as a teacher's camera freezing, can also trigger bursts of humorous danmu like "The ultimate ventriloquism" or "If you were kidnapped, just blink." To-

gether, these rituals connect isolated learners and create a stable, emotionally supportive learning community.

### 4.2 Collaboration Mechanisms: Division of Labor and Coordinated Action

**Functional Differentiation Between Danmu and Comments.** Danmu and comments show clear differences in interaction patterns. Emotional communication accounts for 69.97% of danmu, while rational communication makes up 30.03%, indicating that danmu mainly create real-time collaborative learning and emotional resonance. As shown in Tables 4 and 5, "check-in" (25.23%) and "off-topic content" (19.57%) dominate. Their immediate and fragmented nature makes danmu well suited for emotional synchronization and superficial interaction.

In contrast, comments function in a more balanced and in-depth way, with emotional communication accounting for 55% and rational communication 45%. Although "check-in" (16.7%), "emotional expressions" (11.67%), and "off-topic content" (9.23%) remain common, categories requiring deeper thinking—such as "question & answer" (30.7%) and "course feedback" (3.87%)—appear far more often than in danmu. The asynchronous nature of comments allows learners to write longer and more organized posts, making the comment section the main space for question answering, resource sharing, and structured reflection. Detailed discussions, follow-up questions, and supplementary materials are therefore more likely to accumulate as constructive knowledge in comments.

**Table 4.** Distribution of Comment Types

| Category | Type | Percentage |
|---|---|---|
| Emotional communication | Check-in | 16.70% |
| | Emotional Expression | 11.67% |
| | Off-topic Content | 9.23% |
| | Interacting with Lecturer | 7.87% |
| | Interacting with Other Learners | 5.00% |
| | Goals&Achievements | 3.13% |
| | Find Study Partners | 1.17% |
| Rational communication | Question&Answer | 30.70% |
| | Real-world Connections | 4.37% |
| | Course Feedback | 3.87% |
| | Resource Sharing | 3.30% |
| | Summary & Reflection | 1.30% |
| | Highlighting Key Points | 0.67% |
| | Symbolic Interaction | 0.40% |
| | Extension & Expansion | 0.30% |
| | Questioning & Correction | 0.20% |
| | AI Assistance | 0.13% |

**Table 5.** Distribution of Danmu Types

| Category | Type | Percentage |
|---|---|---|
| Emotional communication | Check-in | 25.23% |
| | Off-topic Content | 19.57% |
| | Goals & Achievements | 10.57% |
| | Whispering | 6.50% |
| | Self-Motivation and Mutual Encouragement | 5.63% |
| | Expressing Gratitude | 1.83% |
| | Maintaining Discipline | 0.50% |
| | Find Study Partners | 0.13% |
| Rational communication | Question&Answer | 18.43% |
| | Study Tips | 4.73% |
| | Course Feedback | 1.83% |
| | Explaining Difficult Concepts | 1.77% |
| | Extension & Expansion | 1.33% |
| | Answer Sharing | 0.97% |
| | Interacting with Lecturer | 0.47% |
| | Sharing Perspectives | 0.30% |
| | Questioning & Correction | 0.20% |

**The Synergy Between Real-Time Danmu and Asynchronous Comments.** An analysis of comments related to danmu shows that the two forms create a collaborative learning interaction. During video viewing, danmu provide immediate, bite-sized explanations that quickly resolve many common questions, as reflected in comments such as “Thank you, danmu—you’ve saved me so many times.” At the same time, fragmented danmu information often sparks deeper questions that are later discussed in comments. For example, users may ask about the principles behind explanations mentioned in danmu. In this process, danmu trigger questions and provide preliminary answers, while comments deepen discussion and seek more accurate explanations. Together, they combine the efficiency and atmosphere of real-time interaction with the depth of asynchronous Question&Answer, supporting a multidimensional learning space.

### 4.3 Knowledge Production and Topic Evolution within the Space

By applying the BERTopic model to comments and danmu, we identified collaboratively produced topics and their dynamic evolution within a user-supported learning space (Figures 2 and 3).

