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Towards Sustainable Learning Materials for MOOC in Poor Network Environments

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Abstract: Videos are highly instrumental to the learning experience in many eLearning platforms. Lecture videos have become crucial to the success of any Massive Open Online Courses (MOOCs). However, conventional lecture videos are typically large computer files. Such videos are relatively enormous in file-size compared to other learning materials in MOOCs. With a slightly long runtime, a high-definition video file transfer comes with a high price. It is rather much expensive and time-consuming over poor or sparse networks. This commonly occurring situation significantly affects the learning experience. Online learners encounter intermittent connectivity or even offline more often during a learning session. In such situations, we claim that the prevalence of videos in MOOCs remains vague and subtle in poor network environments. In the file transfer process, it is not unusual for a video to face constant network disruptions. Therefore, this research work urges to review the provision of alternative, but more effective multimedia. Such multimedia are instead proposed to be much smaller in file-size. However, the multimedia should retain the essential criterion of a video-based format. The new materials are thus deemed less dependent on the bandwidth. This paper focuses on improvising video-based materials during a real-time learning session. Of course, be derived from their original lecture videos. We argue that this approach helps to improve the learning experience, especially for learners situated in low bandwidth areas. Network related issues such as long-wait buffering, low-quality streaming, or slow downloading are therefore tackled by using unconventional materials. The main benefit is to achieve and attain uninterrupted learning session even when the MOOC learner steps into offline or out of reach area. Also, the approach supplements images and audio to support sustainable eLearning – whenever wherever.

Keywords: Video, MOOC, low bandwidth, learning experience, materials, multimedia

1. Introduction

Videos are focal to the student's learning experience in the current generation of Massive Open Online Courses (MOOCs). Popular MOOC providers such as Coursera, edX, and openHPI intensively use videos as learning material. Videos are now an essential lecturing instrument. However, lecture videos used in MOOCs are typically large computer files, relatively big enough to encounter file transfer disruption. The file-size is usually a concerning issue when transmitting a video over a threshold of a network. A diminished bandwidth can prevent the transmission of the video or even corrupt the file. In poor performing networks such as 2G and public WiFi, the learning process might be affected due to slow video processing. These network related issues not only affecting online user experience, but also contribute student's dropout in MOOCs (Kim et al., 2014), (Mamgain, Sharma & Goyal, 2014).

In extended MOOCs; online courses follow the traditional university pedagogically. Online courses are mostly organized as sequences of instructor-produced videos infused with problem sets, reference materials, or other resources (Guo et al., 2014). Online learning is primarily inclined towards the use of lecture videos. Materials such as textbooks, PDFs slides, and reference web links are rather supplements. In MOOCs, videos have evolved to be a vital component in delivering educational content. Many MOOC platforms currently use their multimedia players to stream videos or provide a download mechanism (Meinel & Willems, 2013). The media player offers an interactive interface between the videos and the learners, an essential component of any MOOC. Despite the versatility of control functions, many media players present in MOOC platforms still lack dedicated features designed to sustain the learning process in poor network dynamically (Brinton & Chiang 2014).

Conventional approaches use data compression techniques for transmission of materials to curb broadband issues; however, this solution is limited to certain file-sizes which might not yield a significant gain in low bandwidth environments. A different, but traditional solution progressively reduces the display resolution, but compromises the viewing quality as well as discredits the auditory perception. Popular MOOC platforms, nevertheless fail to enact control over the choice of suitable learning materials based on the healthiness of the network or self-decision of the learner (Barba, 2015).

This research work applies a relatively new approach involving content extraction mechanisms follows by multimedia combination to provide video-based learning materials. The work focuses on the provision of images and audio as alternative multimedia to video. This approach significantly relaxes the necessity of network broadband for MOOCs. In our experiments, we managed to achieve relatively low data consumption using our alternative learning materials due to small file-size. By using suitable types of multimedia that avoid high consumption of network resources, we managed to reduce network dependency, sustain delivery of educational content in poor network environments.

This research work aims to improve the learning experience in MOOCs. In particular, the use of alternative materials in sparse networks. The rest of the paper is structured as follows: Section 2 reviews the challenges of using lecture videos at low bandwidth. Section 3 presents related work with state of the art tools and technologies in MOOCs. Section 4 executes performance experiments with results detailed in section 5. Section 6 concludes and gives a future outlook.

