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ABSTRACT

Interaction is central to any learning experience. Currently, Massive Open Online Courses (MOOCs) rely on discussion forums as a primary means of interaction among learners and instructors. Threaded discussions of such forums help learners to hold an ongoing and recursive discussion over an extended period, but the lack of temporal and spatial contiguity makes it insufficient to deliver a smooth interaction experience. To facilitate such interaction, this study designed DanMOOC, a commenting tool that facilitates timeline-anchored discussion among MOOC learners and instructors. DanMOOC was the first to combine threaded discussions with Danmaku commenting, a video commenting feature that allows viewers of the same video to share comments at the top of the video screen. The design process followed an iterative process of user-centered design. The impact of the new design on learning was assessed empirically through a laboratory experiment comparing DanMOOC with the current MOOC system (video-based learning + forum). The results show that DanMOOC increases learners' perceptions of social, teaching, and cognitive presence, engages learners more in discussion, and improves learners' satisfaction with both the course and the platform.

1. Introduction

Interaction has been found to be central to educational experiences, both offline and online (Bernard et al., 2009; Moore, 1989). Moreover, the amount and quality of interaction in online learning environments influences the development of a community of inquiry (CoI) (Garrison, 2007; Picciano, 2002), in which learners can construct meaning through sustained communication (i.e., cognitive presence), receive effective instruction and guidance from instructors (i.e., teaching presence), and develop a sense of belonging to the community (i.e., social presence). The development of a CoI and each of its three elements (i.e., cognitive, social, and teaching presence) has been found to influence learning performance and student satisfaction in online learning environments (Akyol & Garrison, 2008; Ke & Kwak, 2013; Swan, 2004). Facilitating learning presence has been recognized as a critical factor in the success of online learning.

In recent years, the widespread expansion of massive open online courses (MOOCs) has attracted hundreds of thousands of learners. The open and voluntary nature of the MOOC learning environment, however, imposes new challenges to the development of learning presence among students. Unlike learners in closed online learning programs, who usually share similar academic backgrounds and know each other, MOOC learners sign up voluntarily and may not know each other. Their participation in course activities can be highly selective and relatively free of peer pressure (Xie, Ke, & Sharma, 2008). In addition, the great diversity among MOOC learners in terms of academic and personal backgrounds increases the classroom communication challenges. Finally, the large enrollment sizes further amplify communication problems in MOOC learning compared to other online learning programs. How to effectively support social interaction and presence in the face of these concerns is a significant challenge.

Currently MOOCs rely on discussion forums as the primary means of interaction among learners and instructors. Threaded discussions of such forums help learners to hold ongoing and recursive discussions over an extended period, but the lack of temporal and spatial contiguity make them insufficient to deliver smooth, complete interaction experiences. On the other hand, the recent popularity of Danmaku, a video commenting feature that allows viewers of the same video to share comments on top of the video screen, makes it possible to create a "pseudo-synchronic," co-viewing experience (Johnson, 2013) among viewers who watch the same video and therefore to increase temporal and spatial contiguity for video viewers.

To combine the advantages of threaded-discussions and Danmaku comments, this study designed DanMOOC, a commenting tool that facilitates timeline-anchored discussion among MOOC learners and instructors. The tool collects and displays timeline-anchored discussion as both Danmaku comments that move over the video and listed posts scrolling in a sidebar. The design process followed an iterative process of user-centered design. The first prototype's design was based on the results of in-depth interviews with learners, instructors, and a MOOC system developer. The prototype was improved based on user evaluations. The impact of the new design on

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learning was assessed empirically, through a laboratory experiment comparing DanMOOC with the current MOOC system (video-based learning + forum), with the same amount of information served to both conditions.

The remainder of this article is organized as follows. In Section 2, we provide a review of related literature on the uses and limitations of MOOC discussion forums, and we introduce a new commenting tool design featuring timeline-anchored discussion. Section 3 presents a summary of how we developed DanMOOC and a description of the final design. In Sections 4 and 5, we report on the laboratory experiment and its results, which lead to a discussion of the findings and limitations. along with implications for future work in Section 6.

2. Related work

2.1. Asynchronous discussion forums of MOOCS

Currently, asynchronous discussion forums are the major, and sometimes the only, mechanism for interpersonal interaction among MOOC learners and between MOOC learners and instructors. Whereas a number of studies reported successful use of synchronous communication tools (e.g., chatrooms) for facilitating interaction within small learning groups in MOOCs (e.g., DALMOOC by Rosé, Goldman, Zoltners Sherer, & Resnick, 2015), asynchronous forums are more widely used and preferred in practice because they support discussion among a massive number of learners. The needs of learners in small groups, who were the focus of the studies with synchronous communication tools, would be considerably different than those of learners in very large groups, and asynchronous forums allow individual learners to engage in thoughtful discussion at convenient times (Branon & Essex, 2001).

Forums are used for various purposes in MOOCs, such as sharing information, seeking and offering help, holding discussions, and socializing among peers (Wise & Cui, 2018). Active forum participation (e.g., post, comment) has been found to be positively associated with motivation gains and course retention in a number of empirical studies (Bonafini, Chae, Park, & Jablokow, 2017; Cisel, 2014; Mustafaraj & Bu, 2015; Wise & Cui, 2018). Interestingly, in predicting learning performance among learners who complete the course, passive forum participation (i.e., reading) has been found to be a more reliable and stronger indicator than active contribution (Anderson, Huttenlocher, Kleinberg, & Leskovec, 2014; Brooker, Corrin, De Barba, Lodge, & Kennedy, 2018; Chiu & Hew, 2018; Cisel, 2014; Wise & Cui, 2018).

The availability of learners' digital footprints (e.g., clicks, traces, learner-generated content) in MOOCs allows researchers to investigate learners' patterns of engagement. By aggregating such learning analytics with performance measures and self-reports from students and educators, researchers are able to investigate the impact of learners' engagement in MOOC forum discussions on learning outcomes. Despite the positive impact of forum participation on MOOC learning, many studies have noted that the overall use of forums is often low and that only 3–15% of course members actively participate in forum discussion (Cisel, 2014; Kizilcec, Schneider, Cohen, & McFarland, 2014; Onah, Sinclair, & Boyatt, 2014). These findings contradict the expectation that discussion forums would increase engagement and promote presence among learners. This low participation rate may be attributed to both the characteristics of MOOC learners and the limitations of asynchronous discussion forums. On the one hand, MOOC learners are voluntary, and their learning engagement is fully self-paced (Alraimi, Zo, & Ciganek, 2015). They have the choice to participate in the tasks that interest them and to work at their own pace. The distant relationships with peers and instructors further add to this freedom (Xie et al., 2008). As a result, MOOC learners are highly selective in course participation. They may prefer to read (less time- and cognition-consuming) rather than contribute in a forum discussion. Mustafaraj and Bu (2015) found the population of such passive forum users could be twice as large as the population of active users. If they cannot find enough value from threaded discussion, these learners may not participate in a forum at all, in spite of instructors' efforts to encourage them to do so (Rosé et al., 2015).

On the other hand, the asynchronous communication enabled by discussion forums is inadequate to facilitate a smooth interplay between the content, the community of learners, and instructors. If learners have any questions and opinions about the lecture while watching a video, they need to hold and rehearse them in their working memory until they stop watching the video and visit the forum. This issue can be considered as a lack of temporal contiguity, i.e., the concurrency of presentation of related information for learning (Mayer, 2009). Extra cognitive resources are required for rehearsing comments and questions, and the lack of immediacy combined with the slow response from others often leads to feelings of frustration and social isolation (Branon & Essex, 2001; Hew & Cheung, 2014; Khalil, Ebner, & Herrington, 2013). In addition, the difficulty for individual learners to find interesting information in the overwhelming numbers of threads has been reported as a major reason for the reluctant participation in MOOC forums (Rosé et al., 2015). Forum discussions provide useful information for understanding the lecture video, but the organization of forum discussions is often not well integrated with the instructional content and activities, and it takes extra effort to search for and integrate information related to the video content. This lack of spatial contiguity of related information (Sweller, 1994) also impedes a smooth and effective learning experience.

2.2. Timeline-anchored discussion

To increase spatial contiguity, some systems (e.g., FutureLearn) opt to present the forum discussion on the same page as the video. However, the discussion in FutureLearn is not integrated with the timeline of the video, and learners need to search for and match information from the discussion related to the video content. A possible approach to increase temporal contiguity is to anchor discussion and comments to the playback time of the video. The idea of anchoring learner-generated content to video timelines was first explored as an annotation aid in a number of video annotation applications, such as CLAS (Dawson, Macfadyen, Risko, Foulsham, & Kingstone, 2012; Risko, Foulsham, Dawson, & Kingstone, 2013; Mirriahi, Joksimović, Gašević, & Dawson, 2018), VideoANT (Hosack, 2010), VFR (Hulsman & van der Vloodt, 2015), and L2P-bMOOC (Yousef, Chatti, Schroeder, & Wosnitza, 2015). These systems allow learners to add graphical markers along the video playback timeline and attach textual annotations to these markers. However, these systems were designed with the aim to facilitate individual learners' need for note-taking rather than for social interaction and collaborative discussion. In these systems, extra clicks are often needed to open comments attached to graphical markers on the timeline, and comments are then displayed in a separate area from the video. Social issues such as user roles are not considered.