Comment topics can be grouped into four categories: functional, cognitive, social, and emotional. Cognitive topics such as “help with lecture content,” which appear in every lecture, show that the comment section is the main space for resolving deep

learning issues. Functional topics like “course missing and updates” and “learning materials and resources” reflect learners’ practical needs for complete curricula and supplementary materials. Social themes gradually deepen from “course evaluation and experience” in the first lecture to “comparison of famous physics lecturers” and “‘jargon’ community culture” in the seventh, and finally to “community interaction around lecturer” in the thirteenth. This progression reflects learners’ transformation from users to fans and then community members, marking the shift of the learning space from informational to sociocultural. Emotional themes, centered on “learning motivation and check-ins,” further evolve into “interactive incentives and learning atmosphere,” “stage exams and college goals,” and “college entrance exam countdown and goal motivation,” showing how learners’ goals become clearer and motivation shifts from internal drive to exam-oriented pressure.

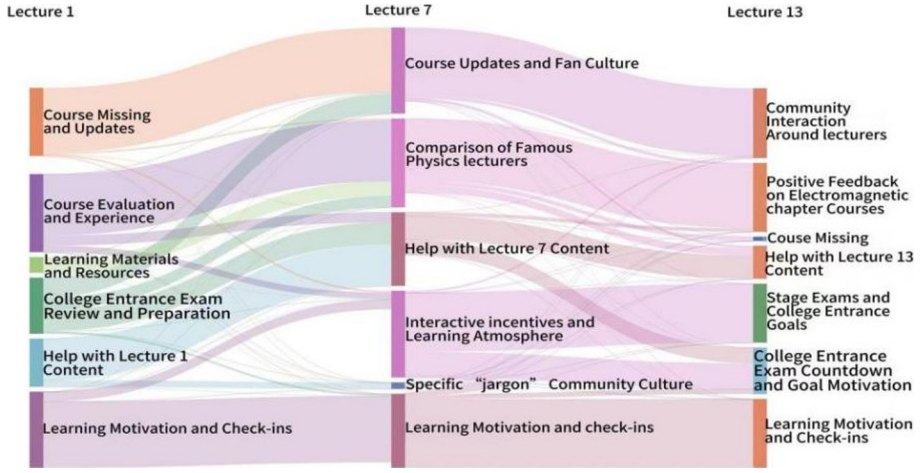


**Fig. 2.** Comment topic evolution Sankey diagram

Danmu themes can be divided into four categories: ritualistic, emotional, cognitive, and social. The ritualistic theme of “check-in” remained constant throughout. Emotional themes became more specific as the college entrance exam approached, evolving from broad “learning goals and motivation” in the first lecture to “college entrance exam countdown and motivation” and “review strategies and time anxiety” in later lectures, often featuring urgent expressions such as “countdown” and “watching lectures at double speed.” Cognitive themes followed the course content, with discussions becoming deeper over time, such as the thirteenth lecture’s focus on vectors and scalars. Social themes evolved from functional complaints about “video stuttering” to “evaluation and interaction with the lecturer,” reflecting learners’ transition from users to emotionally identified fans.

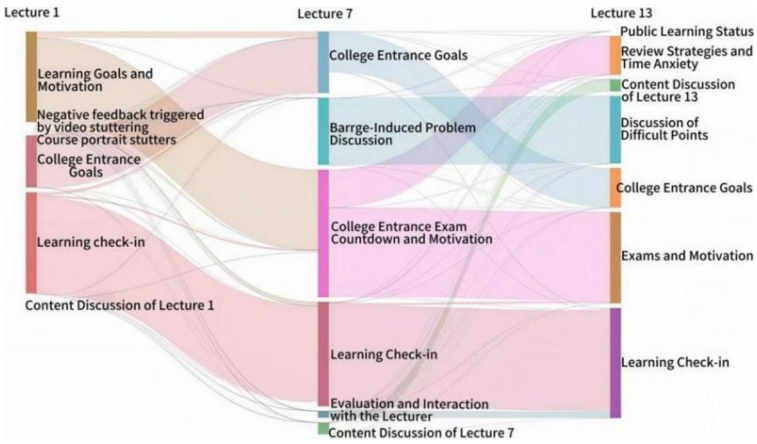


**Fig. 3.** Danmu topic evolution Sankey diagram

### 4.4 Typical Collaborative Behaviors Within the Space

Highly liked comments, as the content most recognized by the community, reflect the forms of collaboration and values encouraged within this informal learning space.