2. Challenges of Lecture Videos for MOOCs in Poor Networks

Video learning materials are more network-resource demanding while transferring from a server to a client –a learner. Contrarily to remaining materials such as PDF or text files due to their relatively small file-size. We set up a computer file transfer experiment to determine the success rate of transmitting a video over the network. The experiment used a real lecture video borrowed from the openHPI MOOC platform. However, the specimen video is roughly shorter in length, and of relatively small file-size compared to many videos in openHPI. Typically, most of the MOOC videos lecture from 8-20 minutes with typical file sizes of 50-140MB in Standard Definition (SD) quality (Stuchlíková & Kósa 2013). In this experiment, the specimen video is about 8 minutes long and 50MB in capacity. For clarity, we opt to use the same exemplary video throughout our experiments for the rest of this paper.

First, we measure the duration it takes to download the video with different download speed over the network. In a low bandwidth setup, the download time is set at less than a 512 kbit/s. A potential learner might fail to watch the video online as a file transfer would take more than 13 minutes to complete. Whenever the download speed drops, network bottleneck could delay or prevent the video streaming process; consequently affecting the student's learning experience. In 2G connections, video streaming takes as long as twice the time of its duration. This situation is undesirable experience in MOOCs. Table 1 summarizes Test Status based on the Internet connection type. Results show 1 Mbit/s is a theoretical minimum download speed required to deliver a video of 50MB in less than 8 minutes to the learner efficiently, i.e., within the running time of the MOOC lecture.

Table 1

Theoretical minimum download times for the 50MB video file with different types of connections.

Connection Type	Download Speed	Download Time	Test Status
Dialup	28.8kbit/s	04:02:43	Fail
Modem	56.6kbit/s	02:04:49	Delay
ADSL	512kbit/s	00:13:39	Hold-up
ADSL Lite	1Mbit/s	00:06:59	Pass
Turbo 3G	7.2Mbit/s	00:00:58	Success
4G LTE	80Mbit/s	00:00:05	Success

In contrast, access to a persistent and high-speed Internet connection is still a continuing challenge to many existing and potential MOOC learners. In reality, many Internet users still live in regions with low coverage. Internet access in many regions is still limited to mobile wireless communications, which are usually more expensive and slow. The challenge is a far difficulty for learners of MOOC in rural and remote areas. Therefore, a different approach should be explored that facilitates the transfer of learning materials from the side of MOOCs (Renz, Shams & Meinel, 2017).

2.1 Motivation, Approach, and Methods

Huge video file-size is a common problem facing MOOC students as it is expensive and time-consuming downloading course content. It is not unusual to receive comments from students concerning the file size problem as one below (Guo et al., 2014).

"First, I would like to share with you (MOOC provider) the trouble of downloading files but also access to your site (MOOC platform). It would be great if you could reduce the file size" and *"Internet in my community is poor and streaming is difficult. Can I get an audio format of the lecture? Where can I download if possible?"*

In response to the challenge above, we aim to provide relevant learning content suitable for narrowband environments. Nevertheless, we are motivated to improve the overall performance of MOOCs in intermittent connectivity. Our approach focuses on the development and provision of alternative learning materials for videos.

The approach primarily advocates the usage of blended multimedia, created from a combination of images and audio extracted from the original video. To achieve relevant content, we have opted to improvise a set of new learning materials from the original video itself. The experiment video would then provide images and audio assets, of course, in an automated digital process. The assets, in turn, would blend in much small file size, enough to sustain sparse networks. Nevertheless, the blended materials are supposed to retain the preferred video-based format. Figure 1 shows the potential benefits of using alternative and blended materials.

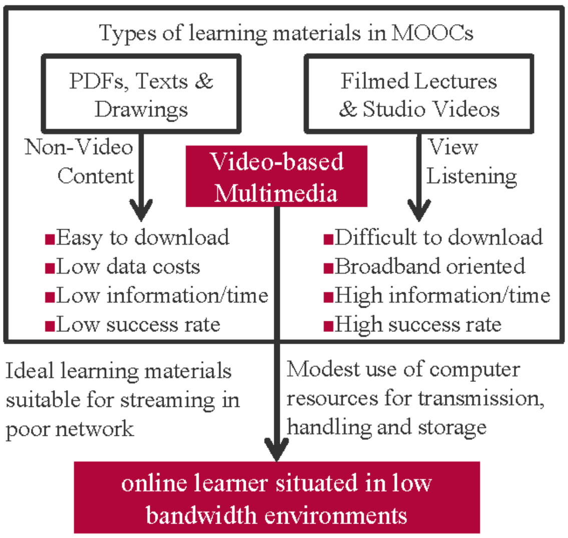


Figure 1. The materials shown on the left side are much easier and faster to download than on the right side.

