Mobile-Friendly Content Design for MOOCs: Challenges, Requirements, and Design Opportunities

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ABSTRACT

Most video-based learning content is designed for desktops without considering mobile environments. We (1) investigate the gap between mobile learners' challenges and video engineers' considerations using mixed methods and (2) provide design guidelines for creating mobile-friendly MOOC videos. To uncover learners' challenges, we conducted a survey (n=134) and interviews (n=21), and evaluated the mobile adequacy of current MOOCs by analyzing 41,722 video frames from 101 video lectures. Interview results revealed low readability and situationally-induced impairments as major challenges. The content analysis showed a low guideline compliance rate for key design factors. We then interviewed 11 video production engineers to investigate design factors they mainly consider. The engineers mainly focus on the size and amount of content while lacking consideration for color, complex images, and situationally-induced impairments. Finally, we present and validate guidelines for designing mobile-friendly MOOCs, such as providing adaptive and customizable visual design and context-aware accessibility support.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; *User studies*; *Empirical studies in ubiquitous and mobile computing*.

KEYWORDS

Mobile Learning; MOOCs; Video-based Learning; Learning Difficulty; Content Design

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1 INTRODUCTION

Mobile learning has gained popularity and has been a key driver in enabling ubiquitous learning [55, 64]. In addition, major online learning and Massive Open Online Courses (MOOC) platforms including edX [19], Coursera [38], Khan Academy [40], and Udemy [41] provide mobile apps to support learning on mobile devices. Despite the rise in popularity, mobile video-based learning has physical (e.g., small screen size) as well as environmental (e.g., limitations on sensory channels posed by ambient noise and light) [66] constraints. Existing learning frameworks suggest that tiny font sizes and content-heavy lecture materials on small screens increase learners' cognitive load [47, 70, 71] and lower judgments of learning (JOLs) [25, 63]. Meanwhile, situational factors such as ambient noise [76], ambient light [21], and the mobile state of the learner [21, 66] may saturate mobile learners' visual and auditory channels and cause situationally-induced impairments and disabilities (SIIDs). Prior work revealed that SIIDs might impede learning, deteriorating text legibility [54], reading comprehension, and cognitive performance [2]. Furthermore, most of the existing educational videos have been primarily designed for desktop environments. Although a body of research suggested design guidelines for mobile educational apps and websites [20, 42, 53, 67], few studies have contributed guidelines specific to mobile video-based learning content. Unlike static content, educational videos are temporally dynamic with both audio and visual information, and contain unique design components such as talking-head instructors and real-time handwriting. Also, existing literature mainly focuses on the learner side, leaving how designers currently consider the difficulties of the learner side in the design process largely unknown.

To fill in this gap, we conducted quantitative and qualitative analysis on the visual design of video content that causes readability issues and SIIDs from three perspectives: (1) learners (through surveys and interviews), (2) video content (through content analysis), and (3) video production engineers (through interviews).

To uncover the challenges learners face in mobile MOOC learning, (1) we surveyed 134 learners and conducted follow-up interviews with 21 learners. The results revealed two main difficulties learners experience with visual content design: readability issues and limitations on sensory channels. We then evaluated whether the current MOOC videos are suitable for mobile learning. Through the content analysis, we diagnosed how severe the problem is, thereby quantifying deficiencies of current design and guiding improvement schemes. (2) We analyzed 41,722 video frames sampled from 168,508 frames in 101 courses from MOOC platforms by applying the known design guidelines. The content analysis results showed a low guideline compliance rate for the key readability design factors (2.79% for font size, 74.20% for the amount of text, 0.94% for the font size of the text in the image, 66.22% for color contrast between text and background). (3) Finally, we interviewed 11 video production engineers to investigate how they currently consider the learners' challenges. The results showed that readability is the biggest concern, and they focus on the font size and amount of content. Meanwhile, little attention has been paid to complex images and images with text in the design process, which was the major learner-reported difficulty. In addition, engineers do not pay significant attention to situationally-induced impairments of learners in the design process. The findings imply a gap between learners' challenges and engineers' design considerations.

Based on the noticeable findings from the study of learners, engineers, and video content, we suggest a set of design guidelines for creating mobile-friendly MOOCs. We then validated the suggested guidelines through an evaluation session with video production engineers. The engineers' ratings on each guideline item demonstrated the guideline's clarity and applicability. We further discuss design opportunities for future research, which include providing adaptive and customizable visual design and context-aware accessibility support. The contributions of this paper can be summarized as follows:

- An identification of the gap between learners' challenges and video production engineers' design considerations on mobile MOOC learning
- A mixed-methods analysis of mobile MOOC learning experiences encompassing three aspects: learners, MOOC video content, and video production engineers
- A set of validated design guidelines for video production engineers and content designers in designing mobile-friendly MOOCs

2 RELATED WORK

Here we introduce existing work on (1) content design for educational videos and (2) design guidelines for mobile learning.

2.1 Content Design for Educational Videos

Studies of content design for educational videos mainly lie in two branches: lecture types and visual design elements. First, studies have explored how different lecture types affect student engagement [8, 24]. For instance, Guo *et al.* [24] analyzed 6.9 million video watching sessions from four courses. They found that talking-head videos and Khan-style tablet drawings are more engaging than slide-based, programming/coding, and classroom recordings.

Other work highlighted the importance of visual design elements in the learning process, such as text and images. Inappropriate font sizes [47] impose cognitive load with reduced readability and lower judgments of learning (JOLs) [25, 63]. Besides, an excessive amount of words increases the cognitive load [47, 71] and information overload [1]. Image elements can also increase the cognitive load by splitting learners' attention when multiple images are presented at once [46, 47] or when the graphics are too complex [27, 74]. Due to the importance of visual designs in a learning context, several studies [14, 72] emphasized readability as a key factor in mobile content design. Also, Cross *et al.* [15] used crowdsourcing to improve the legibility of educational videos.

However, existing literature has only covered content design for instructional videos or mobile learning websites, leaving the intersection area —- mobile video-based learning —- unexplored. Furthermore, previous work mainly focused on learners' perspectives, not involving content creators' viewpoints or interactions between two groups. To fill in this gap, we investigated challenges, perceptions on current content design, and design opportunities from both perspectives of learners and video production engineers.

2.2 Design Guidelines for Mobile Learning

Mobile learners have different requirements from desktop users due to the constraints such as limited screen sizes and distracting mobile learning environments. In consideration of these user needs, several studies suggested guidelines for mobile learning applications, such as interface design (e.g., menu, links, and navigation between pages, etc.) [23] and framework for mobile learning design considering learning contexts [59]. O'Malley *et al.* [57] also presented usability guidelines for mobile learning, which includes segmenting video content into small chunks and giving controls to learners to adjust the pace of learning. Later on, Wang *et al.* [73] gave practical recommendations on utilizing caption, icon, and color to guarantee an adequate mobile learning experience. Huber *et al.* [33] introduced video interface concepts that are GUI-based and touch-based to enhance mobile video browsing. Meanwhile, other research suggested recommendations for the instructional design of mobile learning. Stanton *et al.* [68] investigated how the characteristics of mobile environments are reflected in the procedure of designing mobile learning based on Bloom's pedagogy. Mandula *et al.* [50] recommended instructional designers to limit the graphic content, shorten the lecture length, and support multimedia content for mobile video learning.

Nonetheless, existing guidelines and recommendations are limited to educational websites, applications, and instructional design, which calls for design guidelines for visual and audio elements of mobile video-based content. The visual and audio elements are the main factors that affect mobile learning experience since mobile environments pose physical (e.g., limited screen sizes) and contextual (e.g., ambient noise) constraints on visual/auditory channels. Furthermore, validated mobile video learning guideline that considers the transitional characteristic (e.g., temporal mappings with audio) and unique design components (e.g., talking-head instructors, real-time handwritings) of video-based learning content is needed. To that end, our research suggests design guidelines based on empirical evidence and their applicability and utility evaluation from the content creators.