A small amount of recent research has endeavored to facilitate collaborative discussion by creating a "pseudo-synchronic" co-viewing experience among MOOC learners (Lee et al., 2015; Leng, Zhu, Wang, & Gu, 2016; Yao, Bort, & Huang, 2017). These studies were inspired by the design of the Danmaku commenting system, developed by Niconico, a Japanese video-sharing site. The Danmaku function allows video viewers to post comments specific to the current playback time of the video, and these comments are projected directly onto the video, appearing as anonymous texts scrolling from right to left, synchronized with the playback time. Such a design has the potential to benefit online learning. On the one hand, seeking useful information has been found to be a major reason for watching Danmaku videos (Chen, Gao, & Rau, 2015, 2017). In the context of learning, comments embedded in the video allow learners and instructors to enrich the video content with extra explanations, personal reflections, and extended discussions. Such useful information further benefits subsequent viewers' understanding of the content. Moreover, seeing others' comments within the same image as the video content may the make the asynchronous viewing experience feel as if it is synchronous, invoking a feeling of watching the video alongside other viewers (Chen et al., 2015, 2017). This may improve social presence and encourage active participation.

Lee et al. (2015) were the first to explore these educational possibilities in asynchronous viewing experiences. Their design concept was similar to the Danmaku function from Niconico, but they chose to display comments beside the video (on the top vs. to the right) rather than embedded in the video. The results of their experiment showed that watching videos with timeline-anchored comments, presented in close proximity to the video and synced to the video playback time, could enhance perceived social interactivity, as compared with watching videos with no comments. Leng (2016) examined the design of displaying timeline-anchored comments scrolling from right to left across the top of the video, and found that students studying a lecture video with timeline-anchored comments showed greater improvement in their understanding of course concepts, compared with their counterparts watching the video with no comments. Using an online survey, Yao et al. (2017) compared user attitudes toward the original Danmaku design (comments embedded in videos) with those for a new design for online learning proposed by the authors that displayed timeline-anchored comments as a scrolling list in an area beneath the video. The participants recorded their opinions according to an interface mockup and explanations provided by the researchers. The results showed that the participants considered both designs to benefit both social and cognitive presence.

Though these earlier explorations generally reported promising results, a number of issues need further investigation in order to realize the implementation of the Danmaku function in MOOC platforms. First, the reported learning gains related to timeline-anchored commenting were gleaned from comparisons against the baseline condition of watching videos without any comments (Lee et al., 2015; Yao et al., 2017). The timeline-anchored comments were designed to contain useful information related to the learning content. This resulted in the comparison unfairly favoring the experimental conditions because the participants in these conditions simply had more learning-related information. Second, these systems allowed only single-line comments that could not be replied to, and they did not distinguish user roles (e.g., teachers, teaching assistants (TAs), and students). Such simplicity, adopted from the original Danmaku sites that were designed for entertainment purposes, may be inadequate for learning purposes for the following reasons: (1) it does not allow learners to input long and complex content, which is often required for in-depth and thoughtful discussions; (2) it is insufficient to hold an ongoing and recursive discussion over an extended period among a number of participants; (3) identifying instructors' involvement (teachers and TAs) is important for learning tasks. Research in online learning has found that instructors play a variety of critical roles in developing interactive learning and reflection in forum discussions (Maor, 2003). Students' perception of the instructors' presence and support is associated with their satisfaction and perception of learning (Ke & Kwak, 2013; Picciano, 2002; Swan, 2001). Third, though the original Danmaku system displays timeline-anchored comments as moving comments overlapping the video display, the studies in the learning context opted not to do so. Instead, they display comments in a separate area close to the video-playing window. The main reason behind these designs is to avoid distraction and obscuring the image. However, such a design also increases the distance between the comments and, consequently, the effort to read and integrate related comments during video watching. As previous research showed that reading others' comments is a strong predictor of peer learning and performance (Anderson et al., 2014; Brooker et al., 2018; Cheng, Paré, Collimore, & Joordens, 2011; Chiu & Hew, 2018; Cisel, 2014; Mustafaraj & Bu, 2015; Wise & Cui, 2018), we found it worthwhile to explore the educational potential of pushing comments to learners using the overlaid design.

3. Design of DanMOOC

3.1. Gathering user requirements

The purpose of the current study was to design a commenting tool that facilitates timeline-anchored discussion among MOOC learners and instructors. Following the user-centered design approach, we focused on users' needs throughout the entire design process. Preliminary user requirements were collected through in-depth interviews, and the major functions and features of the application were determined based on the result. A static prototype was developed for evaluating the design concept through user tests. The testing results were used for further improving the design.

We identified two major groups of users for this tool: learners, who participate in discussion to achieve learning goals, and instructors, who guide and facilitate the discussions. To understand the current situation of interaction in MOOCs and the possible uses of a Danmaku-based discussion system, we carried out a preliminary study of user needs by interviewing five participants, including two students with MOOC experiences, two MOOC TAs, and one MOOC system developer. The two students were an undergraduate student (aged 22), who was interested in MOOC courses about computer science, business, and management, and a PhD student (aged 30), who was interested in math, statistics, and data analysis. Both of them had experience of MOOCs for more than 6 months. The two TAs were both graduate students, aged 23, who their advisor to prepare lecture videos and manage a course about aerospace propulsion theory and engineering through the online education system, icourses.cn. They also took MOOC courses as students for about one year, and they were icourses.cn. interested in courses about daily life, science, and engineering. The developer (aged 29) worked in XuetangX.com, which is one of the most popular MOOC platforms in China. He had two years of experience of MOOC development. In addition, he had also studied a number of MOOC courses in XuetangX.com and other MOOC platforms, including Coursera and edX. All the participants had experience in using Danmaku videos, and this experience ranged from six months to seven years. Though the sample size was small, the high diversity of the participants' roles and experiences with MOOC systems allowed us to gain a rich understanding of the issues from multiple perspectives.

The participants were interviewed about the following topics: (1) What are the motivations for learning with MOOCs, according to their own experience and knowledge about other MOOC learners? (2) How are the interaction experiences among learners, instructors, and content in the MOOCs with which they have been involved, especially compared to their experience of traditional classroom teaching? and (3) What are their opinions (after being introduced to the idea of implementing timeline-anchored comments and shown a storyboard about the design) regarding the possible benefits and problems of incorporating timeline-anchored comments in the MOOC videos? Each interview lasted about 30 min. The interviews were audio recorded and later fully transcribed into text. The content of the transcriptions was analyzed in order to identify and describe user motivations and interaction needs. Coding categories were derived inductively from the interview data.

The results show that learners have various motivations for joining in MOOCs, which lead to various interaction needs. All five participants agreed that many learners took MOOCs to improve their knowledge or skills in fields that are useful to their study, work, or life. In such situations, MOOCs were treated as supplementary resources instead of a formal course that must be followed through promptly and must be completed on a schedule. These learners needed effective and efficient ways to retrieve knowledge relevant to their interests. Four participants observed that sometimes learners took MOOCs to earn certificates or credentials. These learners undertook MOOC learning the most seriously, and they have strong needs for interaction with instructors so that they can get timely support. The two TAs reported another motivation of MOOC learning: to satisfy the need for entertainment and curiosity, e.g., to learn about a novel topic or a famous professor. Learners driven by this need preferred a lively and entertaining atmosphere. Finally, one student mentioned that sometimes learners seek to make friends with participants who share similar interests or they keep in touch with friends via MOOC learning. The respondents expressed a strong need for the system to support collaborative learning and social interaction with peers.

The five participants reported a number of differences in interactions between classroom teaching and MOOCs. All participants considered interactions in classroom teaching to be more natural and immediate than in MOOCs. They pointed out that a particular convenience in classroom teaching is the ability for students to find someone to discuss a subject or to receive immediate replies from instructors as soon as they have problems. Discussions in MOOC forums, however, are asynchronous in nature, and the feedback is often slow. In addition, the organization of the discussions is often poor, and searching for useful information from forums is often time-consuming. Two students reported difficulties for students with diverse educational backgrounds in terms of initiating and maintaining a meaningful discussion. Despite these limitations, all the participants appreciated a significant advantage of MOOC forums: all the discussions are archived and searchable. In addition, two students and the engineer found that the structure of the learning content is often more explicit and clear in MOOC lecture videos than in classroom teaching. The two students also greatly appreciated the possibility of learning at their own pace with MOOCs.