3. Related Works

3.1 Usage of Videos as Learning Materials in MOOCs

Increasing use of smartphones, tablets, and similar mobile devices among students elevates enrollments in MOOCs. Operating systems of mobile devices, together with mobile applications, are now capable of processing varieties of videos. MOOCs are made possible because of readily availability and access to lecture videos via mobile devices (Jordan 2014, Bralić et al., 2015).

In contrast, mobile computing power is still constrained to battery power, display screen size, and wireless communications. All three factors are prone to poor performance whenever a video is used as prominent learning materials in MOOCs. Typically, many MOOCs try to address the network problem by reducing the video resolution, which affects the visual quality. Some MOOCs deploy compressed videos to tackle network issues. Nevertheless, in most cases, these approaches fail to deliver videos in poor network environments because the file size of the video is still not low enough to pass the threshold of the network (Huang N et al., 2017).

openHPI[1] MOOC by Hasso-Plattner Institute (Meinel & Willems 2013) aims to influence an offline mode in MOOCs. The first step involves the use of lecture slides, video transcripts, audio, and other alternative learning materials to supplement its High Definition (HD) quality videos. The material's file size is first supposed to be practical for local storage in cache memory for offline use. Manipulation of MOOC videos in previous research works is an interesting approach that provides distinctive multimedia files useful as alternative learning materials (Zhao H et al., 2018).

3.2 SMIL of Multimedia in MOOCs

Synchronized Multimedia Integration Language (SMIL) describes multimedia presentations. SMIL allows presenting media like images, audio, and other SMIL presentations (Téllez 2010). Multimedia processing includes encoding, image extraction, and audio synchronization. To our video, we deployed an existing online tool[2] developed by the Tele-Task system to extract slides from the video (Haojin & Meinel 2014).

The tool applies automatic video segmentation and key-frame detection to offer a visual guideline for the video content navigation. Consequently, it detects the slide area from video frame and captures the content of the slide area to produce a thumbnail image. The margins surrounding the slide area are discarded, including the instructor. Figure 2 shows the extraction of content from the video.

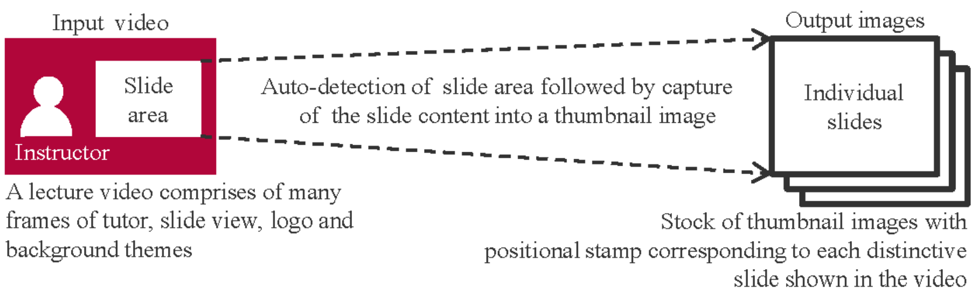


Figure 2. Automatic extraction of content from the slideshow. A stock of thumbnail images is thus produced over time that corresponds to the distinctive slides shown in the video.

For handling multimedia data, we use *FFmpeg*[3], an open-source command line that provides codec library for digital manipulation of a video into an audio file. An FFmpeg library is integrated into the MOOC platform to enable automatic read of an input video file, transcode and produce an audio file in that sequence. By using related research works, we can acquire thumbnail images and audio from the conventional video (Lei, Jiang, & Wang 2013).

At this stage, we require another tool that stitches together images and audio files to create on-the-fly video-based multimedia. The multimedia should suitably play in the media player. For re-usability of web-based HTML elements, we use *Polymer*[4], an open-source JavaScript library for building components to the media player that promptly combines images and audio files.