3 STUDY1: LEARNER PERSPECTIVES

To investigate the difficulties of mobile learners when consuming video-based lectures, we conducted surveys and follow-up interviews with mobile MOOC learners.

3.1 Survey Study

3.1.1 Survey Protocol. The survey questions include demographic questions, mobile learning context (e.g., devices, learning platforms, subjects, and situations in which learners take mobile MOOCs), learning behaviors (e.g., how frequent and how long for mobile MOOC lectures), and difficulties on visual design elements (e.g., text, image, and color). The question on design elements provides ten multiple-choice options (Table 5 1st, 2nd column) that are most frequently reported as main visual factors by the existing 25 design guidelines. The 25 guidelines (Table 5) are selected from the literature, which are the guidelines for visual design elements of educational content. The survey also contains multiple-choice questions about which lecture type causes the difficulties in mobile learning. We provided eight lecture types based on an existing taxonomy of video lecture styles [11, 13, 16, 35, 58] as multiple-choice options: animation, recorded classroom, programming/coding, hand-drawing, interview/discussion, screencast, slide-based, and talking-head. We ended the survey with a section for respondents to leave their email if they were open to a follow-up interview. We added the detailed survey questions in the supplementary materials.

3.1.2 Respondents and Recruitment. We recruited 134 respondents (43 female, 90 male, one prefer not to specify) with ages ranging from 18 to 74 (18-24: 40, 25-34: 73, 35-44: 16, 45-54: 4, 65-74: 1) from 11 countries (South Korea: 48, Brazil: 25, The United States: 23, India: 22, Others: 16) through Amazon Mechanical Turk (AMT) and advertisement posts on online university communities. We ensured that all respondents had a mobile MOOC learning experience by asking them to upload a mobile screen capture of learning history or certificate from MOOC platforms.

3.2 Interview Study

3.2.1 Interviewees. To get a deeper understanding of the learners' challenges and requirements in mobile MOOC learning, we followed up with a subset of respondents who left their email addresses in the survey response. We reached out to 56 surveyors by email, and 21 responded (13 male, 8 female). We provided a $10 Amazon gift card as compensation for each interviewee. Their age ranged from 18 to 44 years old. Interviewees were from South Korea (11), Brazil (4), the U.S. (3), India (2), and Canada (1). We refer to these interviewees as P1 through P21.

3.2.2 Interview Protocol. We conducted semi-structured interviews remotely using an online communication tool, Zoom, and audio-recorded the interviews under consent. The interviews took 30-40 minutes with four main sections: (1) whether they think the current visual design of MOOCs is suitable for mobile environments; (2) the main visual design elements that have caused difficulties in mobile MOOC learning; (3) the lecture types they experienced on mobile devices and challenges of each lecture type; and (4) how they currently deal with the difficulties and their features they want to have to mitigate the challenges mentioned above, regardless of technical feasibility. The complete set of questions is included in the supplementary materials.

3.2.3 Interview Analysis. To analyze learners' challenges caused by visual design elements and types of lectures, we followed an

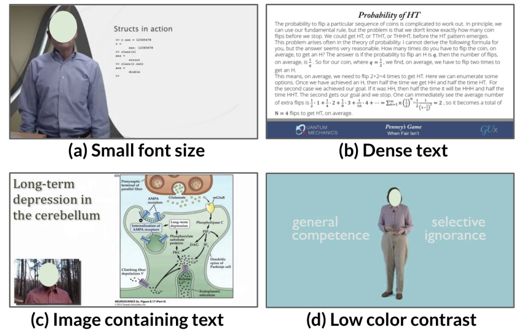

Figure 1: Example of learner-reported challenges from sampled video lectures. (Lecture Source and License: Mike Fitzpatrick, James Freericks, Leonard E. White, Barbara Oakley)

iterative coding process [32]. The two authors coded three randomly selected interview transcripts from the dataset using the codebook. We then computed Cohen's kappa to access inter-rater reliability. The average Cohen's kappa score across all codes was 0.85 (SD=0.05, ranging from 0.80 to 0.89) with an average of 92.75% agreement. Each of the two authors then coded the remaining interviews independently. After independent coding, they met to discuss in two 1-hour meetings the interpretations, discrepancies until they reached a consensus on the codebook. They adjusted their coded data accordingly.

3.3 Survey and Interview Results

Results show that the mobile phone and tablet PC were the primary device used for mobile learning. 68% of respondents reported using mobile phones, 31% tablet PC, and 1% laptops. In terms of mobile MOOC learning frequency, 33% of respondents replied 3-5 times a week. The learners did mobile learning during their free time (42%) and while commuting (36%). The respondents' experiences cover a wide range of subjects and lecture types. The complete survey results are in the supplementary materials. We analyzed learners' challenges with visual design elements and lecture types in mobile learning environments. The list of challenges and frequencies of responses are presented in Table 5. The readability issues caused by small font size, dense text, and small text in complex images were primary pain points, followed by challenges related to image elements such as small image sizes and too many images.

3.3.1 Challenges on Visual Design Elements. In general, many interviewees (16 out of 21 in the interview) shared that the visual design of current MOOC content is not suitable for mobile devices (Fig. 1). We organize the reasons by visual design elements below.

Text Element

Small Font Size (survey: 63/134, interview: 19/21). The small font size was the most frequently reported pain point in both the interview and the survey. P19 reported that he "*relies on the audio instead of trying to read the small fonts*" and others (P4, P12, P20) re-watched the content using large-screen devices later. The problem deteriorated further due to the distracting learning environments. For example, P11 stated that "*When I'm on the bus, small fonts cause* *eye fatigue and motion sickness.*" Meanwhile, the readability issue even causes dropouts. In contrast, interviewees "*could bear with small fonts in stable environments such as home or library*"(P20) even with the small mobile screens. P17 also mentioned that "*I have readability issues when I'm working out, but I don't have any (issue) when I'm home.*" In other words, learners' preferences and requirements differ depending not only on the screen size but their context and environment.

The most commonly used solution to address the small font size was zooming in on the video content. However, all of the interviewees pointed out the inconvenience of the current pinch-zoom interaction of the video interface of MOOC platforms. Some interviewees (P1, P5, P6, P7, P11, P16, P18) found it irritating to keep zooming in content every scene changes. P11 commented on the inconvenience of adjusting the zoomed area, stating that "*It's annoying to move the zoomed area back and forth since zooming always results in part of the content getting cut off.*" P6, on the other hand, encountered technical issues while using zoom interaction, which resulted in unwanted actions such as exiting full-screen mode and scene transitions. Interviewees wanted element-wise and tap-based zoom interaction, which would allow them to enlarge certain design elements such as textboxes or images without cutting off (P10). They suggested an automatic zoom-in feature that enlarges the current spot on the slide being explained.

Dense Text (survey: 36/134, interview: 8/21). Several interviewees (P1, P7, P9, P10, P12, P16, P18) complained that text-heavy content on mobile screens makes it difficult for them to concentrate. Because of the dense text, P12 abandoned mobile learning and used a laptop to rewatch the lecture. P16 suggested that "*chucking long lines of text can mitigate the problem*" and P18 proposed "*reducing the amount of text responsively to fit the mobile display.*" On the other hand, P10 wanted more cues such as highlighting on the current explanation spot since "*it's easy to lose the instructor's explanation spot in the lecture material in the distracting mobile environments.*"

Inappropriate Text Spacing (survey: 18/134, interview: 4/21). P7 and P20 said that the inappropriate text spacing and line spacing make text harder to read on a mobile device.

Inappropriate Font Style (survey: 14/134, interview: 0/21). Inappropriate font style was not mentioned by interviewees, while 14 respondents in the survey reported this issue.

Image Element

Image Containing Text (survey: N/A, interview: 9/21). Since "image containing the text" was not included in multiple-choice options in the survey, we have no such data to report as a survey result. However, nine interviewees stated that the main challenge with images was the small text contained in the images. The font sizes of labels in charts and graphs were often too small to read (P2, P10, P20). P10 complained that he "*should rely on the instructor's narration without access to the small labels in the graphs.*" This happened especially when the images were copied and pasted from the sources such as textbooks without adjusting font sizes.