All of the five participants agreed that Danmaku commenting had the potential to improve interaction among learners, but they also worried about the visual clutter and distraction created by comments overlying the screen. Three participants expressed concern that reading the flying comments while watching video lectures may be too demanding. Furthermore, the two TAs were concerned that the increase in discussions could lead to an increased workload for them as they respond to greater numbers of students' questions. They suggested that effective approaches for organizing and managing questions should be provided.

From the user interviews, we identified the following major user needs to be addressed in our design:

(1) The tool should allow learners to join in discussion as soon as the need arises while watching a lecture video.
(2) The tool should allow user input that is rich enough for in-depth and thoughtful discussion.

(3) The discussion should be archived and easy to search and retrieve afterwards.
(4) Involvement of instructors in discussion should be highlighted.
(5) Learners should be allowed to customize the display of timeline-anchored comments. In particular, the option of hiding overlapping comments should always be provided.

3.2. Prototyping, evaluation and modification

Based on the understanding provided by the interviews detailing MOOC users' needs for interaction, we proposed a Danmaku-based commenting tool supporting timeline-anchored discussion among MOOC learners, named DanMOOC, to meet the following design goals:

(1) Pedagogical goals: simulate real-time discussion experiences similar to classroom study, and facilitate discussions related to video content.
(2) Social goals: encourage social interaction and enhance learning presence.
(3) Workload goals: avoid excessive visual clutter and overwhelming attention demands for video-based learning.

We defined two types of discussion content: single-line comments and threaded conversations. A comment consists of a single-line of text that cannot be replied to, just as in other Danmaku video systems. A thread includes an initial post and all the replies to it, just as in forum discussions. Threads were further classified into two types: questions, which demand explicit and correct answers, and general discussion, for which correct answers are either unavailable or unnecessary.

In this design, both comments and threads are anchored to the video timeline. They are displayed both as flying Danmaku overlapping the video screens and as scrolling items in the right sidebar list. The flying and scrolling actions are synchronized with the video timeline. For threads, only the title of the initial post is displayed as Danmaku overlapping the video and in the sidebar list. The user can click the title of a thread in the sidebar list, and the full content of the thread will be shown under the video playing area. We offered filtering functions for learners to select the types of discussions they would like to see. A static prototype was developed to show four key features of DanMOOC: (1) watching the video with timeline-anchored comments, (2) sending a comment or thread, (3) filtering discussions, and (4) reading the detailed content of a thread and its replies.

The prototype was then demonstrated and evaluated by four MOOC lecturers, eight MOOC TAs, and seven MOOC learners. The teachers and TAs interviewed were invited from among the MOOC lecturers of XuetangX. To make sure that our interviews covered subjects as diverse as possible, we invited lecturers and TAs from courses on a variety of subjects, including science, medical science, computer science, engineering, business and economics, art and design, languages, and liberal arts. The seven learners, aged from 18 to 28 (M = 21.6, SD = 3.3), were recruited from WeChat groups of active users of XuetangX and the personal social networks of the research team. Six of them were college students. Their experience of MOOCs ranged from two months to four years.

Each session began with a brief introduction for the participants on the purpose of the research, followed by a prototype walkthrough and evaluation. The facilitator demonstrated the prototype for each scenario and interviewed the participants about their opinions regarding the function, the design, and any possible concerns for the system's implementation in a learning environment. The participants were encouraged to ask questions or provide their own comments. At the end of the session, each participant was interviewed about (1) possible pedagogical benefits or problems brought by DanMOOC, (2) the possible influences of DanMOOC on the interactions among learners, lecturers, and content, (3) other issues related to the usefulness and usability of the design, and (4) overall attitudes and intentions for further use of DanMOOC. Each session lasted about 30 min, including the walkthough, the DanMOOC session, and the interview.

The results showed that the majority of the participants (three lecturers, seven TAs, and six students) were positive about the usefulness of the system, believing that the design would enhance the interactions among learners, lecturers, and content. Showing lecture videos with timeline-anchored discussion was expected to inspire learners to talk and facilitate Q&A that was specific to a certain part of a video, to enhance the sense of community and support collaborative learning, and to attract learners with the lively discussion atmosphere. All the participants, including those who were negative about the overlying Danmaku feature, reported that they were interested in trying the system to see its impact in practice, except for one lecturer, who found the overlying Danmaku annoying and stated that she would never try it in her course.

The teachers and TAs were concerned more about content-related discussions. They expected that aggregating the discussion data and behaviors could produce more useful information about teaching and learning status. For example, the intensity of discussions related to a specific point in time or a specific video may reflect students' learning interests or difficulties. But they were also concerned about the possible increase in workload required to check the discussions and to respond to students' questions. Effective measures to filter the discussions and to aggregate similar questions were expected.

Six students found DanMOOC useful for supporting content-related discussions, but their attitudes toward social-oriented discussions were diverse. Whereas three students found social-oriented comments interesting and useful for creating a lively atmosphere, two students considered such contents distracting and believed that they should not be allowed. Three students considered that the filtering functions we provided (filtering by the authors or the types of the discussion) were adequate for protecting them from unwanted distractions, whereas four students were still concerned that their learning might be distracted by unrelated or superficial comments. While appreciating the possibility of starting a threaded conversation specific to a timeline point, the majority of participants found it confusing and inconvenient to read the full content in a separate area below the video and sidebar list. Based upon the evaluation results, we improved the design. The final design will be introduced in the next section.

3.3. Final design of DanMOOC

3.3.1. Reading comments and threads

The final system is shown in Figure 1. DanMOOC allows learners and instructors to interact through single-line comments and threaded conversations that are anchored to the video timeline. These comments and threads are presented to subsequent viewers as (1) Danmaku overlapping the video screen, flying from right to left, and (2) items in the scrolling list on the right sidebar, both synchronized with the video timeline. For threads, only the title of the initial post is displayed as Danmaku overlying the video. The sidebar shows more information on each comment or thread (see Figure 2 for details): (1) the avatar of the author, (2) the type of discussion, indicated by different background colors (light for comments, and dark for threads); (3) (for threads) the type of the conversation, indicated by a small icon in the top left corner of the avatar (question mark symbols for Q&A, and talking bubbles for general discussions), (4) the playback point to which this comment or thread is anchored in the video; (5) whether the thread or comment is verified by the instructor (either a lecturer or a TA), indicated by a green checked label; (6) and the number of likes given to the discussion by other users. By clicking an item in the sidebar list, the user can jump to the specific time point of the video to which the item is anchored. By default, only the title of the initial post of a thread is shown in the sidebar. The replies to the thread are nested under the initial post. Users can access replies by double-clicking the title to expand the full thread in the sidebar (see Figure 3), with a reply area for the user to join in the discussion. The replies to the thread are attached to the same timeline point as the initial post and do not have their own time stamps.

3.3.2. Filtering

By clicking the settings in the sidebar list, the user can access the filtering function. As shown in Figure 2, the user can choose to hide all the discussions and focus on the video, or to show the discussions in the sidebar but hide the flying subtitles on the video. The user can also filter the discussions by (1) the type (comments or threads), (2) the participation of the instructor, and (3) and the user's own participation.

3.3.3. Posting a new comment or thread

The user can choose to post a comment or a thread by clicking the corresponding tab in the input area below the video (see Figure 1). The comment input area includes a single-line text input area and a submit button, as shown in Figure 1. The thread input area, as shown in Figure 4, includes a single-line input area for the post's title, a multi-line input area for the post's body, and a submission button. In addition, the user can indicate whether the post is a question (i.e., requesting answers from others), or a general discussion about the content in the video.

4. Experimental design

4.1. Hypothesis

In order to examine whether the design of DanMOOC is effective in promoting the social interaction and learning presence of learners, we conducted a laboratory experiment to compare DanMOOC with the traditional MOOC design in a separate forum. We compared the effectiveness of the two platforms under the CoI framework (Garrison, Anderson, & Archer, 1999), which integrates interaction, presence, and learning outcomes. According to CoI, learners interact with content, instructors, and other learners, and then they develop cognitive, teaching, and social presence. The enhanced presence would lead to more meaningful learning.

The purpose of DanMOOC is to facilitate passive participation and encourage active participation of MOOC learners in video-lecture-related discussions. Previous studies found that MOOC learners are highly selective in course participation, and many of them participate in the forum only passively, i.e., they read forum discussions to receive useful information for

(a) (b)

Figure 1. Screenshot of DanMOOC: (a) the overall layout and (b) translations.