[1] https://www.openhpi.de
[2] http://fb10mas02.hpi.uni-potsdam.de
[3] https://www.ffmpeg.org
[4] https://www.polymer-project.org/

4. Performance Experiments

Lecture videos in MOOCs are typically recorded in a production studio with professional cameras before publication which is generally a costly process. Most of the videos are at least in standard definition quality with resolutions options of 240p, 360p, and 480p. Some MOOCs platforms provide 720p, 1080p, and original, which is the highest quality setting. As mentioned earlier, the video's running time usually varies from 8 to 20 minutes, with around 50-120MB of file-size.

First, we examine the properties of the specimen video from the MOOC course. Table 2 lists technical features of the approximately 50MB video file used in this representative experiment.

Table 2

Technical specifications of the 50MB specimen video

Duration ~8 min	File size 51MB	Bit rate 715kb/s	Codec H.264
No. of frames 11786	Frame rate 25fps	Audio mp4	Streams 2
Channel Stereo	Width 1280p	Height 720p	Display 16:9

Apart from the technical aspects, the video also contains a standing instructor (tutor) on the left side of the slide show display. The background is made up of MOOC logo, computer table, and any other background themes.

4.1 Multimedia and Design of Media Player Prototype

To validate our approach, we build a prototype to test our hypothesis. Our initial model consists of a media player that handles multimedia assets to produce video-based learning materials.

The early model of a media player is expected to render images while playing audio asset promptly to produce video-based learning content to the learners. The prototype comprises two main components which are slide extraction and video-audio transformation.

The first component intakes a chosen video as input and extracts its distinctive slides based on the number of pages in the wholly slide document. This process produces a stock of thumbnail images as an image asset. A single thumbnail image thus contains the content per page of the slideshow. In this case, a total of eight unique pages of slides are produced corresponding to eight thumbnail images. The second component employs an *FFmpeg* tool that transforms the video to an audio asset digitally; merely an audio output encoded in MP3 format.

In the next stage, The *Polymer* components combine the two assets promptly within the multimedia player. The elements supposedly display thumbnail images based on timing/positional information while playing audio. The combination of assets within the media player creates video-based learning content on-the-fly. The prototype makes use of play and pause function controls over the multimedia.

Besides, the player enacts control over slide seek and the time shift of the slides that offer added experience to learners. Figure 3 shows the design and workflow principal of the prototype. The two components work individually but promptly produce video-based content. The next subsection gives an in-depth detail of the two components.

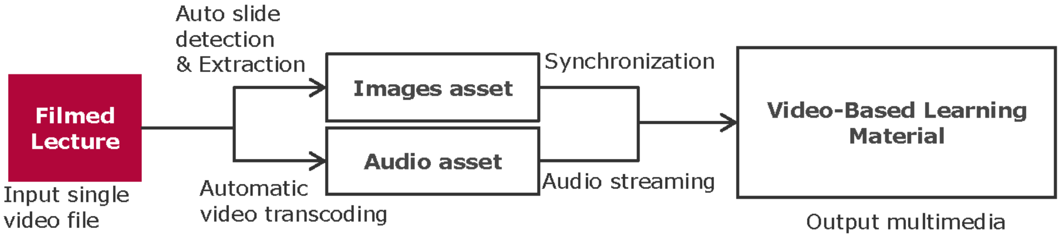


Figure 3. The architecture of the prototype for the media player outlining the production of new learning materials from a video input.

4.2 Slide detection and analysis of Thumbnail Images

A video is merely an integration of imageries. A burst of thumbnail images can be used to create a video when images are then displayed one after the other several times a second. The eye perceives this sequential display of images like a film - a video of moving objects. The quicker the images are played, the smoother and more fluid the movement looks.

A video file on computer stores all the frames together in a container and presents them in order, and the total frames stored for a typical MOOC video reach into tens of thousands. Our specimen video has 11,786 individual images, filmed at nearby 24 images per second. Each image is called a frame.

The image extraction tool is supposed to capture all distinctive frames based on the textual content of the slides. The tool thus produced only eight frames while discarded the rest (thousands of images with quite a similar slide content). The mechanism ensures extraction of unique frames from slides, i.e., eight images corresponding to the total page number of slides. The frames are stored as thumbnail images, entirely occupying as low as 593kb of disk space. Table 3 shows file-sizes as well as the position of each frame corresponding to the video.