Complex Images (survey: 32/134, interview: 7/21). Complex images include graphs, charts, tables, and infographics. P3 mentioned that "*complex images with subtle details were not recognizable even if they are presented as full-screen images*". They were using pinch-zoom interactions to mitigate the problem. Similar to interviewees' comments on the small font sizes, P10 wanted to use element-wise and tap-based zoom interaction for the complex images.

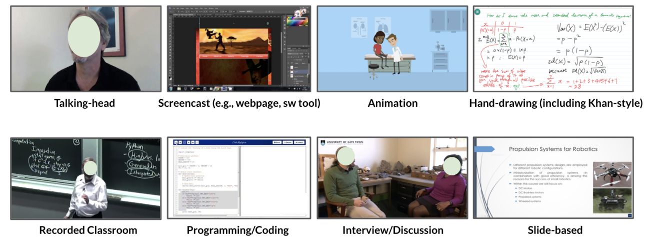

Figure 2: Eight lecture types summarized from existing work [11, 13, 16, 35, 58]. (Lecture Source and License: Joe Warren, Rajagopal Raghunathan, John Guttag, Anusuya Chinsamy-Turan, Autonomous Robots Lab)

Small Image Size (survey: 51/134, interview: 5/21). Similar to interviewees' comments on complex images, some interviewees (P1, P11) complained about the text inside the small images, stating "*I had no difficulties with simple and straightforward pictures even their sizes are small, but I could not read the text inside the small-sized images.*" (P1). On the other hand, P3 pointed out that the size of the images was not a problem since most of the complex images are displayed in full-screen mode. However, he needed additional zooming in or cropping for interest in complex images.

Too many images (survey: 23/134, interview: 3/21). One interviewee found it challenging to know which image is currently being explained by an instructor (P10). P1 stated that he is "*easily overwhelmed by many images on small mobile screens compared to desktop environments*".

Color

Low Color Contrast (survey: 19/134, interview: 3/21). Some interviewees (P20, P2) encountered readability issues due to the low color contrast between the fonts and background. According to P2, a fancy background with a low color contrast with text, in particular, decreases the readability of the content: "*It's hard to read text on fancy graphics such as background using the Chroma Key technique. It might make the lecture more engaging in desktop environments, but readability is more important for me on mobile screens.*"

Too Bright Color (survey: 15/134, interview: 2/21). Interviewees explained that bright colors cause eye fatigue when mobile environments have low lighting. P5 and P16 wanted to have a dark mode option for video content.

3.3.2 Challenges per Lecture Type. We now report mobile learners' challenges for each lecture type (Fig. 2). The four major pain points were content-heavy lecture material (in slide-based, programmingcoding), low readability & legibility (in slide-based, screencast, recorded classroom, hand-drawing, programmingcoding), lack of visually organized lecture material (in talking-head, interview/discussion), and the unavailability of following software tutorials or coding practice (in the screencast, programmingcoding).

Talking-head (survey: 89/134, interview: 3/21). The main pain point of talking-head was a lack of visually organized lecture material such as on-screen text and lecture slides. Some interviewees (P7, P9) preferred to have visual lecture material in mobile learning, particularly when their auditory channel becomes unavailable in noisy environments. P7 additionally stated that "*it was hard to get lecture content organized in the head in distracting environments without on-screen lecture material that provides a summary at-a-glance.*" (P7).

Although displaying the instructor's talking-head is engaging, picture-in-picture talking-head along with main content "*decreases readability limiting space for main content*" (P2) and "*split attention in already distracting mobile environments*" (P17, P18). For this reason, P2 wanted to turn on and off the picture-in-picture talking-head as needed, and P19 suggested toggling feature to switch between lecture types.

Slide-based (survey: 84/134, interview: 8/21). While the slide-based lecture is a commonly used lecture type in MOOCs, interviewees found it challenging to consume it in mobile environments due to the content-heavy lecture materials, low readability, and limitations on visual channels. The text and images in lecture slides incurred visual load to interviewees in mobile environments. P12 and P14 pointed out that slide-based lectures usually contain more content than other lecture types, such as taking-head. P12 said that "*I don't take slide-based courses on mobile phones since it's hard to concentrate on text and images on small screens.*" P1 and P5 mentioned the readability issues due to the small text in the slides. Furthermore, the distracting mobile environments, especially when interviewees are on the move, limit access to visual lecture materials (P12).

Hand-drawing (survey: 44/134, interview: 7/21). The main difficulty was the legibility of the handwritten text. Some interviewees (P1, P6) explained that the font size of the handwritten text was small, and others (P2, P4, P14, P15, P21) complained about the poor handwriting of the instructor.

Screencast (survey: 44/134, interview: 4/21). Interviewees found it difficult to follow the screencast lectures for two reasons. First, the shared desktop screens were not readable on mobile devices due to the small UI elements (e.g., mouse pointer, buttons) and tiny text (P7, P18, P21). Second, some interviewees pointed out the unavailability to practice the screencast tutorials using mobile devices. According to P10, "*it is hard to take screencast lectures without actual practice on desktops.*"

Programming/coding (survey: 55/134, interview: 8/21). Similar to screencasts, programming/coding lectures also had low readability, and interviewees could not practice coding on mobile screens. For example, many interviewees (P2, P7, P14, P15) complained that long code lines were not readable and digestible on small screens. Meanwhile, due to the unavailability of coding practice, some interviewees (P2, P10, P11) did not use mobile devices for the lectures containing coding practices, stating "*I use mobile phones for the theoretical part of programming lectures and move to a laptop for the coding part.*" (P10). P21 mentioned the limited keyboard input as a challenge on mobile coding. Some interviewees suggested providing an interactive code editor embedded in the video content, which enables scrolling on long lines of code (P7) and displaying small chunks of code in a single video frame instead of screencasting the mere code editor (P10).

Recorded Classroom (survey: 60/134, interview: 3/21). Interviewees avoided taking recorded classroom lectures on mobile devices since it is hard to read chalkboard writings: "*the instructor's writing on the chalkboard was not legible*" (P3).

Animation (survey: 63/134, interview: 0/21). Although only two interviewees (P20, P21) have a mobile learning experience with the animation type, they both showed a strong preference for the animation type. P20 found it "*most engaging and interesting*" and P10 said that "*other lecture types such as slide-based type and screencast type should be redesigned to be suitable for mobile devices, but animation type does not need the mobile-specific version.*"

Takeaways. To summarize the survey and interview results, the readability issues were mainly caused by small font size and dense text. In particular, slide-based, hand-drawn, and programming lectures deteriorated readability and legibility problems. On the other hand, learners' situational auditory impairments worsen due to a lack of visually organized learning materials to compensate for the saturated auditory channel, especially in talking-head lectures. Other noticeable findings include that the inappropriate designs can lead mobile learners to dropouts and learners' requirements in mobile environments vary depending not only on the screen size but their context.

4 STUDY2: CONTENT ANALYSIS

In this section, we evaluated the mobile adequacy of MOOC videos based on existing visual design guidelines. Through the content analysis, we diagnosed how severe the learners' difficulties are and quantified deficiencies of the current design, guiding improvement schemes.

4.1 Data Set

We evaluated 101 MOOCs selected by Class Central, a search engine and review site for MOOCs. We sampled 51 courses based on their popularity and 50 courses from top user reviews [37, 39]. We selected the top 51 and 50 courses from the lists, respectively, except those whose language is not English and to which we had no access (e.g., limited registration period). Two of our authors selected the video frames considering the diversity of the design elements and lecture material. Our final set comprises courses from 64 institutions in 19 countries across five MOOC platforms, Coursera (54), edX (25), FutureLearn (19), Complexity Explorer (2), and an Independent University (University of Urbino). The complete course list is added in the supplementary materials. The 101 sampled courses contain 3,951 video clips with an average length of 8.1 minutes (min = 12 seconds, max = 54.85 minutes, SD = 6.63 minutes). For each video clip, we detected video frames by calculating edge-based differences to extract unique lecture material [2, 43, 79], ending up with 168,514 frames (M = 1668.5 frames/course, SD = 2599.6). To normalize the number of frames per course, we randomly sampled 500 (1/5 of standard deviation) video frames from each course. For 38 courses containing frames smaller than 500, we used all of the frames without filtering. The average number of frames per course after the normalization was 413, ranging from 31 to 500. In total, we analyzed 41,722 frames.