Among the top five comment types by likes (Table 6), "summary & reflective" comments are the most popular, far exceeding other categories. These comments often share learning experiences, comparisons of learning methods, and reflections on the learning process, providing reference and motivation for others. "Resource sharing" comments rank second because they offer practical materials and guidance, reducing the effort required to search for resources. Highly liked interactive comments further highlight the importance of emotional connection in online learning. Interactions with instructors express belonging and support through gratitude, advice, or humor, while interactions among learners foster peer resonance and community through encouragement and mutual support.

**Table 6.** Breakdown of Comment Types with the Most Likes

| Encoding type | Average number of likes | Number of comments | Total likes |
|---|---|---|---|
| Summary & Reflection | 2775.17 | 6 | 16651 |
| Resource Sharing | 1896.8 | 10 | 18968 |
| Interacting with Other Learners | 1752.24 | 21 | 36797 |
| Interacting with Instructors | 1687.45 | 29 | 48936 |
| Off-topic Content | 1490 | 2 | 2980 |
| Course Feedback | 1153.75 | 4 | 4615 |
| Symbolic Interaction | 969 | 2 | 1938 |
| Emotional Expression | 837.36 | 11 | 9211 |
| Goals&Achievements | 693.17 | 6 | 4159 |
| Real-world Connections | 498.38 | 8 | 3987 |
| Question&Answer | 286 | 7 | 2002 |
| Check-in | 278.9 | 10 | 2789 |

High-impact comments with many likes are usually 200 characters or fewer, suggesting that this length balances depth of expression with readers' patience. The weak positive correlation between comment length and likes (R = 0.202) further indicates that while longer comments provide more room for expression and may slightly increase likes, length itself is not a decisive factor.

### 4.5 The Dual Impact of Collaboration on Learning Effectiveness in Online Spaces

User collaboration through danmu and comments both enhances learning and introduces disruptions. Positively, danmu enable real-time interaction, shared presence, and quick Q&A through check-ins, while comments support deeper Q&A, summaries, resource sharing, and reflection. Together, they reduce isolation, improve efficiency, and promote knowledge internalization. However, distractions persist—mainly in danmu—including off-topic discussions (often from technical issues), misinformation, misinterpretations, and peer anxiety (e.g., visible user counts). Some users also criticize its "fan club-like" and anxiety-inducing atmosphere. Besides, misinformation correction is limited. downvotes lack feedback, and danmu replies are fragmented, so corrections rely on user responses. The interaction network is decentralized, with no clear KOL control, forming a crowdsourced model of knowledge production.

From a cognitive load perspective, excessive danmu can cause information overload—especially in subjects like physics—by increasing extraneous cognitive load and distracting from core understanding. Only concise tips or summaries are beneficial. Thus, while comment–danmu collaboration creates an engaging environment, it also risks distraction and cognitive burden, requiring platform optimization and strategic use by learners.

## 5 Conclusions

This study finds that learning behaviors in Bilibili's high school physics videos align with the formal education cycle. Danmu and comments serve distinct roles: danmu enable real-time emotional interaction and atmosphere-building, while comments support asynchronous, in-depth exchanges such as Q&A, reflection, and resource sharing. Together they form a multidimensional informal learning space, where discussion evolves from information acquisition to community identity, with reflective and resource-sharing comments most valued. While collaboration improves learning and emotional support, danmu may also cause distraction through overload and misinformation.

To improve this space, platforms should enhance interaction modes while reducing disruption, e.g., through "Focus Mode," danmu filtering, and better comment features like pinned answers, search, and tagging. Big data and AI can support learning tracking and content summarization. Collaborative governance between educators and

users should guide proper use of danmu and comments, promote constructive interaction, and address emotional needs to balance cognition and support.

For learners themselves, it is recommended that they strategically use both danmu and comments to combine emotional engagement with deep learning. Turning off danmu during initial viewing may reduce distraction, while re-enabling it during review can support problem-solving and collaboration. Learners should also move from passive consumers to active contributors by sharing summaries, frameworks, and resources in the comment section, thereby reinforcing their own understanding and enriching the community. Finally, learners should regulate the emotional impact of online interactions, avoid peer anxiety, and make constructive use of community support when facing learning difficulties.

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