Figure 2. List of comments and threads in the sidebar: (a) the layout and (b) translations.

learning but do not post publicly. Mustafaraj and Bu (2015) found that the population of passive forum users could be twice as large as the population of actively posting users. Such passive forum participation (i.e., reading), however, has been found to be a reliable and strong predictor of learning performance, even stronger than active contribution (i.e., posting) (Anderson et al., 2014; Brooker et al., 2018; Chiu & Hew, 2018; Wise & Cui, 2018). By integrating discussion content with videos, we expected the design to reduce the extraneous load required for learners to shift their attention between watching the video and discussing it, and, therefore, to save cognitive resources for learning (Ginns, 2006; Sweller, 1994). On the one hand, DanMOOC reduces the demand on working memory for rehearsing while watching the video as well as the need for reconstructing the retrospective information about the video content during discussion. Allowing students to offer feedback in the middle of a video, instead of afterwards, has been found to yield more specific responses (Shin, Ko, Williams, & Kim, 2018). On the other hand, the spatial integration of the video content and related comments also improves spatial contiguity and reduces the need to find and integrate information related to a specific part of the video. The saved cognitive resources can be directed to essential learning activities, e.g., reflecting on what they have learned and paying attention to areas of the lecture that may have fallen outside of their own consideration. A recent study found that in-video prompting encourages learners to pay more attention to the video and to reflect on what they have learned (Shin et al., 2018). Being "pushed" with others' comments may further encourage learners to explore and integrate more levels of understanding, to confirm their own understanding, and to construct knowledge based on cognitive exchange in a CoI. According to CoI, such a process of exploration, confirmation, and construction of understanding contributes to cognitive presence. Thus, we propose the following hypothesis:

Figure 3. Detailed content and replies of a thread.

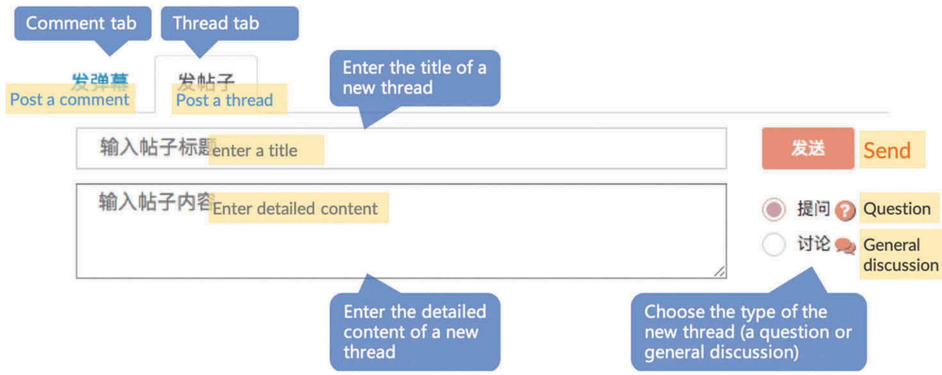

Figure 4. The interface for posting a new thread.

(a) (b)

Figure 5. Screenshots of the system with a separate forum: (a) the video page and (b) the forum page.

Hypothesis 1: Learners will perceive a higher level of cognitive presence with DanMOOC than with MOOC + forum.

Embedding collaborative discussion into lecture videos may also enhance the awareness or visibility of instructors' and other learners' participation in the discussion. This may help to develop a sense of being accompanied by peers and instructors even without active participation in the discussion. Prior research on Danmaku video systems found that being socially connected without directly interacting with others is a major motivation for using the Danmaku function (Chen et al., 2015, 2017). Further, there has been evidence that showing timeline-anchored comments in a separate window beside the video can improve the social presence of learners (Lee et al., 2015; Yao et al., 2017). Compared with the presentation of comments in those studies, DanMOOC displays comments from peers and instructors in even closer proximity to the video content, and we expected that this design would enhance the social presence and teaching presence perceived by learners.

Hypothesis 2: Learners will perceive a higher level of social presence with DanMOOC than with MOOC + forum.

Hypothesis 3: Learners will perceive a higher level of teaching presence with DanMOOC than with MOOC + forum.

We also expected such a design to encourage more active participation by MOOC learners. DanMOOC allows learners to share their immediate and ephemeral thoughts as soon as they are evoked by the video content. Such thoughts may easily decay when learners try to recall them afterwards. In addition, the high spatial and temporal proximity of the two functions (video watching vs. posting) reduces the extra workload required to find and join ongoing discussion that is related to the current playback time of the video. Furthermore, reading others' comments may inspire more personal reflection, elicit agreement and disagreement with others, or induce emotional resonance with others. These reactions may encourage the users to increase involvement in the discussion.

Hypothesis 4: Learners will post more messages with DanMOOC than they do with MOOC + forum.

Learning outcomes can be measured by cognitive learning and affective learning. Cognitive learning refers to the comprehension and retention of knowledge, as well as the development of intellectual abilities and skills (Bloom, 1956). Cognitive presence has been found to be related to better perceived cognitive learning and learning performance (Akyol & Garrison, 2011). In addition, teaching presence and teacher immediacy have been found to be significant predictors of cognitive learning (Ke & Kwak, 2013; Kelley & Gorham, 1988; Swan, 2001). Furthermore, social presence may play an indirect role in facilitating cognitive learning by creating a lively atmosphere for collaborative learning (Richardson & Swan, 2003). As discussed above, we expected that DanMOOC would improve cognitive, teaching, and social presence. We hypothesize that this increase of presence will benefit cognitive learning.

Affective learning refers to the positive attitudes that learners develop toward the course, the content, and the instructor (Russo & Benson, 2005). We expected that DanMOOC would improve teacher immediacy, teaching presence, and social presence, all of which have been found to be associated with affective learning (Baker, 2010). In addition, the form of flying Danmaku texts also adds a recreational flavor to the learning video, which may make the learning more interesting and enjoyable. Therefore, we hypothesize that DanMOOC will improve affective learning.

Hypothesis 5: Leaners will have better cognitive learning with DanMOOC than with MOOC + forum.

Hypothesis 6: Leaners will have better affective learning with DanMOOC than with MOOC + forum.

Previous research has found that interaction, both student–instructor and student–student, improves learners' satisfaction with the course (Garrison & Arbaugh, 2007; Kuo, Walker, Belland, & Schroder, 2013; Rovai, 2002; Swan, 2001). DanMOOC is expected to create a feeling of being accompanied and supported in learning, which has been found to be important to online course satisfaction (Hui, Hu, Clark, Tam, & Milton, 2008; S. J. Lee, Srinivasan, Trail, Lewis, & Lopez, 2011; Sher, 2009). Therefore, we hypothesize that DanMOOC will improve the course satisfaction of learners because it better supports interactions of the CoI.

We also expected that learners would be more satisfied with the DanMOOC learning system than the traditional MOOC + forum system. By presenting the learning content and its related discussions in both spatial and temporal proximity, DanMOOC represents the learning content in such a way that related materials are integrated and relatively easy to learn. Yet the filtering function allows learners the flexibility to access the learning content and associated discussions. Both the enriched content and the interaction flexibility were expected to improve learners' satisfaction with the system.

Hypothesis 7: Learners will be more satisfied with courses on DanMOOC than with courses on MOOC + forum.

Hypothesis 8: Learners will be more satisfied with the DanMOOC system than with the MOOC + forum system.

4.2. Experimental platforms

The experiment compared two designs: DanMOOC and MOOC + forum. The design of DanMOOC is described in Section 2.3. The interface design used in the MOOC + forum condition is shown in Figure 5. The video module and the forum module were displayed on two tabs within a single window. The layout of the video lecture interface was similar to that of DanMOOC, but there was a video playing area only in the center of the page. The tab of the forum showed a list of threads ordered by their post time on the left and the detailed post content to the right. The layout was adopted from XuetangX.com, but the detailed designs of the fonts, colors, and icons were the same as the thread design in the DanMOOC. The threads could be filtered by the participation of the instructor and the learners' own participation.

Both experimental platforms were developed using the Django 1.10.4 framework, python 3.5.2, and the following standard Web technologies: HTML5, CSS3, and JavaScript. Both platforms were instrumented so that participants' message postings and their uses of the filtering function were recorded in a database with timestamps. In the experiment, the learning platforms were shown in a Chrome browser on a 13.3-inch screen with a resolution of 1920 ×1080.

4.3. Learning materials

Each participant was asked to watch two videos chosen from a neuroscience course, Perception and Action: System Neuroscience, which was available on XuetangX.com. The first video was about sensory receptors and sensory coding, and the second was about eye movements and extraocular muscles. A major reason for choosing these videos was that we believed that the knowledge was unfamiliar to the majority of college students, but the topic was interesting for many of them. Thus, it was easy to recruit participants with similar levels of knowledge in this field. Each video lasted about 9 min.

A major goal of the experiment was to investigate whether DanMOOC facilitates learners' joining ongoing discussions that are related to the video. Therefore, it was necessary as part of the experimental preparation to generate users' comments and discussions in order to simulate a discussion environment for an ongoing course. Three graduate students and one undergraduate student (aged 20–34) from the department of industrial engineering of X University were invited to generate comments and threads. Each person watched the two videos two times independently and left comments or threads whenever they found a need to question, to discuss, or to share ideas or information. They were asked to refer to the language style of the existing threads of this course in XuetangX and in the Danmaku comments for the learning videos from Bilibili. Then the comments and threads were gathered and sorted. Similar threads were combined into a single thread with multiple replies. Similar comments, however, were reserved as they were, because it is common for a Danmaku video to have a number of similar or even the same comments flying over the screen.