4.2 Evaluated Design Guidelines

Instead of analyzing all the visual design factors, we selected representative ones based on learners' interview results. In the interview, the top four challenges learners faced in mobile MOOC learning for each category were small font size (19 out of 21 learners), images containing text (9 out of 21), dense text (8 out of 21), and low color contrast (3 out of 21 learners). Besides, the interview showed that learners' perception of different visual elements is affected by lecture types. For example, learners suffered from the dense text, mainly in programming/coding lectures. Hence, we analyzed the guideline compliance rate for the four visual design elements—font size, word count, the font size of the text inside an image, color contrast—across different lecture types. For comparison, we estimated the font size in video lectures that are displayed on the most common mobile screen size at the time of analysis: 5.5-inch diagonal size [46, 48].

4.3 Results of Guideline Compliance Analysis

The overall compliance rates of each design element are shown in Table 1. We present the guideline compliance rate of each design element across different lecture types as follows.

4.3.1 Distribution of Lecture Types. The sampled set covered all eight types of video production. The talking-head (37.8%) was most common followed by slide-based (34.6%), interview-discussion (11.4%), class recording (5.8%), programming/coding (4.7%), screencast (4.3%), hand-drawing (0.8%), and animation(0.5%) among 41,722 frames.

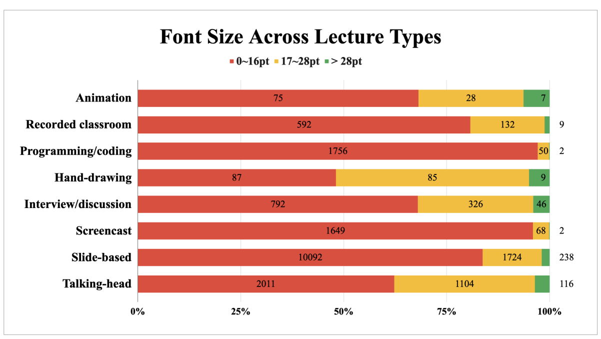

Figure 3: The font size compliance rate across different lecture types based upon existing guidelines.

4.3.2 Font size. The suggested body text size in a mobile device is 17pt by the Human Interface Guidelines of Apple [36]] and 16 pt by Google Material Design Guideline [49]]. We also considered guidelines for presentation slides that suggest 28 pt[4, 31] as the minimum font size. To evaluate the font size, we unified the different font size units (pt, px, sp) into a point (pt) for ease of comparison. Then we used the Pytesseract OCR engine, which showed reliable accuracy in previous work [34, 78, 79], to detect font sizes. The average font size was 13.9pt (SD=8.57, min=1.14, max=80.50). Adopting Apple and Google's guidelines, 75.5% of the video frames had font sizes smaller than 16pt. Adopting the guidelines for presentation slides, 97.2% of the video frames had font sizes smaller than 28pt. We then investigated the guideline compliance rate across eight lecture types (Fig. 3). Overall, more than 50% of video frames contained font sizes smaller than 16pt except for animation, revealing that font size guidelines are not followed in most lecture types. Especially for programming/coding and screencast lecture type, over 95% of the video frames did not meet the 16pt standard. These results match the learners' survey and interview results: font size was the main pain point across lecture types, particularly for programming/coding and screencast lectures.

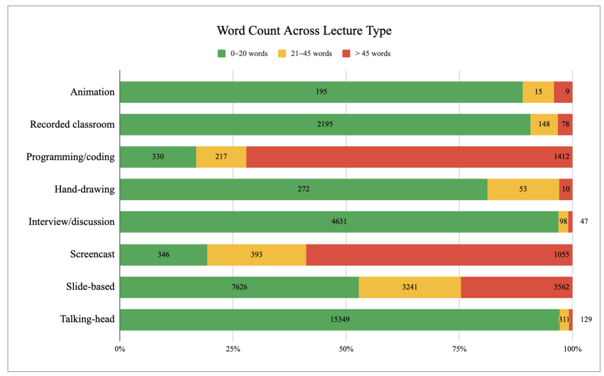

Figure 4: The word count compliance rate across different lecture types based upon existing guidelines. Programming/coding, screencast, slide-based lectures were the bottom three.

4.3.3 Word count. Using less than 45 words per presentation slide is recommended [5], while stricter guidelines advise using less than 20 words per slide [6, 69]. The average of word counts was 46.2 (SD=73.2, min=1, max=2431). Of the sampled frames, 25.8% had more than 20 words, and 15.1% contained more than 45 words. We used the Pytesseract OCR engine to detect the words. The guideline compliance rate across lecture types is shown in Fig. 4. Programming/coding, screencast, and slide-based were most text-heavy, with 72.1%, 58.8%, and 24.7% of frames having more than 45 words, respectively. This analysis result was parallel with Section 3: dense text was the second most frequently reported pain point by learners, especially for programming/coding, screencast, and slide-based lectures.

4.3.4 Font Size of Text Inside Images. We evaluated the font size of any text inside images (e.g., graphs, tables, etc.) using the Pytesseract OCR engine. A total of 1,278 video frames had images with text inside them and the mean font size was 11.15pt (SD=6.51pt, min=2.42pt, max=81.65pt). The three lecture types, including talking-head, slide-based, animation, contain images with text from our dataset. Our results show that 95.0% of the frames had font sizes smaller than 16pt, and 99.0% of the frames had font sizes smaller than 28pt. These confirm the findings in learner interviews: among 11 interviewees who claimed difficulties with image elements, 9 of them had problems with the font size of the text inside images. Fig. 5 shows the compliance rate across the three lecture types that

Design Element	Existing Guidelines	Guideline Compliance Rate
Font size	above 28pt	2.79%
	above 16pt	24.5%
Word count	below 20 words	74.2%
	below 40 words	84.9%
Font size of text in images	above 28pt	0.94%
	above 16pt	5.00%
Color contrast	above 7	66.2%
	above 4.5	80.0%

Table 1: The guideline compliance rates of sampled video frames for the three design elements based on existing guidelines.

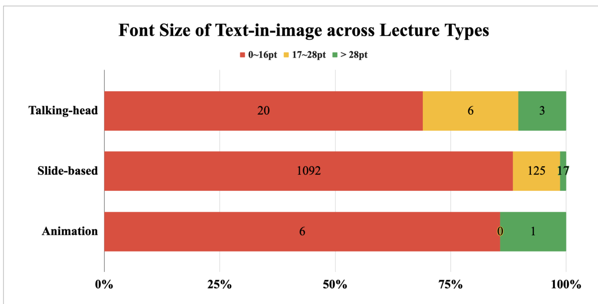

Figure 5: The font size compliance rate of text in images across different lecture types based upon existing guidelines. The compliance rates are lower than 15% across all three lecture types.

contain images with text. More than 85% of fonts from all three lecture types violate the guideline. The extremely low guideline compliance rate indicates that engineers' careful consideration of font size is needed when designing images containing text.

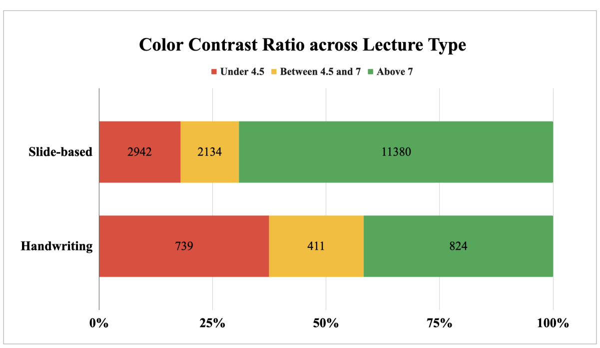

Figure 6: The guideline compliance rate of color contrast ratio across different lecture types. About 70% of color contrast from the slide-based lecture type complies with the guideline while 40% from the handwriting type complies with the guideline with a higher ratio than 7.0:1.