Table 3

File size and position of each extracted individual frame

Thumbnail Image	1	2	3	4	5	6	7	8	Total
File size in KB	102	52	52	43	61	67	64	100	593
Position of a Frame	25	675	2000	3925	5675	8825	10400	11786	n/a

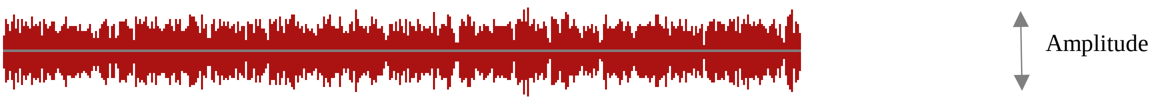
The actual position of such a video frame is presented in the last row in the table. This information is vital for a later stage of synchronization, which stitches the time of thumbnail and its corresponding starting position while audio is being played.

4.3 Video transcoding and Audio Analysis

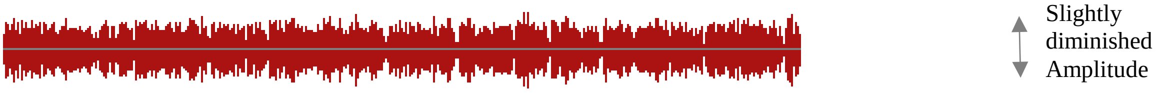
Using FFmpeg library, a video file is fed as input to produce digital audio by the transcoding process. The library provides customized options to transcode video, as demonstrated in the following piece of code provided in the programming terminal.

```
ffmpeg -i input_video.mp4 -acodec libmp3lame -qscale:a 9 -ac 1 output_audio.mp3
```

This short, robust code encodes audio in MP3 format with a quality scale of 32 bit-rate as a scaled in 9. It is monophonic with a single channel layout, and the most important property in this context is its file-size of 1.88MB. The duration of the audio is 417 seconds, similar to the video length. The output audio is stored in local storage of the computer or mobile device.



(a) The audio waveform from the video



(b) The audio waveform from the produced audio

Figure 4. The audio waveform on top (a) shows a striking resemblance to the audio waveform on (b).

Figure 4 shows a time-domain display, a display of amplitude versus time waveform properties for both input video and output audio. The audio waveforms seem to be quite similar to each other, without major signs of distortions, implying that the sound quality offers a relatively similar listening experience as the video.

4.4 *Combination and Synchronization of Multimedia*

The media player finally combines images and audio in the browser and load a document as an HTML page. Regarding the file-size of the assets, thumbnail images altogether occupy 0.59MB while audio asset mounts to 1.88MB, yielding the multimedia with a total file-size of 2.47MB. An extreme reduction in file-size compared to the 50MB of the original video.

For a single video file, a page loading time of 2-3 seconds is registered of which a complete web page is rendered to the learner. The page loading time is much higher when using multiple files as it takes longer to assemble and load all the files. In our prototype, it takes up to 57 seconds to load all thumbnail images and audio files. Repetitive experiments with the help of cache memory show a decrease of page loading time, which improves the performance of the web page in poor networks.

5. Results and Discussion

Non-video learning materials such as PDFs, slides, and textbooks are easy to download and cost fewer data in low bandwidth environments, however, they are less prevalent in MOOCs, and their success rate is low compared to their corresponding videos. Video records of lectures and animations are the most preferred teaching materials in many MOOCs. Despite their prominence, transfer of videos over the network is broadband oriented and comes with high data costs that might fail to sustain access to MOOCs and learning events in poor network environments.