Whereas all the threads were course-related, the single-line comments could be either related or unrelated to the course content. Course-related comments and threads included personal reflections on the content, explanations of concepts or terms used in the video, and the raising and answering of questions. Comments unrelated to the course content (referred to as "content unrelated" hereafter) were socially oriented content, such as "The teacher looks cute" or "It's my second time to learn this video," comments which were common in the online Danmaku videos. For the first video, 7 content-related threads, 14 content-related comments, and 19 content-unrelated comments were retained; for the second video, 7 content-related threads, 11 content-related comments, and 22 content-unrelated comments were retained. The same threads and course-related comments were included in the MOOC + forum condition. The comments were transformed into the form of threads by turning the comment texts into titles and using "as title" as post bodies. The post times of the threads were randomly generated.

4.4. Measurement of variables

4.4.1. Cognitive, teaching, and social presence

The levels of the three types of presence were measured by a nine-item five-point Likert scale that was adapted from the Community of Inquiry Questionnaire (Akyol & Garrison, 2008; Arbaugh et al., 2008) The Cronbach's α coefficients of cognitive, teaching, and social presence were calculated as 0.75, 0.72, and 0.77, respectively, indicating an acceptable level of internal consistency. The complete items are shown in the Tabel A1.

4.4.2. Cognitive learning and affective learning

Perceived cognitive learning was measured by a three-item, five-point Likert scale that was adapted from the CAP Perceived Learning Scale (Rovai, Wighting, Baker, & Grooms, 2009). Affective learning was measured with a five-item five-point Likert scale adopted from (Rovai et al., 2009) and (Gorham, 1988). The Cronbach's α coefficients of cognitive and affective learning were 0.71 and 0.80, respectively, indicating an acceptable level of internal consistency.

4.4.3. Learning performance

Objective measurement of cognitive learning included a closed-book quiz and an open-book quiz designed for each video. The closed-book quiz was aimed to test the participants' retention of critical concepts and knowledge points in the lecture videos. The quizzes were administered using a traditional pen-and-paper method. The computer screen was turned off, and the participants were not allowed to use the computer during the quiz. The questions were all objective questions in the formats of multiple choice, true or false, matching, and fill-in-the-blank. The first video had three multiple choice questions, five true or false questions, and a matching question containing nine types of sensation and five receptors. The second video had three multiple choice questions, eight true or false questions, and three fill-in-the-blank questions. The score was calculated based on the number of correct answers from the participant divided by the total number of questions.

The open-book quiz session was administered after the closed-book quiz. The open-book quiz session was designed to simulate real-life scenarios when MOOC learners look through learning materials and discussions to construct meanings or apply learning into practice after they have been taking the course for a longer time. This quiz was also administered by paper and pen, but the participants were allowed to look up any information from the learning system, including the videos and the associated discussions from the computer. They were, however, prohibited from getting any information from outside the experimental system. The open-book quiz questions were designed to test the participants' ability to integrate various knowledge points in the lecture in order to develop a deeper understanding of key phenomena. An example question was "what is the characteristic of vergence movement that distinguishes it from saccade and smooth-pursuit?" The score of an open-book question was calculated by the number of correct points given by the participant divided by the total number of points in the correct answer. In addition to the test score, the time of finishing the open-book quiz was measured with a stopwatch. We found the time required to complete the quiz to be a useful indicator of the effectiveness of the learning system in supporting information retrieval tasks.

4.4.4. Workload

Workload was measured by an instrument adapted from a Chinese version of the National Aeronautics and Space Administration task load index (NASA-TLX) (Gao, Wang, Song, Li, & Dong, 2013; Hart & Staveland, 1988). The original NASA-TLX has six dimensions. We adopted five of them (i.e., mental demand, temporal demand, effort, performance, and frustration), while the dimension of physical demand was excluded because it was less relevant in our experimental scenarios. To make it easier for the participants to respond, we used a five-point Likert scale to measure the responses to each dimension. The total score was calculated as the mean of the five dimensions.

4.4.5. Satisfaction

Course satisfaction was measured by a two-item five-point Likert scale (i.e., "I am disappointed with the way this course worked out," or the inverse, "I am very satisfied with the course"). System satisfaction was measured by another two-item five-point Likert scale (i.e., "I am very satisfied with the system," "I will take more MOOCs through this system"). Given that each satisfaction scale contains only two items and that the Cronbach's alpha coefficient may underestimate the reliability in this case, the Spearman–Brown coefficient was used to predict the reliability improvement if the number of items is doubled. The predicted values were .82 and .96, indicating an acceptable level of reliability.

4.5. Participants

Twenty-eight students (12 females and 16 males) from X University participated in the experiment. They were aged from 18 to 30 (M = 22.64, SD = 2.74). All of them had experience in learning using MOOCs (from half a year to 9 years), but they were not familiar with the neurosciences. All of the participants had studied science- or engineering-related majors, but students majoring in psychology- or neurosciences- related disciplines were not included. Their attitudes toward Danmaku videos in general were surveyed before the experiment. The results showed that 14 were positive, 7 were neutral, and 7 were negative. Thirteen of them watched Danmaku videos every day. Thus, the sample covered a variety of attitudes toward Danmaku videos.

A within-subjects experiment design was used. Each participant was asked to learn one video using DanMOOC (experimental condition) and another video using MOOC + forum (baseline condition). The orders of the interfaces and the videos were all counterbalanced.

4.6. Procedure

Each participant took part in the experiment individually in a quiet room. The participant first filled in the background questionnaire and was then asked to learn a video using either DanMOOC or MOOC + forum, decided by the counterbalanced sequence, within 20 min. Through two pilot experiments, we found that 20 min was enough time for the participants to watch the video (9–10 min) and read all of the pre-generated discussions. The participants were encouraged to get involved in the discussion, and each was asked to post at least one message. The message could be a comment, a thread, or a reply to an existing thread. The participants could decide to finish their learning sessions at any time within the 20 min. They then filled out the questionnaire about learning presence, cognitive and affective learning, workload, and satisfaction based on their experience of this learning session. After that, they took the closed-book quiz, followed by the open-book quiz about the first lecture. Upon completion of the quizzes, the participants took a rest for about 2 min before starting to learn the second video with the same procedures. After finishing the two learning videos, the participants were interviewed about their preference between the two systems, their feelings about the two formats of presenting timeline-anchored discussion (Danmaku text vs. sidebar list), and their thoughts about the type of discussion content in a MOOC learning environment. The entire experiment took approximately 60–80 min. Finally, the participants were paid RMB 60 Yuan as compensation for their participation.

5. Results and discussion

5.1. Cognitive, teaching, and social presence

Table 1 shows the descriptive statistics of the cognitive, teaching, and social presence of the two conditions. Paired *t*-tests were used to examine the differences between the two conditions regarding these variables. As shown in Table 1, the design of the discussion system has a significant effect on cognitive, teaching, and social presence. The participants perceived a significantly higher level of cognitive ($M = 4.10$, SD = 0.61), teaching ($M = 3.62$, SD = 0.66), and social ($M = 4.00$, SD = 0.58) presence with DanMOOC than with MOOC + forum (cognitive presence: $M = 3.67$, SD = 0.61, $t_{27} = 3.17$, $p = 0.004$, $d = 0.60$; teaching presence: $M = 3.09$, SD = 0.51, $t_{27} = 4.11$, $p < 0.001$, $d = 0.78$; social presence: $M = 3.34$, SD = 0.69, $t_{27} = 4.07$, $p < 0.001$, $d = 0.77$). The results support hypotheses 1, 2, and 3, stating that DanMOOC will increase learners' perceptions of cognitive, teaching, and social presence.

Cognitive presence reflects the levels of reflection and discourse that are required for the development of meaningful learning outcomes (Garrison, Anderson, & Archer, 2001). Our results suggest that the integration of the lecture video and related discussions across time and space is an effective measure to enhance individual learners' cognitive presence. It fosters an active learning climate and reduces the extraneous workload required in searching for and combining related information from different sources.

The timeline-anchored discussion of DanMOOC also improves the social presence perceived by learners. Reading others' discussions as flying Danmaku while watching the video improves the salience of other learners' presence and the salience of social interactions among learners. In addition, we found that the number of posted messages correlated significantly with social presence (Spearman's correlation: rho = 0.325, $p = 0.015$). On the one hand, the increase in social presence cultivates a sense of connection with peers in the learning community, which may encourage more active participation; on the other hand, learners' participation behaviors can add to the level of interaction in the learning community, which may further improve the perceived social presence.

Previous research on incorporating timeline-anchored discussion into MOOC learning did not consider the roles of participants. DanMOOC was the first to define and represent teaching-related roles (e.g., instructors and students) in timeline-anchored discussion. Whereas the level of the instructors' involvement in discussion was kept the same in the two conditions, embedding instructors' feedback (to other learners' questions) and comments in the timeline of the video seems to improve the "visibility" and immediacy of the communications. In the post hoc interviews, 15 participants reported that they paid extra attention to the posts with instructors' involvement, as indicated by the "checked by the instructor" icon, and that they appreciated the filtering function for showing instructor-involved posts only.