4.3.5 Color Contrast. We calculated the color contrast ratio between the background color and font color of 10,420 video frames that contain text elements in them. 33 frames were excluded for having too low a contrast ratio due to the patterned background or low resolution. We first extracted color palettes from each text box in video frames and compared the color contrast between the most dominant color value and the second frequent color value. Two types of lectures, including slide-based and handwriting types, out of 8 lecture types contain text boxes with which we can estimate the color contrast ratio. Web Content Accessibility Guidelines (WCAG) [7] level AA suggests that the contrast ratio should be larger than 4.5:1, while level AAA guideline recommends 7.0:1. The analysis results revealed that about 20% of the sampled frames have a contrast ratio lower than 4.5:1 and 34% lower than 7.0:1. The handwritings have a lower guideline compliance rate (42%) compared to the typed text in slide-based lectures (70%) (Fig. 6). The color components can be overlooked compared to other design components such as text and images, having less related guidelines, but the current design calls for careful consideration for color contrast for improved readability.

The low guideline compliance rates demonstrated that the current design of video lectures is not suitable to be consumed in mobile learning environments. Several lecture types (programming/coding, screencast, slide-based, and handwriting types) need engineers' attention when considering mobile learning.

5 STUDY3: ENGINEER PERSPECTIVE

We interviewed 11 video production engineers to investigate considerations and challenges in designing lecture videos for mobile users.

5.1 Participants and Recruitment

We recruited 11 engineers from the U.S. and South Korea via a campus mail list. The participants had 11 years of experience on average and reported their roles as a video editor, video production engineer, and video content designer (Table 2). Seven participants were university staff with design experience on MOOC content, and one was an independent engineer with experience in editing and publishing video-based learning content. Three of them were working in video production companies. We used a saturation method [3] to determine the number of participants. We refer to these participants as E1 to E11.

5.2 Interview Protocol

We conducted remote semi-structured interviews using ZOOM and audio-recorded the interview under consent. The interviews took

ID	Role	Experience (yrs)	Affiliation
E1	Video Editor	1	Freelancer
E2	Video Production Engineer	6	University
E3	Video Editor	10	University
E4	Video Content Designer	10	University
E5	Instructional Designer	6 months	University
E6	Video Content Designer	15	University
E7	Instructional Designer	18	University
E8	Video Editor	25	University
E9	Video Producer/Director	9	Video Production Company
E10	Video Content Designer	17	Video Production Company
E11	Video Content Designer	12	Video Production Company

Table 2: Information of interview participants

1.5 hours with four main sections: (1) general design process of video lecture content, (2) considerations and challenges in designing content for mobile users, (3) perception on learner survey, interview, and content analysis result, and (4) communication channels with learners. The complete set of questions is in the supplementary materials.

5.3 Interview Analysis

Two of our authors and one external researcher who has rich experience in qualitative analysis extracted thematic codes through an open-coding approach [9]. They separately performed open-coding for the interview responses. We used affinity diagramming to cluster the generated codes [56] and iterated until we met a consensus over two 1.5 hour-long meetings. Finally, we identified four themes for challenges in designing mobile-friendly content.

5.4 Interview Results

We report the findings from the interviews on considerations and challenges of mobile content design.

5.4.1 General design process of video lecture content. To publish a video lecture, experts from various fields collaborate. The instructor first shared their lecture materials in slides or documents with the video production team. Then they discuss with the video production engineers and instructional designers the specific curriculum, lecture types, and video designs. Based on the discussions, the video production team start filming. Then video production engineers post-process the recordings: designing subtitles, fonts, images, and video effects. The design process goes through many iterations with instructors. After the instructor's final confirmation, the videos are posted on the platform.

5.4.2 Considerations and challenges in designing content for mobile users. Most engineers know that more and more learners are using mobile to learn. Many already consider them as a target user group. Seven out of eleven engineers keep mobile environments in mind during the design process. But due to limited resources and time, lectures are designed for desktops first.

Design Considerations

Design Element. Much consideration for mobile learners was the readability of content. They simplified the content design to fit the small screen by reducing the amount of content (e.g., segmenting content in one slide into multiple slides). They also enlarge the size of the content. For example, E7 explained, "*Font size is our main concern since it determines the readability in mobile screens. We next adjust the amount of dense text that is not digestible in mobile environments.*" As for the style, they preferred readable fonts such as sans-serif fonts and used font colors that had high color contrast ratio with the background.

Lecture Type. The engineers do not specifically consider mobile environments while deciding the lecture types. They chose the lecture type that is most suitable for the lecture content or preferred by an instructor.

Situationally-Induced Impairments and Disabilities (SIIDs). Most of the engineers have not considered the situationally-induced impairments and disabilities in their design process.

Design Guidelines for Mobile Video-Based Learning. When asked about guidelines for mobile learning environments, they responded that there are no design guidelines specific to mobile environments. They noted that they rely on subjective intuition based on their experiences.

Challenges of Content Design for Mobile Learners

In particular, we identified four main challenges for considering mobile devices during the design process. First, their design process in desktop environments makes it challenging to know how the content will look on mobile devices. The diversity of mobile devices deteriorates the problem. For example, E10 said, "*In the current design process (on desktops), it's hard to imagine how the content I created will be displayed on very diverse mobile screens including laptops, tablet PCs, and smartphones.*". Second, they mentioned the lack of design guidelines for mobile environments. For example, E10 commented, "*We currently have guidelines for font size and color contrast. However, they are not mobile-specific, and more diverse aspects should be considered (in designing content for mobile learners).*". E2 also mentioned that "*It is difficult to measure the readability, so for now, we just rely on the subjective intuition of an individual engineer.*". Third, they encounter conflicts with instructors. In most cases, the engineers prioritize content readability. A few instructors wanted to use the same offline class learning materials. Some instructors do not prefer changing the original content design since the flow of the lecture can be disrupted. In this case, the engineers and instructors discuss whether to segment or summarize the dense content. Lastly, the engineers pointed out that it's hard to set the design directions due to a lack of understanding of the lecture materials. For example, they find it challenging to reduce word count while preserving the key information with a limited understanding of the lecture.

5.4.3 Perception on learner survey, interview, and content analysis result.

Learner Survey and Interviews. All of the engineers replied that it was an expected result that the biggest challenge was the readability issue. Even though they consider readability a high priority, they elaborated that it is difficult to make every content readable on mobile devices due to the challenges of coordination with instructors, considering multiple mobile devices, understanding lecture content, and lack of mobile design guidelines. Several instructors insist on their own design styles that are inappropriate for mobile devices. Furthermore, the engineers are mostly working under tight deadlines and could not afford to create different designs for multiple devices or understand the entire lecture content. Meanwhile, the engineers did not expect that the second major difficulty was the SIIDs. They mentioned that they could understand that the learners suffer from SIIDs, but have not considered it in their general design process. When asked about the expected challenges of considering SIIDs in the design process, they mentioned the needs for the design guidelines, elaborating that they cannot think of any possible solutions to alleviate SIIDs.

Content Analysis. The engineers said that both the guideline compliance rate for font sizes and the amount of text are lower than they expected. For example, E2 said, "*I expected that 30-50% of the current video lectures follow the guideline. I think it can be because most engineers don't have guidelines for mobile content design.*" In the case of font sizes of text in images, most of them noted that it was an expected result. Some engineers mentioned that the source image provided by an instructor sometimes has poor readability. One participant noted that "*The instructors provide us with figures with too small text in them since they are not professionals in design. We sometimes redesign the figure based on the provided image, but we should use them as they are in many cases when we have a tough deadline.*" (E6).