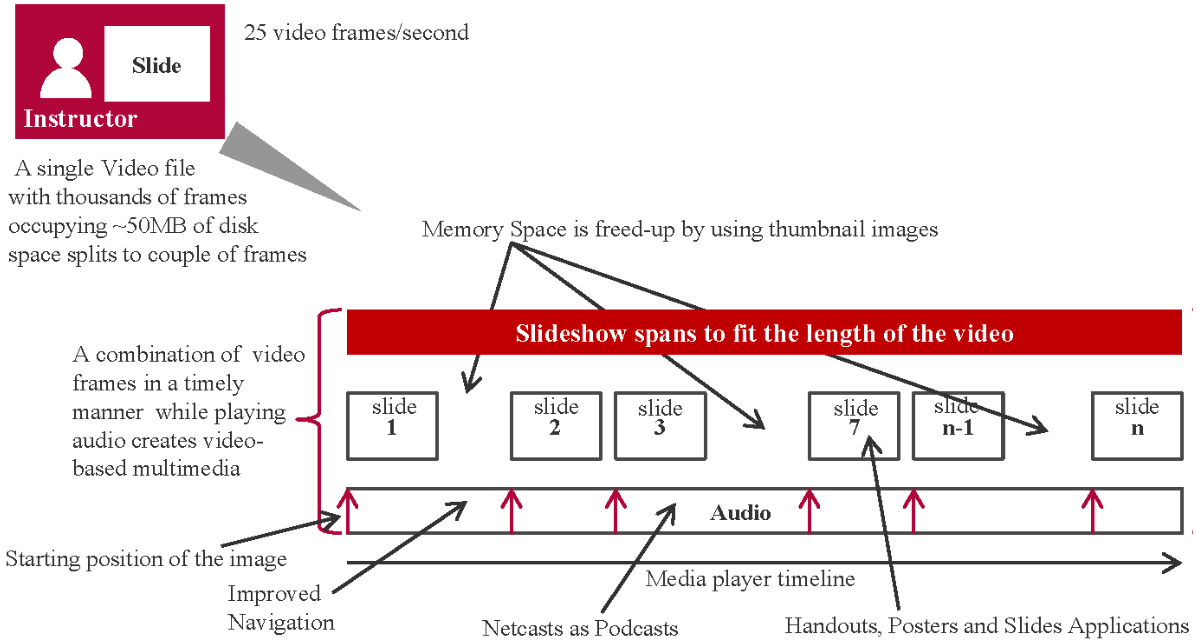


Figure 5. The structure and features of the video-based multimedia as alternative learning materials for MOOCs in a poor network environment.

To improve sustainability, we introduced an alternative, small-sized multimedia aimed to reduce network dependency as well as free-up disk spaces. Figure 5 illustrates the structure of lightweight learning content. The top left side of the image shows a single input entity as a video file, while the right side demonstrates the outcome derived from the prototype. Synchronous thumbnail images mount to an n integer which was 8 in the experiment. All thumbnail images are displayed within the playing time frame of the audio file.

Video-based multimedia presented in this paper fits in between the non-video and the conventional video learning materials in term of file-size, network transfer, handling, and storage. The said video-based multimedia consumes moderate bandwidth due to its file-size, which is suitable enough to sustain low bandwidth environments.

Regarding usage in mobile devices, a moderate computing power might be sufficient enough to process the learning materials due to the nature of the multimedia, i.e., a small number of thumbnail images rather than tens of thousands of video frames. Mobile devices only are expected to compute n numbers of images while playing audio to deliver educational content to the learner. This approach successful renders the content, but also saves battery power in comparison to video computation.

The alternative video-based multimedia has improved access to learning materials in poor network environments. Multimedia in small file sizes use fewer network resources and incur low Internet data costs. In reducing network dependency, offline capabilities might be enabled when multimedia files can fit cache memories of the browsers. MOOCs can thus stream video-based learning materials directly from its local storage - cache memory even in offline mode. The offline-enabled MOOC is potentially in demand and useful to many students and professional whose access to the Internet is only limited at universities and workplaces.

In this experiment, we digitally split a single video file into many images as well as audio files. The splitting process brings new types of learning materials, as benefits brought forward by different multimedia than a single video file. The resulting images, for example, are used for creating posters, printing hand-outs, thumb-nailing lecture courses and other educational purposes within and outside the realm of MOOCs. For instance, audios are useful in net casting, and a user can download and listen to as Podcasts. The formed multimedia also provides component re-usability and re-applicability potentials in MOOC.

A compromised learning mode surfaced as a drawback once lecture videos are removed from MOOCs since a video is more informative than combined still images and audio. Narration style and body language of the instructor affect the perception and understanding of the learner. In eLearning, the appearance of the tutor on the video is an added advantage to the learning process. However, In this case, the educational context depends on the slide's content and tutor's sounds alone. Self-adjustment in learners is, therefore expected by carefully listening while paying concentration to the images.

The implementation of the new learning materials has one more shortcoming concerning system dependability and complexity. There is an increase in system dependability due to the usage of two or more components such as image extraction tools, and codec library that comes from third parties. This increases unreliability as well as elevates the complexity of the overall system. The website in a process also needs to load many images and audio at first place before rendering them to the user. A page loading time usually increases with the addition of individual multimedia files. A browser needs to process every additional multimedia file rather than a single video file. Consequently, the learner might wait for several seconds (might be more than a minute in poor networks) before the media player is completed loaded and ready to use.