5.2. Posted messages

The participants posted 87 messages (including threads, comments, and replies) in total, with 50 in the DanMOOC condition and 37 in the MOOC + forum condition. As shown in Figure 6(a), 12 participants posted more than one message with the DanMOOC platform (maximum 5 messages), whereas only 7 participants posted more than one message with the forum platform (maximum 3 messages). Since the data violate the normality assumption for parametric tests, a Wilcoxon signed rank test, the non-parametric testing method for within-subject design, was used to compare the difference between the two conditions. The results (see Table 2) showed that the participants posted signifi-

Table 1. Comparing presence, perceived learning, workload, and satisfaction between DanMOOC and MOOC + forum.

	DanMOOC	MOOC+ forum	Paired T test[1]		
Items	Mean (SD)	Mean (SD)	t value	p value[2]	Cohen's d[3]
Cognitive presence	4.10 (0.61)	3.67 (0.61)	3.17	0.004**	0.60
Teaching presence	3.62 (0.66)	3.09 (0.51)	4.11	<0.001***	0.78
Social presence	4.00 (0.58)	3.34 (0.69)	4.07	<0.001***	0.77
Cognitive learning	3.37 (0.63)	3.26 (0.56)	1.20	0.24	0.23
Affective learning	3.64 (0.69)	3.55 (0.61)	1.10	0.28	0.21
Workload	3.00 (0.53)	3.18 (0.59)	−1.51	0.14	0.29
Satisfaction with course	3.95 (0.60)	3.59 (0.69)	2.50	0.02*	0.47
Satisfaction with system	3.80 (0.77)	3.16 (0.90)	4.01	<0.001***	0.76

1. Degrees of freedom = 27
2. *** <0.001, ** <0.01, and * <0.05
3. $d = 0.2$, small effect; $d = 0.5$, medium effect; $d = 0.8$, large effect

cantly more messages with DanMOOC (M = 1.79, SD = 1.13) than with MOOC + forum (M = 1.32, SD = 0.79, p = 0.02). Hypothesis 4 was supported. As hypothesized, learners posted more messages with DanMOOC than with MOOC + forum.

In addition, the number of original posts (replies to existing threads excluded) was also significantly higher in the DanMOOC condition (M = 1.61, SD = 1.20) than in the MOOC + forum condition (M = 0.82, SD = 0.72, p = 0.003). Furthermore, within the DanMOOC condition, the participants posted significantly more comments (M = 0.86, SD = 0.76) than threads (M = 0.25, SD = 0.70, p = 0.009). A likely reason for this is that single-line comments are a good choice for the immediate expression of quick thoughts and emotions. Comments seem a more convenient and suitable expression when the participants have only a few words to say, whereas threads are more suitable for longer and more complex content, requiring the effort to compose both a title and the text.

Figure 6(b) shows the distribution of message length (measured with the number of characters). Short messages, consisting of no more than 30 characters, accounted for a higher percentage in the DanMOOC condition (84%) than in the MOOC + forum condition (60%). The Wilcoxon signed rank test (Table 2) showed no significant difference in the number of posted characters between the two conditions, despite the difference in the number of messages.

We manually coded the messages as content-related or content-unrelated. As shown in Table 3, content-related messages included questions, answers to pre-defined questions, and other messages related to the lecture content. On the other hand, content-unrelated messages are inherently off-topic and, thus, were often socially oriented discussions or expressions. These socially oriented messages were significantly shorter than course-related messages (Number of characters: M = 10.67, SD = 6.48 vs. M = 36.38, SD = 35.31, t (76.70) = 5.62, p < 0.001). In total, the participants posted 35 related and 15 unrelated messages with DanMOOC, and 32 related and 5 unrelated messages with MOOC + forum (see Table 4 for details). The chi-squared test showed that there was a slight trend for the participants to post more social messages with DanMOOC than with MOOC + forum (χ^2_1 = 2.40, p = 0.12).

We also qualitatively compared the ideas and topics explored in the DanMOOC and forum conditions. The course-related messages in the two conditions covered similar topics, such as discussion of concepts taught in the video, inquiry into related knowledge, Q&As about details in the lecture slides, and terminology translation issues. In the DanMOOC condition, however, 7 messages (out of 35 course-related messages) were phrases or lists that summarized key concepts in the course content, as though these entries were notes taken for individual learning rather than for sharing with others. Emotional expressions (e.g., frustrations with the difficulty of the material) and social comments (e.g., thanks for others' explanations) were the majority of social messages in both conditions. It is interesting to note that in the DanMOOC condition, 3 messages commented about the cuteness of the lecturer or objects in the lecture slides. No such comments appeared in the MOOC + forum condition. DanMOOC, therefore, seems to stimulate an informal social climate.

Table 2. The number of messages posted by each participant.

The number posted by each participant	DanMOOC Mean (SD)	MOOC + forum Mean (SD)	Wilcoxon signed rank test V	p[1]
Number of original posts (threads and comments)	1.61 (1.20)	0.82 (0.72)	123	0.003**
Number of all posts (threads, comments, and replies)	1.79 (1.13)	1.32 (0.79)	59	0.02*
Number of characters being posted	25.94 (33.96)	35.89 (30.66)	617.5	0.008**

*** <0.001, ** <0.01, and * <0.05

The results indicate that DanMOOC encourages learners to participate more actively in discussions and, in particular, to share their emotional reactions. The numbers of content-related messages were similar in the two conditions, but the

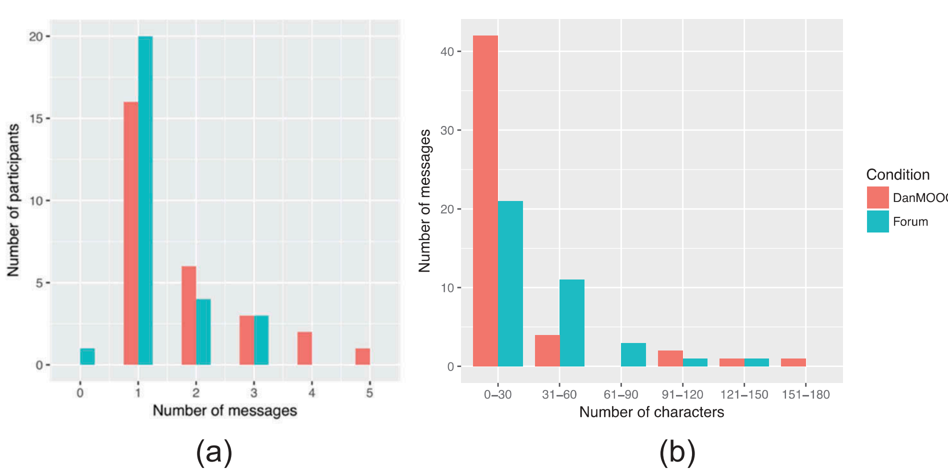

Figure 6. Distribution of posted messages. (a) Distribution of the number of messages. (b) Distribution of the number of characters. *Note*: one participant did not to post at least one message under the forum condition.

Table 3. Types of messages posted and corresponding examples.

Type of messages posted		Examples
Content-related	Questions	"What is the small section of the line in the opposite direction in this picture of pursuit eye movement?"
	Answers	(Pre-populated question: "what is the difference between the dotted lines and the solid lines in the diagram?") "The dotted line represents the movement of the target, and the solid line represents the eye movement."
	Other related messages	"Non-visual stimuli can also stimulate eye movement."
Content-unrelated	Course-unrelated messages (social)	"It is too difficult for me." "I don't know whether it is because the concept was not well explained, or it is because I am not good at it."

Table 4. Comparing the number of messages posted between DanMOOC and MOOC + forum.

	Course-related messages			
The number of posted…	Questions	Answers	Other related messages	Course-unrelated messages (Social)
DanMOOC	14	3	18	15
MOOC + forum	14	4	14	5

number of social messages in the DanMOOC condition was three times the number in the MOOC + forum condition. These comments were short and usually emotional expressions. Two reasons may contribute to this effect. On the one hand, the high temporal and spatial proximity of the video playing and discussing areas in DanMOOC reduce the extraneous effort required for users to share their immediate feelings; on the other hand, seeing others' emotional comments flying on top of the video may trigger the emotional contagion phenomenon, i.e., a social tendency of people to mimic and synchronize their expressions with those of others and to converge with others emotionally (Hatfield, Cacioppo, & Rapson, 1993). The sharing of emotions has been found to lead to benefits such as reduced distress from the sharing of negative experiences (Rimé, Paez, Kanyangara, & Yzerbyt, 2011), increasing video-viewing enjoyment by building synchronized experiences (Lin, Sung, & Chen, 2016), and facilitating the development of relationships by fostering emotional connections and synchrony (Cohen & Lancaster, 2014; Hatfield et al., 1993; Rimé et al., 2011).