5.4.4 Communication channels with learners. All of the engineers agreed with the need for getting learners' feedback. Some engineers collected user feedback via survey, and others communicated with learners through online bulletin boards on MOOC platforms. However, they noted that most students do not respond to surveys, emphasizing the lack of communication channels. In particular, they have difficulty reflecting feedback on design elements, which requires a complete redesign or reshoot of the video. For instance, they mentioned that it is too costly to reshoot the entire lecture to fix minor issues such as font sizes or content layout. It was due to the video medium's characteristics that it is hard to be edited once it is released or encoded.

6 DESIGN GUIDELINES

In this section, we suggest a set of design guidelines for creating mobile-friendly MOOCs. The guidelines are based on our learner studies and content analysis. In particular, one of the main focuses of our guideline was not to pose additional workloads to video production engineers in following the guidelines since the interviews revealed that they are suffering from time constraints of design tasks. For example, our guideline suggests automation of the design process and encourages support from diverse stakeholders, including instructors and MOOC platform engineers.

We validated the guidelines through an evaluation session with the video production engineers. We also discuss design opportunities for mobile-friendly MOOCs. Based on the surveys and interviews with learners, we identify three design opportunities: (1) readability support via adaptive and customizable visual design, (2) context-aware accessibility support, and (3) informed lecture selection. We expand on each design opportunity along with design recommendations derived from noticeable findings and learner suggestions. The summary of findings (**F1-9**) and design guidelines (**G1-9**) on visual design elements are shown in Table 3.

6.0.1 Readability Support via Adaptive and Customizable Visual Design. Existing design techniques such as responsive web design provide customized views across various mobile devices. However, responsive video design is challenging because of the inflexible nature of the video, making it difficult to be edited or deconstructed after release. The lack of support for responsive video design leads to readability issues, in particular, in content-heavy materials (F1, F4). This suggests novel design opportunities for an adaptive and customizable visual design for video content. Specifically, the key is to automatically generate responsive video content and provide customizable design options to fit diverse learners' needs without making separate versions of the content for each device. For instance, Optical Character Recognition (OCR) or edge detection techniques in computer vision can be used to extract in-video elements such as text boxes and images. Once the in-video elements are detected and deconstructed, it becomes easier to adapt them like static content such as websites and ebooks. Then we can enlarge the font size, adjust the layout depending on screen sizes [65, 75] (G1a). Furthermore, the extracted elements can be customized, providing options (e.g., font size, color) for different designs to learners to choose from (G1b, G4a, G4b, G8) by adjusting and redesigning the deconstructed elements based on users' preferences on color or size. On the other hand, learners currently use pinch-zoom interactions to alleviate the readability problem (F2, F3). They complained that zooming sometimes results in missing other important content and that pinch interactions cause unwanted actions such as the exit of fullscreen mode. As an alternative, they mentioned tap or long-press interactions. By deconstructing recorded video into design elements, an improved adaptive video content design technique could enable element-wise zoom interaction by magnifying a complete element (e.g., text box, image) without cut-off parts (G2).

6.0.2 Context-Aware Accessibility Support. Mobile learning is distracted by situational factors, so-called Situationally-Induced Impairments and Disabilities (SIIDs) [66, 77]. A design opportunity

Challenge	Finding	Guideline	Design Process (Target User Group)
Readability Issues	F1. Learners require different font sizes depending on screen sizes.	G1. Provide options for different font sizes. Let users choose their preferred font size like PowerPoint font size option.	Video Content Design (Platform developers, System researchers)
	F2. Learners' pinch-zoom interaction to mitigate readability issues may cut off parts of elements.	G2. Provide element-wise zoom interaction that magnifies the complete element (e.g., text box, image) instead of parts of elements. Enable zooming in the whole content without cut-offs.	Video Interface Design (Platform developers, System researchers
	F3. Learners' pinch-zoom interaction to mitigate readability issues may cause unwanted actions (e.g., scene transition, exit of fullscreen mode).	G3. Provide alternative zoom methods that can prevent unwanted actions. Provide zoom methods such as tap or press, since current pinch-zoom interactions lead to unintended actions such as the exit of fullscreen mode or scene transitions.	Video Interface Design (Platform developers, System researchers)
	F4. Decorative video designs (e.g., slide transition effect, fancy background using Chroma Key) can decrease readability.	G4a. Avoid using decorative visual effects such as slide animations and fancy backgrounds. G4b. Provide a design option to change decorative visual effects. Provide different design modes, for example, basic mode and decorative mode.	Video Content Design (Video production engineers, Platform developers, System researchers)
Situational Impairments	F5. Ambient light and the mobile state of the learner can cause situational visual impairments.	G5. Provide a context-aware* audio description or extended audio**.	Video Interface Design (Instructors, Platform developers, System researchers)
	F6. Noisy mobile environments can cause situational auditory impairments.	G6a. Provide a context-aware* subtitle. Turn on, for example, subtitle automatically when a learner is in noisy environments. G6b. Provide redundant on-screen text with audio narration. Display, for example, a summary of the audio narration in the form of keywords or a bulleted list.	Video Interface Design (Instructors, Platform developers, System researchers)
	F7. Learners easily lose instructor's current explanation spot in on-screen lecture material.	G7. Display cues or signals on the current explanation spot, both for images and text. Visual cues include underlines, highlighting, and arrows.	Video Content Design (Instructors, Video production engineers)
	F8. Low ambient light can cause eye fatigue.	G8. Provide dark mode for video content with light color text in a dark background.	Video Content Design (Video production engineers)
Inaccessible Information	F9. Learners have difficulty knowing if a lecture of interest is mobile-ready, resulting in dropouts due to uninformed lecture selection.	G9. Provide information on video content design in the lecture selection stage. Improve information scent about mobile-friendliness. The information scent, for example, includes the design guideline the compliance rate of font sizes or involvement of programming practice.	Learning Platform Design (Video production engineers, Instructional designers)

Table 3: Summary of notable findings and design recommendations on visual design elements to create mobile-friendly MOOCs. *Context-aware learning detects learners' context (e.g., ambient light, mobile state of users) and adapts learning materials to match the context [29]). **Audio description is a narration added to the soundtrack to describe important visual details that cannot be understood from the main soundtrack alone. An extended audio description that is added to an audiovisual presentation by pausing the video so that there is time to add additional description (https://www.w3.org/WAI/WCAG21/Understanding/extended-audio-description-prerecorded.html).

is to provide context-aware support for addressing SIIDs in mobile video-based learning (G5, G6a). To detect learners' learning contexts, existing detection sensors such as eye trackers or accelerometers can be used [21]. For example, an audio description for visual lecture material can be provided when learners' eyes are not fixed on the screen. In particular, our findings draw a parallel and contradiction with Mayer's Multimedia Learning Theory [51] at the same time. The learners strongly wanted cues or signals on the currently explained spot due to distraction in mobile environments (F7), corroborating the signaling principle of Multimedia Learning Principles [52]. They even required adding cues or signals on image elements as well as text elements (G7). On the other hand, our findings mildly contradict the redundancy principle, which suggests that the same information presented both on-screen and orally interferes with learning [52]. In mobile environments, learners suffered from the lack of visually organized lecture materials on the screen (F6). For example, when a learner was in noisy environments such as a gym or subway, they wanted redundant on-screen text together with audio narration. In distracting mobile environments, learners' available sensory channels quickly alternate, not allowing consistent use of a single channel. Hence, it is recommended to provide redundant information in both auditory and visual modalities to complement each other (G6b). More theoretical and empirical research is required to validate the impact of these mobile learning techniques on learning effects.

6.0.3 *Informed Lecture Selection.*

As reported in our interview, the illegible and indigestible content may even cause dropouts of mobile learners. Learners express the need for information on mobile adequacy of lecture content at the lecture selection stage. This points to an opportunity to support informed decision-making in lecture selection. Our findings revealed that visual design elements and lecture types are critical factors that determine the mobile adequacy of the lecture content. Instructors or platform engineers can provide the information (e.g., font size, word count, the existence of coding) on video content design to improve information scent [12] (G9). Future work can develop a mobile adequacy index or score by investigating the weighted importance of each factor, providing a simple and quantitative measure for mobile adequacy.

