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Web Accessibility Evaluation of Videos Published on YouTube by Worldwide Top-Ranking Universities

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ABSTRACT Video consumption on the web has increased markedly in recent years. Universities use videos in different teaching-learning modalities, as well as on their websites, to publish information aimed at their stakeholders. Access to education and information has been recognized as a human right in several international conventions and the constitutions of most countries. Therefore, it is essential to ensure that videos published on the web can be accessed by people with disabilities. The universality of the web is so important that some organizations worldwide have contributed to the development of standards and recommendations focused on web accessibility. Despite these efforts, the rights of millions of people are currently violated, as they are excluded from access to both education and information published on the web. Regarding videos, the reasons are a lack of captions, sign language, audio descriptions, and transcriptions, among others. The objective of this study is to evaluate the accessibility of videos published on YouTube by the best universities in the world based on compliance with the Web Content Accessibility Guidelines (WCAG) 2.1 of the World Wide Web Consortium. We carry out a manual evaluation of 91,421 videos, which were all published on YouTube by 113 universities taken from the Shanghai Ranking. Our purpose is to highlight the urgent need to change the current low level of accessibility that their educational videos show. Consequently, statistical results are presented regarding the compliance with video accessibility according to the regions and positions of the universities in the ranking.

INDEX TERMS Accessibility, audio description, captions, disabilities, education, subtitles, videos, web Content accessibility guidelines (WCAG).

I. INTRODUCTION

Currently, we live in an era of digitized information, in which communication is easy and fast because of the development of information and communication technologies (ICTs). The web is probably the most important ICT because it provides instant access to a nearly limitless source of information from anywhere and anytime. Access to information and knowledge on the web is provided through hypertext, images, audio, and video [1].

Videos are one of the technological resources with the greatest potential on the web because they are widely used in many fields, such as education, the economy, entertainment, business, and politics [2]–[4]. Statistics show that 78 % of internet users watch online videos every week [5]. On YouTube, people watch 1 billion hours of videos every day [5]. Facebook sees 100 million hours of video playback per day [6]. Snapchat users daily watch an average of 10 billion videos [7]. At the time Instagram presented the functionality to publish videos, more than 5 million were shared in 24 hours [5]. In the latest Cisco Annual Internet Report, it was estimated that the total number of internet users for the year

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2023 will be approximately 5,300 million, compared to the 3,900 million users of the year 2018. That is an increase in the compound annual growth rate of 6 % [8]. Additionally, Cisco has estimated that due to the magnitude of the consumption of videos and other applications, there will be a demand for bandwidth even beyond what is forecast for 2023 [8].

In higher education, the use of videos in different teaching-learning modalities has allowed universities to share essential information with their stakeholders. The use of videos is highly valued for its ability to expand student commitment and development, as it provides the opportunity to create an attractive and collaborative learning environment [9]. As institutions continue to become more upgraded in their use of video, their students will acquire valuable skills and critical thinking [9]. These skills will allow students to perform better in the workplace [9]. Additionally, with the use of videos and captioning, institutions improve accessibility, allowing a greater number of students to access information at any time, regardless of their skills, hours, and locations [9].

In view of the historical moment in which this investigation is carried out, we highlight the fact that due to the COVID-19 pandemic, thousands of educational institutions have closed their physical doors, affecting over 91 % of the student population in the world [10]. The pandemic of COVID-19 has forced educational institutions to continue their activities by distance learning. UNESCO suggests the implementation of large-scale distance learning and recommends the use of platforms to reach learners remotely [11]. Those learning platforms that support e-learning are characterized by frequent use of videos [4]. It is therefore necessary, now more than ever, to provide accessibility features to videos to guarantee the inclusion and access to education of all students worldwide. The present study aims to highlight the reality of universities and determine whether they are prepared to provide inclusive and accessible education in this challenging period.