5.3. Learning outcomes

Table 1 shows that the participants reported a slightly higher level of cognitive learning and affective learning with DanMOOC than MOOC + forum, but the pairwise t-tests showed that the differences were not significant, at the level of 0.05. The results did not support hypotheses 5 and 6, which stated that DanMOOC will result in significantly better cognitive and affective learning.

Table 5. Performance comparison in quizzes between DanMOOC and MOOC + forum.

	DanMOOC	MOOC + forum	Paired T test[1]		
Items	Mean (SD)	Mean (SD)	t-value	p-value[2]	Cohen's d[3]
Closed-book quiz score	0.83 (0.16)	0.84 (0.18)	−0.12	0.90	0.02
Open-book quiz score	0.69 (0.27)	0.51 (0.29)	2.78	0.0098**	0.53
Open-book quiz time (seconds)	144.71 (74.50)	141.36 (79.44)	0.25	0.81	0.05

1. Degrees of freedom = 27
2. *** <0.001, ** <0.01, and * <0.05
d = 0.2, small effect; d = 0.5, medium effect; d = 0.8, large effect

Table 5 shows the pairwise t-test of learning performance in the closed-book and open-book quiz. No significant difference was found regarding the closed-book quiz. In the open-book quiz, however, the participants had significantly higher scores with the DanMOOC system (M = 0.69, SD = 0.27) than with the MOOC + forum (M = 0.51, SD = 0.29, t_{27} = 2.78, p = 0.0098, d = 0.53). Further examination of the time spent on the open-book quiz showed that this performance improvement was not a result of the longer quiz time.

In two previous research studies on integrating timeline-anchored commenting into MOOC systems, timeline-anchored discussions were found to improve learning performance (Lee et al., 2015; Yao et al., 2017). These studies, however, unfairly favored the experimental conditions by selecting a baseline condition in which the participants watched videos without any discussions (therefore with less useful information than the experimental condition). Our study has endeavored to make the comparison fair by supplying the same amount of learning-related information to both the experimental and the baseline conditions. Although the timeline-anchored discussion feature does not significantly improve learners' memory of the content (examined by the closed-book quiz), learners can search for information related to a specific concept or question more efficiently and integrate it into a deeper understanding (examined by the open-book quiz) with DanMOOC, thanks to the temporal and spatial integration between lecture videos and discussions. The timeline stamps of discussions in DanMOOC provide an efficient scheme for searching for content-related discussions, whereas the traditional "sort by post time" or "sort by update time" organization schemes may not support such tasks very well.

Though the DanMOOC condition yielded higher mean values of cognitive learning and affective learning than the MOOC + forum condition, the difference was not significant. The improvement of presence in our study was not accompanied by an improvement of perceived learning. This result may be attributed to the limited learning time and scope of learning. Most early research verifying the effect of presence on learning performance involved long-term learning, i.e., an entire course lasting for a number of weeks (Borokhovski, Bernard, Tamim, Schmid, & Sokolovskaya, 2016; Finnegan, Morris, & Lee, 2009; Gillani & Eynon, 2014; He, 2013; Picciano, 2002; Yang, Quadir, Chen, & Miao, 2016). The limited time and scope of learning in this experiment might be inadequate to develop a real impact on the participants' understanding of the course and their attitudes toward the course and the instructor.

5.4. Satisfaction and workload

As shown in Table 1, the participants were significantly more satisfied with the course delivered through DanMOOC (M = 3.95, SD = 0.60) than with the course delivered through MOOC + forum (M = 3.59, SD = 0.69, t_{27} = 2.50, p = 0.02, Cohen's d = 0.47). They were also more satisfied with the DanMOOC system (M = 3.80, SD = 0.77) than with MOOC + forum (M = 3.16, SD = 0.90, t_{27} = 4.01, p < 0.001, d = 0.76). In addition, DanMOOC did not involve an extra workload for learners. In fact, the participants even reported a slightly lower level of workload with DanMOOC (M = 3.00, SD = 0.53) than with MOOC + forum (M = 3.18, SD = 0.59, t_{27} = −1.51, p = 0.14, d = 0.29). The results supported hypotheses 7 and 8, stating that learners will be more satisfied with courses delivered through DanMOOC and with the DanMOOC platform.

Our results provide positive evidence in favor of integrating timeline-anchored discussion into MOOC systems. The participants reported a significantly higher level of satisfaction with both the course and the platform when learning with DanMOOC. In the post hoc interviews, 21 of the 28 participants preferred learning with DanMOOC to learning with MOOC + forum, including some participants who were negative about the Danmaku function in entertainment videos. A major concern with incorporating timeline-anchored discussion into MOOC systems is that it may increase the mental workload of learners, particularly as Danmaku texts overlie the videos. Our results suggest that this may not be the case. In a learning context, discussions are useful and often necessary to help learners to clarify and understand educational material. By integrating the lecture video and related discussion, DanMOOC allows learners to process these in parallel. In addition, the filtering function allows learners to adjust the information load to suit their preference. In the experiment, four participants who felt the overlaid flying subtitles were distracting turned off the Danmaku display and kept the scrolling list only. Three of them, however, still preferred to learn with DanMOOC than with MOOC + forum.

5.5. Post-task interview

In the post-task interview, 21 of the 28 participants said they preferred DanMOOC, five participants preferred MOOC + forum, and two participants did not have a preference for either system. The main reason for preferring DanMOOC was the convenience of engaging discussion while learning the lecture video and accessing content-related discussions. The primary reason for preferring MOOC + forum was the need to concentrate on the video for learning without distractions.

The majority of participants considered that both the Danmaku display and the sidebar list were necessary features. The flying texts made it easier for them to notice useful information from others. The linear display of comments and threads in the sidebar list, however, favored search and navigation. It also allows a quick glance over all the discussions related to the video. The filtering function was considered helpful by all the participants, but 18 of the 28 participants did not use any filtering function during the experiment because they found the total amount of information acceptable.

Nearly all the participants found content-related discussions useful. Regarding socially oriented discussions, however, there was a clear divide. Whereas 13 participants did not want to see such discussions, the other 15 participants found that such comments can make the discussion atmosphere more active and the learning process more relaxing. But even advocates of socially oriented discussions noted that the number of messages unrelated to learning should be controlled so as not to dilute the quality of discussions or cover too much of the screen space. Compared with Lee et al.'s study (2015), in which 42% of the participants liked social-oriented comments even more than content-related comments, our participants were more disinclined to social-oriented discussions.

In summary, we found that the presentation of timeline-anchored discussion should be customizable to suit learners' preferences and to fit diverse course needs. In particular, the amount of content-unrelated discussions should be controlled. Whereas instructors' involvement in a discussion can be considered an obvious criterion for filtering content-related discussions from unrelated discussions, more advanced methods based on text analysis and behavior analytics should be developed when the number of discussions is very large.

6. Conclusions

Interaction between learners and instructors and among learners helps learners to construct their own meaning from learning materials by articulating their own ideas, sharing others' perspectives, and elaborating their ideas further, based on feedback from others. To facilitate such interaction in MOOCs is a challenging task. On the one hand, the need to support deep reflection and recursive discussion demands structured communication with a time lag, such as threaded-discussion in forums; on the other hand, the need for reducing attention-split across space and time requires proper integration of videos and related discussions. To address this challenge, this study designed a commenting tool that facilitates timeline-anchored discussion among MOOC learners and instructors by combining the advantages of threaded-discussions and Danmaku comments. To the best of our knowledge, we were the first to integrate the two types of communication to support collaborative discussion in learning communities, and we were the first to combine both embedded and separate displays of timeline-anchored comments. The final design, called DanMOOC, allows students and instructors to leave short comments and join in lengthy conversations related to a specific time point of the video. These discussions are displayed as both Danmaku comments moving over the video screen and listed posts in a scrolling sidebar, and learners can personalize the display and the content according to their needs.

Compared with prior studies on timeline-anchored discussion in MOOCs, our study featured an iterative process, user-centered design approach. Whereas designs in prior studies were mainly based on researchers' inspirations and intuitions, our design decisions, on user roles, types of discussion content, and representations of discussion during video watching, were based on obtained understanding of user needs for learning and interacting during MOOC video learning. We gathered user requirements from the perspectives of both students and instructors and evaluated our understanding through iterative user studies. Furthermore, we empirically assessed the impact of the new design on learning through a laboratory experiment comparing DanMOOC with the current MOOC system (video-based learning + forum) with the aim of verifying its effectiveness in promoting interaction and enhanced presence for learners. By supplying the same information (both the video and the discussion content) to both groups, the current study provides more valid and reliable evidence to justify the potential of incorporating timeline-anchored discussion in lecture videos as compared with prior studies.