6.1 Design Guidelines on Mobile-Friendly Lecture Types

The findings on lecture types from section 3 indicate that each lecture type has different challenges and needs to be tailored to mobile learning environments. In particular, several findings mildly contradicted the general conclusions from the previous work that assumed desktop environments, calling for the need for mobile-specific design considerations and recommendations. The summary of findings **(F10-14)** and design recommendations **(G10-14)** on lecture types is shown in Table 4.

Talking-head. Previous research demonstrated that talking-head videos engaged learners more with personal feelings [24, 30]. On mobile devices, however, learners easily get lost in talking-head due to the lack of visually organized lecture material (F11). The lack of visual material also caused VIIDs and loss of concentration. Hence, we recommend adding visual lecture materials such as text and images beside the instructor's talking head in post-production editing (G11). Another pain point of talking-head was when the picture-in-picture talking-head is displayed along with the main content [44] (F10). First, the picture-in-picture talking-head split learners' attention in distracting mobile environments. Second, the juxtaposition of the main content and talking-head as a split view limits the space for the main content and decreases the readability of the main content. Therefore, we advise providing an option to turn off the picture-in-picture talking-head display (G10).

Programming/coding. Prior work introduced the effectiveness of live-coding in learning programming, including the ease of understanding [10, 62] and a decrease in extraneous cognitive load [61]. However, the programming and screencast were not readable on mobile screens due to small font sizes and an excessive amount of code (F12). We recommend instructional designers encourage instructors to zoom in on the code editor if instructors insist on the live-coding type (G12a). We recommend zooming in on the code editor at opportune times in post-production editing (G12b). On the other hand, some learners wanted to practice coding on mobile (F13). They complained about the unavailability of mobile IDEs and limited keyboard input. To address this problem, we suggest providing lightweight IDEs to practice coding and providing code snippets so that learners do not have to write long lines of code from scratch (G13).

Hand-drawing. Hand-drawing videos are another recommended lecture type in desktop environments, highly engaging students in desktop environments [17, 24]. However, learners preferred the hand-drawing type the least in mobile learning environments due to its low legibility (F14). We recommend providing corresponding typewriting (print) to the handwritten materials (G14) [15].

Recorded Classroom. Recorded classroom lectures are also not preferred in mobile environments due to their low legibility and small font sizes (F15). Similar to the hand-drawing type, it is recommended to provide lecture notes in digital text to allow the learners to refer to them as needed (G15).

Slide-based. Slide-based videos are prone to containing cluttered materials (F16). As suggested by previous work [20, 47, 68], we recommend segmenting long text into small chunks or summarizing the content into several bullet points (G16).

6.2 Expert Evaluation of Design Guidelines

We conducted interviews with 11 video production engineers to investigate the applicability and clarity of our design recommendations.

6.2.1 *Procedure.*

At the end of the interview in section 5, we had an expert evaluation session for the design recommendations. The participants were asked to fill out a form that evaluates the items. For each recommendation, we first confirmed the right target group of the item. Since the content design process of video lectures necessarily involves multiple stakeholders such as platform developers, instructors, and instructional designers, the participants might need collaboration or cooperation between multiple teams to implement the recommendations. The form then asked the participants to provide ratings on clarity, understandability, applicability, actionability, and the easiness to work with the recommendations, on a 5-point semantic differential scale (e.g., from 'very confusing' to 'very clear'). We inquired about the reasons for the ratings with the

Challenge	Finding	Guideline	Design Process (Target User Group)
Talking-head	F10. Displaying talking-head along with main content decreases readability of main content, and splits learner's attention with increased visual clutter in mobile learning environments.	G10. Provide an option to toggle picture-in-picture talking-head window [44].	Video Interface Design (Video production engineers, Platform developers, System researchers)
	F11. Learners easily get lost without visually organized lecture material (e.g., lecture slides) in mobile learning environments.	G11. Add visual lecture material such as overlay text or images to pure talking-head lectures in post-production editing.	Video Content Design (Video production engineers, Instructors)
Programming/coding	F12. Programming screencasts are not readable in mobile learning environments.	G12a. Encourage instructors to increase the zoom level of code editor screen during live coding. G12b. Zoom in code editor window in post-production editing.	Video Content Design (Video production engineers, Production directors)
	F13. Despite the small screen size and limited keyboard input, learners want to practice coding on mobile devices.	G13. Provide a lightweight IDE with code snippets for simple coding practice.	Video Interface Design (Instructors, Platform developers)
Hand-writing	F14. Hand-written text is not legible on mobile devices due to cursive fonts and inappropriate text spacing.	G14. Provide a typed version of hand-written text as lecture notes.	Learning Material Design (Instructors)

Table 4: Summary of notable findings and design recommendations about lecture types to create mobile-friendly MOOCs

following question. We also asked anticipated challenges of applying the recommendations. The participants were then requested to improve the recommendations by editing, adding, and deleting the suggested items. Lastly, we asked the participants if there is any wanted system or tool for implementing the recommendations.

6.2.2 Results. In this section, we report the video production engineers' feedback on the clarity and applicability of the recommendations, expected challenges of applying the recommendations, and revisions suggested by the engineers. Fig. 7 presents the subjective ratings from video production engineers for each guideline item.

Related Stakeholders. The engineers reported that most of the guideline items are within the scope of their roles. Meanwhile, some of the items require them to collaborate with other teams. For example, they noted that they need to collaborate with learning platform developers to apply some guidelines, including G1-3, G5, G6, G9, G12, G13, which involve development work for a new video interface or mobile sensor. On the other hand, G14 requires the help of instructors who have a complete understanding of the lecture materials.

Clarity and Understandability. The mean of the ratings for clarity and understandability was 5.99 and 6.07 out of 7, respectively. Some engineers wanted to see the working system or prototype which applies the guidelines for new features in the video interface. For example, E1 commented on G2 that "*It's hard to imagine how the new video interface (with the element-wise zoom feature) works without the actual system*". They reported that the guidelines are clear and easy to understand overall.

Applicability, Easiness to Use, and Actionability. The mean of the ratings for applicability, easiness to use, and actionability was 5.71, 5.18, and 5.51 out of 7, respectively. For G1 and G2, the engineers rated them less applicable (4.43, 5) and easy to work with (4.33, 4.2) compared to other guidelines. They expressed concerns about the spatial relationships between elements. For example, "*(For G1) a simple adjustment for font sizes can break the layouts of the content.*" (E9) and "*(For G2) the element-wise zoom can cover the rest of the content and distort the whole layout.*" (E5). For G4 and G9, the engineers mentioned that they need more precise criteria for decorative visual effects and mobile-friendly design. E2 said that

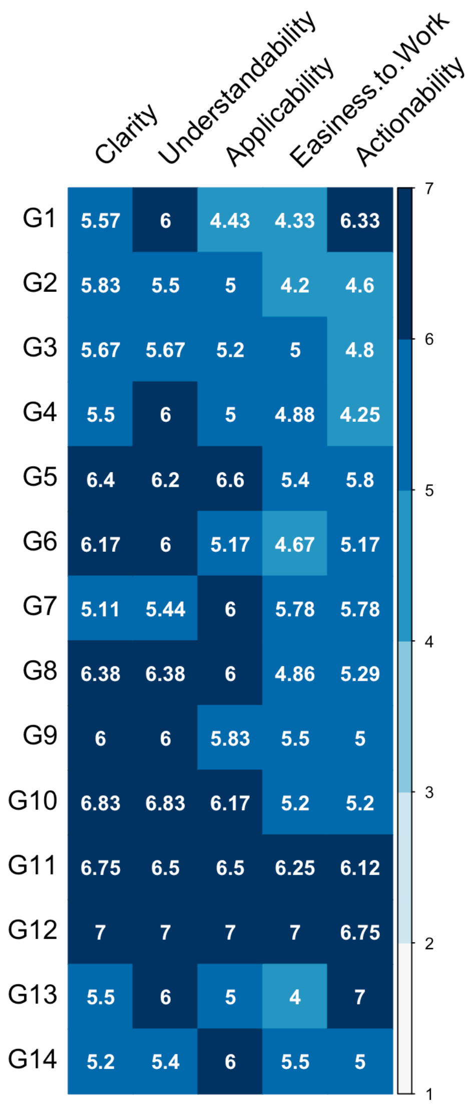

Figure 7: Subjective evaluations by video production engineers about the clarity, understandability, applicability, easiness to use, and actionability of the suggested guideline items.