The incorporation of videos in massive open online courses (MOOCs) has similarly increased notably in recent years, further contributing to inclusive education [12], [13]. Therefore, there is an obvious need for the information contained in videos to be accessible to students with or without disabilities, as well as to all people who access university websites [14]. In a previous work, we presented the evaluation results of compliance with the accessibility requirements of 30 MOOCs offered by 10 educational platforms [15]. The results demonstrated a low level of compliance with the accessibility requirements in the videos published in the MOOCs [15]. Additionally, the results showed that people with or without disabilities who enroll in MOOCs face serious problems in accessing the information included in videos [13].

According to the latest report on disability presented by the World Health Organization (WHO) in 2011, the number of people with disabilities worldwide reached approximately 1 billion [16]. Amy F. Robertson, coexecutive director of the United States Center for Civil Rights Education and Compliance, stated, ''There's no excuse for any institution to shortchange the millions of people who are deaf and hard of hearing. We cannot pick and choose what types of accessibility we want to provide — it's a fundamental right that everyone deserves…'' [17]. Therefore, in the field of web accessibility, there is still much to be investigated.

Additionally, it is essential to emphasize Article 24 of the Convention on the Rights of Persons with Disabilities, which recognizes the right of people with disabilities to develop in a just and inclusive society, free from discrimination and that offers them the same opportunities to access information and education [18].

The problems caused by the lack of accessibility in videos are so serious that very prestigious universities, such as Harvard University and the Massachusetts Institute of Technology (MIT), were sued by the National Association of the Deaf (NAD) in 2015 [19]. These demands were made because thousands of videos included in the MOOCs and on the websites of these institutions lacked captions or otherwise contained captions with errors or were of inadequate quality [19], thus demonstrating the importance of providing accessible videos both on educational platforms and in general on the web. Additionally, it is important to consider that these demands cause damage not only to universities but also to affectations economically due to the legal consequences caused by not publishing accessible videos. A study carried out in 2016 [20] mentions that despite the relevance of web accessibility, there are websites that are inaccessible to certain sectors of the population. This inaccessibility occurs for a number of reasons, including little or no developer experience on web accessibility and a lack of information about the best ways to quickly and easily identify accessibility problems using different accessibility evaluation methods [20]. To contribute to the understanding and compliance of accessibility requirements by content authors and web developers, in 2020, we presented a proposal with 278 techniques to guide content authors, programmers, designers, and evaluators in the publication of accessible multimedia on the web [21].

In this study, our objective is to evaluate the accessibility of a sample of videos published by universities worldwide. Currently, there are no automatic tools that allow evaluating all the accessibility requirements; therefore, in this study, we manually evaluate 91,421 videos published by a sample of 113 universities selected from the best universities in the world.

In this research, we propose four hypotheses as a starting point:

Hypothesis 1 (H1): The number of videos published on the websites of the best universities in the world does not have a normal distribution.

Hypothesis 2 (H2): The distribution of videos with captions varies according to the region of the world where the universities are located.

Hypothesis 3 (H3): The distribution of videos with captions has significant differences according to the rankings of the universities.

Hypothesis 4 (H4): The Shanghai Ranking is a good indicator of the level of accessibility of videos published by universities considered the best worldwide.

The rest of this paper is structured as follows. Section II describes web accessibility standards and presents works related to our research. Section III explains the method and materials used in evaluating the accessibility of videos published on YouTube by the best universities in the world. Section IV presents the results obtained. Section V shows a discussion of the results and a comparison with previous studies. Finally, Section VI gives the conclusions and possible further work that might arise from this study.

II. BACKGROUND

In the present section, some standards and concepts that are necessary to understand both web accessibility and video accessibility are presented.

Web accessibility involves a set of characteristics that are the essence of providing the possibility for people with disabilities to access websites, tools, and technology [22]. Accessible web design allows everyone to have the same opportunities to access information, regardless of the hardware and software used, the physical location, the language, the culture, the network infrastructure, and the capacity of the people, among others [22].

On June 5, 2018, the Web Accessibility Initiative (WAI) [22] of the World Wide Web Consortium (W3C) proposed the Web Content Accessibility Guidelines (WCAG) 2.1 [23].[1] On February 20, 2020, the draft Media Accessibility User Requirements were published [25].