The results show that DanMOOC increases the cognitive, teaching, and social presence perceived by learners, and it stimulates learners to engage more actively in discussions. The results suggest that embedding timeline-anchored discussion into videos can effectively facilitate interaction in learning contexts. The timeline stamps of discussions provide a common ground for learners to easily converse about a specific topic taught in the video. In addition to the enhanced convenience of direct interaction, the enforced visibility of discussions embedded in the video screen also increases the awareness of other participants on the course and facilitates a passive socialization strategy, i.e., learners can observe others' opinions, drawing comparisons with their own opinions, and get connected to others without directly interacting with them (Tidwell & Walther, 2002). Previous research shows that such presence increases the usage intention especially for passive users (Akar, Mardikyan, & Dalgic, 2018). These enhancements effectively improve their satisfaction with the course and with the system.

Our study also found that embedding timeline-anchored discussion in videos improves the learning performance in the open-book quiz. This can be attributed to the improved spatial contiguity of the design, i.e., the related comments and discussions were integrated with the video rather than spatially separated from it. In this way, the extraneous workload needed for searching for and matching information is reduced, and more cognitive resources can be used for mentally integrating and understanding a single issue. We found that this scenario is representative of real-life cases when MOOC learners want to apply what is learned to real practice after taking a MOOC course. In these cases, they often have ready access to the learning materials. Our results suggest that DanMOOC makes information retrieval and integration easier in these scenarios.

Future work may further elaborate this design concept to serve more practices of online learning and education. First, though the purpose of DanMOOC was to improve social exchange and though all the information added to the timeline is public, we found that a number of our participants used the function to take notes for themselves. As effective learning involves both note-taking and social engagement, further research may explore the possibility of integrate timeline-anchored note-taking and discussions into one system. By incorporating both personal annotations and collaborative discussion, the system may turn lecture videos into hypervideos, which support dynamic processes of learning lectures instead of a traditional linear learning process (Sauli, Cattaneo, & van der Meij, 2018). Second, the content of timeline-anchored discussion, the timeline stamps of the posts, and the frequency of posts provides rich information to be mined. Current learning analytics research either endeavors to make sense of the video content or attempts to understand learners' usage patterns (Mirriahi & Vigentini, 2017). Timeline-anchored comments would feed both types of research with rich and ready-for-triangulation data. Data analysis and visualization techniques can be applied, on the one hand, to develop crowdsourcing outlines or summaries of video lectures and, on the other hand, to reveal learners' behavior patterns and the distribution of interests on the video timeline, which are important feedbacks to instructors' work. A number of recent studies have designed visualization tools for forum discussions (Fu, Zhao, Cui, & Qu, 2017; Song, Zhang, Duan, Shamim Hossain, & Rahman, 2017; Wong & Zhang, 2018) and timeline-anchored comments (Sung et al., 2016). Future study may work on visualizing data of timeline-anchored discussion to support pedagogical goals for both instructors and students. Third, there is a clear divide in learners' attitudes toward course-unrelated discussions: whereas half participants found unrelated discussions relaxing, the other half found them distracting. This indicates a strong need to allow learners to filter Danmaku comments based on their relevance to the video content, which can be assessed through text mining and semantic analysis. These issues can be explored in further study. Finally, though distractions of the Danmaku design were reported in post-task interviews, the current study did not investigate directly how learners allocate their attention between video content and Danmaku contents. Future study involving eye-tracking analysis may help to obtain deeper insights about learners' attention and cognitive processes.

Nearly all the participants found content-related discussions useful. Regarding social-oriented discussions, however, there was a clear divide. Whereas 13 participants did not want to see such discussions, the other 15 participants found that such comments can make the discussion atmosphere more active and the learning process more relaxing. But even advocates of social-oriented discussions noted that the number of messages unrelated to learning should be controlled so as not to dilute the quality of discussions or cover too much of the screen space. Compared with Lee et al.'s (2015), in which 42% of the participants liked social-oriented comments even more than content-related comments, our participants were more conservative about participating in socially oriented discussions.

In summary, we found that the presentation of timeline-anchored discussion should be customizable to suit learners' preferences and to fit diverse course needs. In particular, the amount of content-unrelated discussions should be controlled. Whereas instructors' involvement in a discussion can be considered an obvious criterion for filtering content-related discussions from unrelated discussions, more advanced methods based on text analysis and behavior analytics should be developed when the number of discussions is very large.

Whereas the current study provides evidence for the potential of timeline-anchored discussion to facilitate MOOC learning, still, caution should be exercised in generalizing the findings. The current experiment investigated the impact of different designs through a laboratory experiment for about one hour. The participants' motivations for interacting with others may be different from real-life scenarios when they learn MOOCs at their own pace and in their own place. In addition, as in a cross-sectional study, only one learning session was observed for each participant in each condition, and the participants read comments that were pre-defined by the researchers. In reality, the interaction among learners and instructors is dynamic and reciprocal, and the interaction dynamics often changes throughout the duration of the course. To understand how to foster and maintain a healthy atmosphere for learning-oriented discussions, longitudinal studies are required. The next step of our research plan is to refine the design and validate the effectiveness of the design through a pedagogical experiment in which the behaviors of instructors and students in a course taught on two platforms will be collected and compared.

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Appendix

Table A1. The items and descriptive statistics of presence, perceived cognitive and affective learning, workload, and satisfaction.

Items	DanMOOC Mean (SD)	MOOC + Forum Mean (SD)
Cognitive presence	4.10 (0.61)	3.67 (0.61)
1. The video and the discussion increased my interest in the course.	3.86 (0.71)	3.61 (0.83)
2. The system provides useful information related to the course, and it can help me think, solve problems, and learn from other learners' perspectives by the discussion.	4.18 (0.77)	3.79 (0.74)
3. Integrating the information can help me think about concepts and solve problems.	4.21 (0.74)	3.96 (0.64)
4. I can know the key points in time while learning the lecture.	4.14 (0.80)	3.32 (1.22)
Teaching presence	3.62 (0.66)	3.09 (0.51)
5. The instructors help learners to study, facilitate the discussion, guide learners to study better.	3.96 (0.84)	3.32 (0.94)
6. The instructors can easily answer common questions from learners	3.54 (0.88)	3.25 (0.59)
7. The instructors provide quick feedback to learners.	3.39 (0.88)	2.86 (0.71)
8. The instructors help to make learners feel as if they belong to a class.	3.57 (0.88)	2.93 (0.94)
Social presence	4.00 (0.58)	3.34 (0.69)
9. I can read or take part in the discussion and feel comfortable.	4.00 (0.77)	3.11 (1.13)
10. Reading or taking part in the discussion makes me feel I belong to a group or a community.	3.79 (0.92)	2.93 (0.98)
11. Reading or taking part in the discussion makes me feel that many other learners are learning the course with me.	3.96 (0.74)	3.25 (0.84)
12. If my posted messages are accepted or agreed by other learners, I will have a sense of achievement.	4.25 (0.70)	4.07 (0.77)
Cognitive learning	3.37 (0.63)	3.26 (0.56)
1. I can organize course materials into a logical structure.	3.75 (0.70)	3.68 (0.61)
2. I can produce a course study guide for future students.	3.29 (0.76)	3.11 (0.79)
3. I can intelligently critique the texts used in this course.	3.07 (0.94)	3.00 (0.67)
Affective learning	3.64 (0.69)	3.55 (0.61)
4. I have a positive attitude toward the way the course worked out.	3.61 (0.83)	3.46 (0.69)
5. I feel the content of the course is valuable.	3.89 (0.63)	4.11 (0.50)
6. I have a positive attitude toward the instructor of the course.	3.39 (1.03)	3.50 (0.96)
7. I would take another course on related content, if my schedule permits.	3.79 (0.92)	3.32 (0.98)
8. I would take another course with the instructor of this course, if I have a choice.	3.54 (1.00)	3.36 (0.95)
Workload	3.00 (0.53)	3.18 (0.59)
1. When learning the video by the system, how much mental effort or cognitive activities (e.g., attention, memory, thinking, decision, calculation, searching) did you need and how much mental load did you feel you had?	3.71 (0.81)	3.64 (0.73)
2. To finish learning within the time limit, how much time pressure did you feel?	3.07 (0.94)	3.14 (1.04)
3. When learning the video by the system, how much effort did you make?	3.39 (0.88)	3.46 (0.69)
4. How satisfied are you with your learning performance? (inverse)	3.64 (0.62)	3.11 (0.74)
5. How frustrated did you feel when learning the video?	2.46 (0.88)	2.75 (0.89)
Course satisfaction	3.95 (0.60)	3.59 (0.69)
1. I am disappointed with the way this course worked out. (inverse)	1.86 (0.71)	2.21 (0.83)
2. I am very satisfied with the course.	3.75 (0.65)	3.39 (0.79)
System satisfaction	3.80 (0.77)	3.16 (0.90)
3. I am very satisfied with the system.	3.75 (0.80)	3.00 (0.86)
4. I will take more MOOCs using this system.	3.86 (0.80)	3.32 (1.02)