"*We will need clear criteria or even experts' advice to determine the mobile-friendliness of the video content*".

The engineers also indicated that G7 and G8 could pose additional workloads. They explained that visual cues need additional graphic work, and creating a dark mode for the whole content can double the workload. Several engineers (E4, E7, and E10) mentioned the possibility of automating the design process to apply these two guidelines. E4, for example, said "*It would be efficient if there were some programs that extract text and background from the video and convert the color for the dark mode*".

Another problem was the difficulty of completely understanding the lecture materials. To apply G11, the engineers "*might need close cooperation with instructors, which requires much effort.*" (E4). Similarly, for G14, they noted that they cannot understand the whole lecture content each time and necessarily need help from instructors to provide correct lecture notes for handwriting.

Usefulness. The engineers agreed on the need to apply the suggested guidelines to improve the mobile learning experience. Many engineers like the idea of giving options to learners customizing, for example, font sizes (G1) and lecture designs (G4, G10). G10 commented that "*(For G10) it's a good idea to provide options to users considering their personal preferences because a single design cannot satisfy every user*". Some engineers appreciated the guidelines (G1-4) that can alleviate the readability issues in mobile devices. On the other hand, they valued the guideline for providing information for mobile-friendliness (G9), with one expert commenting that "*the information scent can benefit many mobile learners.*" (E5).

Revisions. When asked if there is any guideline they want to add, remove, or edit, the engineers indicated that G2, G5, and G6 have room for improvement. E5 pointed out that G2 overlaps with G3 in that they both suggest a new zoom interaction. E5 also commented that G5 and G6 need to clarify how the context-aware system should be designed, including details such as the minimum level of noise that requires the context-aware subtitle. The rest of the engineers were satisfied with the current guidelines without further modifications.

7 DISCUSSION

We investigated mobile video-based learning using a mixed-method analysis on learners, MOOC content, and video production engineers. In this section, we discuss extended design implications and future work.

7.1 Gap between Learners and Engineers

First, several design factors need to be paid more attention to in the design process. As shown in Table 5, engineers may be paying relatively little attention to complex images, images containing text, and too bright color. The learners complained about complex images with intricate details and small unreadable text usually accompanied by complex images. We recommend adjusting text design when bringing images containing text from other sources such as textbooks instead of copying and pasting them directly. We also encourage engineers to crop or zoom in on the area of interest in the complex image. Meanwhile, the video production engineers try to make lectures more engaging by adding video effects. However, readability was more critical than engagement for mobile learners. On the other hand, engineers were unaware or had not considered SIIDs in the mobile learning environments, implying the need to extend existing guidelines, education, or design tools for engineers. Second, some design factors did not meet learners' needs despite the engineers' considerations. For example, the small font size was learners' primary pain point, although they were also engineers' main consideration, with a guideline compliance rate of 2.79%. The engineers' challenges resulting in low compliance rates include the difficulty in considering diverse mobile screen sizes (e.g., smartphones, tablet PCs, and laptops), not having design guidelines for mobile environments, coordinating with instructors, and deciding design directions with limited understanding of the lecture content.

Visual Design Element	Pain Point	Learners		Engineers	Guideline	Prior Work
		Surveys	Interviews	Interviews	Compliance Rate	
Text Element	Small Font Size	63/134	19/21	✓	2.79%-24.5%	CL [47], JOLs [25, 63], DG [22, 26, 31, 36, 45, 47, 49, 60]
	Dense Text	36/134	8/21	✓	74.2%-84.9%	CL [47, 70, 71], IO [1], DG [5, 26, 31, 36, 73]
	Inappropriate Text Spacing	18/134	4/21			DG [60]
	Inappropriate Font Style	14/134	0/21			DG [18, 26, 31, 36, 47, 49, 60, 73]
Image Element	Images Containing Text		9/21		0.94%-5.00%	DG [22, 26, 31, 36, 45, 47, 49, 60]
	Complex Images	32/134	7/21			CL [27, 46, 74], DG [23, 47, 59]
	Small Image Size	51/134	6/21	✓		DG [26, 59]
	Too Many Images	23/134	3/21	✓		CL [47], IO [1], DG [45, 47]
Color	Low Color Contrast	19/134	3/21			DG [26, 28, 31, 36, 47, 60, 73]
	Too Bright Color	15/134	2/21			DG [28, 31, 36, 60, 73]

Table 5: Triangulation of learner-reported difficulties, design considerations of video production engineers, and guideline compliance rate of current MOOC content, including ties to existing learning framework. *CL: Cognitive Load, JOLs: Judgements Of Learning, IO: Information Overload, DG: Design Guidelines.

7.2 Extended Content Analysis

There is still room for improvement for the content analysis of MOOCs. In analyzing the amount of text in the lectures, we did not distinguish learning critical text from those that are not. In screencast-type lectures, for example, text in software interfaces (e.g., text in menu bars of Photoshop) is not learning critical and should have different weights than the learning critical text elements. Meanwhile, our work did not consider the image elements in the lectures (e.g., charts, diagrams, pictures). Future work on an extended content analysis can use image captioning techniques to estimate the information density of the image elements.

7.3 Design Opportunities for Design Tools

One of the challenges of engineers comes from the practical challenges, including lack of design guidelines for mobile environments and difficulty of understanding every lecture content under tight deadlines. Based on the findings, we identify opportunities for design support systems for engineers: (1) A diagnosis or evaluation tool that detects and measures mobile adequacy of lecture material; (2) A collaboration tool that supports communication and application of consistent guidelines among multiple engineers; (3) A design tool that automates tedious editing tasks; and (4) A design tool that supports a cross-device design process.

7.4 Design Opportunities for Mobile Design Guidelines

We recognize that multiple teams and stakeholders are involved when applying our guidelines. The video production engineers we have interviewed mentioned learning platform developers and instructors as potential stakeholders of the suggested guidelines. The future work can reflect the perspectives of broader stakeholders, including instructors, instructional designers, and educational system researchers. Lastly, we recognize our research as an initial attempt to suggest design guidelines for mobile video-based learning. The future work can elaborate the guideline items with detailed criteria such as proper color schemes for dark mode for video content (G8) or measurement for mobile-friendliness of video lectures (G9). We expect our work to provide building blocks for increasing accessibility to learners under various constraints and contexts.

8 CONCLUSION

We presented the findings of a mixed-methods analysis on learners, MOOC content, and video production engineers, aiming at (1) investigating the discrepancy between learners' challenges and video production engineers' design considerations; and (2) suggesting a set of design recommendations for creating mobile-friendly MOOCs. The survey and interview with learners demonstrated major challenges of learners: readability issues and situationally-induced impairments. The content analysis results showed a low guideline compliance rate for the key readability design factors, revealing that the current content designs are unsuitable for mobile learning. The interview with video production engineers showed that although readability has been concerned, there is a mismatch between learners' challenges and engineers' considerations. Informed by the findings, we suggest a set of guidelines to design mobile-friendly MOOCs, which includes providing adaptive design, customizable design options, and context-aware accessibility support. We verify the clarity and applicability of our design guidelines through expert evaluation sessions with 11 engineers. Finally, we envision design opportunities for the mobile-friendly design of the lecture content and video interface.

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