Despite the potentials of MOOC such as free and open online education, only a handful of Internet users - potential students participate in eLearning. Participation is relatively less in disadvantaged regions where access to higher education remains a challenge. The reasons for shallow MOOC activities are usually associated with unreliable access to a persistent and high-speed Internet connection, thus hindering potential learners from streaming lecture videos to their mobile devices or laptops (Renz, Ahmed, & Meinel, 2017).

Recent advancement in mobile technologies and wireless communications produces a conducive digital environment enough to support eLearning at the pace and discrete of the learners despite mostly being in a broadband state. With Internet access even in low bandwidth, MOOC courses are expecting development anywhere the learner sees fit, for example, while commuting between cities, at home in rural areas or even in remote places (Renz, Shams & Meine 2017). The current state of the existing digital environment is thus a motive for the development of eLearning features sustainable in poor networks. Potential learners of MOOC expect the provision of course materials to be readily accessible to their systems regardless of the needy broadband. Figure 6 shows the expectation level of learner's participation in MOOCs provided that solutions to challenges such as access to alternative materials suitable for low bandwidth exist.

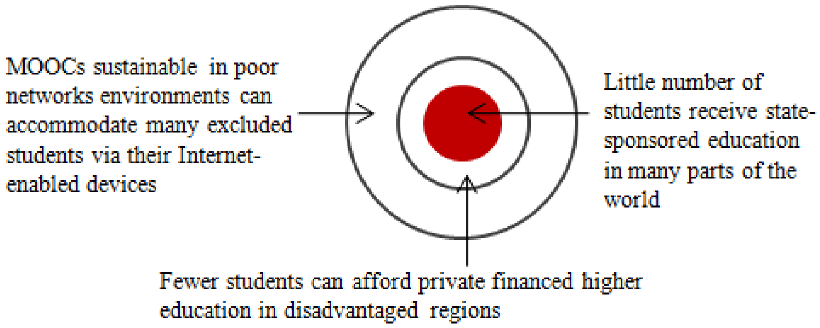


Figure 6. Conceptual Framework of MOOC Experiences based on General Expectation of Learner’s Participation and Completion of Online Courses.

6. Conclusion

This research work presented and evaluated alternative multimedia that comprises images and audio assets. In an automatized process, the assets are extracts from existing lecture videos in MOOCs. The alternative multimedia are created on-the-fly and displayed in a video-based format to the learner. They have a significantly small file-size overall compared to the lecture video. The video-based display is a result of the timely ordering of images while playing audio. The educational content of the alternative multimedia seems to be suitable for MOOC in low bandwidth, intermittent Internet connection, and similar poor network environments.

In our opinion, the results presented here are of great interest to MOOC providers and learners, especially those potential learners living in regions where access to a persistent and high-speed Internet connection is still a challenge. The implementation of the alternative multimedia in MOOCs adds a choice value of learning materials while boosts learning experience. It is an important initial step towards the provision of educational content with versatile adaption to low bandwidth environments. Despite the potential observed success, this research is limited to a single MOOC platform with a small sample of research materials, the short duration of the study, and potentially biased choice of technologies involved. Different MOOCs might offer distinctive forms of learning materials from our experiment as there are no standard regulations that MOOCs must conform.

In addition, further research is needed to study the effects of learning materials in MOOCs in sparse networks. First, the conceptual framework for the selection and provision of learning materials to improve learners experience in this article required further application across diverse MOOC environments and learner populations to determine if it is a viable framework to consider when developing and implementing customizable learning materials. Second, there is a need to design technologies, such as versatile media player, which support different network environments and Internet connection types where learners can self-determine their personal preference and select an appropriate form of learning materials for success and completion of the online course. Third, future research should also examine MOOC design and conditions for engaging learners in offline. The offline capability in MOOC can bring new impulses and impact to high education.

Future Work: Despite the promising improvements of using on-the-fly, and relative small file-size multimedia to deliver video-based educational content to MOOC learners, our model is still at an infancy stage which requires further improvements to achieve efficient learning, particular to those situated regions prone to poor networks. Technical developments such as for network control feature that enables a user to toggle between different modes of the network depending on the Internet connection and bandwidth consumption. A toggle button is thus a useful feature to allow switching between different network modes. We also expect to deploy the media player online soon. Thus we can observe and study the usage of the prototype. The process, in turn, provides essential data which, upon analysis, might help to determine deciding factors to improve learner's experience in MOOC platforms.

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