The WCAG 2.1 aim to enable a broader range of people, mainly those with disabilities, to perceive, understand, navigate, and interact on the web [23]. The WCAG do not address all the needs of people with disabilities but are aimed at satisfying some requirements that include "accommodations for blindness and low vision, deafness and hearing loss, limited movement, speech disabilities, photosensitivity, and combinations of these, and some accommodation for learning disabilities and cognitive limitations" [23].

The WCAG 2.1 are organized into 4 general principles (perceivable, operable, understandable and robust) and 13 general guidelines, 78 testable success criteria and 3 levels of conformance (A minimum level, AA medium level, AAA high level), sufficient techniques, advisory techniques, common failures, resource links and code [23]. The techniques are aimed at meeting the success criteria. However, it is important to take into account the fact that the application of the techniques does not guarantee the total fulfillment of the success criteria [26].

Table 1 shows the success criteria aimed at the accessibility of multimedia content proposed by the WCAG 2.1. These success criteria should be met regardless of the authoring tools used to create the multimedia content.

TABLE 1. Success criteria of WCAG 2.1 focused on the accessibility Of video players.

Success criteria – Level	Description
1.2.1 Audio-only and Video-only (P) – A	Allows people to access information transmitted by prerecorded audio-only and video-only.
1.2.2 Captions (P) – A	Provides captions for all prerecorded audio content in synchronized media, except when the media are a media alternative for text and clearly labeled as such.
1.2.3 Audio Description or Media Alternative (P) – A	Allows people who are blind or visually impaired access to the audio description of video content or to visual and auditory content in text form.
1.2.4 Captions (L) –AA	Provides captions for all live audio content in synchronized media.
1.2.5 Audio Description (P) – AA	Provides audio descriptions for all prerecorded video content in synchronized media.
1.2.6 Sign Language (P) - AAA	Provides sign language interpretations for all prerecorded audio content in synchronized media.
1.2.7 Extended Audio Description (P) - AAA	Allows people who are blind or visually impaired to access an audio track with more detailed information than the standard audio description.
1.2.8 Media Alternative (Prerecorded) - AAA	Provides an alternative to time-based media for all prerecorded synchronized media and for all prerecorded video-only media.
1.2.9 Audio-only (Live) - AAA	Provides an alternative to time-based media that presents equivalent information for live audio-only content.

P= Prerecorded, L=Live

In this research work, we focus on evaluating the accessibility of prerecorded videos. Note that herein, we use the term videos to refer to audio-visual resources published on the web.

The WCAG also consider the possibility that accessible multimedia resources may cease to be due to the lack of accessibility of user agents. Thus, a video provided with captions, sign languages, and transcriptions will not be accessible if the media player is not accessible. Table 2 shows the success criteria that video players should meet to be accessible, according to the recommendations given by the WCAG 2.1.

Referencing the previous works related to this research, to the best of our knowledge, no research has been carried out on the accessibility of the videos published on the websites of the best universities worldwide. Nonetheless, the results of research focused on one to several web accessibility features of videos, as well as video players and multimedia in general,

[1] On February 27, 2020, the W3C drafted the WCAG 2.2 [24], which include a new success criterion (2.4.11 Focus Visible (Enhanced)) that has no relation to videos. For this reason, we refer to version 2.1 of the WCAG in the rest of the article.

TABLE 2. Success criteria of WCAG 2.1 focused on the accessibility of video players.

Success criteria - Level	Description
1.4.2 Audio Control - A	Allows people to pause or stop audio when the audio plays automatically for more than three seconds.
1.4.3 Contrast (Minimum) - AA	Allows people with moderately low vision or people who have a color vision deficit to have an adequate contrast between the text and the background.
1.4.4 Resize text - AA	Allows people to resize captions by up to 200 % without losing content or functionality.
2.1.1 Keyboard - A	Allows people to operate content through a keyboard or keyboard interface.
2.2.2 Pause, Stop, Hide	Allows people to pause, stop, or hide any motion, blink, or scroll information that (1) starts automatically, (2) lasts for more than five seconds, and (3) is presented in parallel with other content.

have been presented. Similarly, numerous studies have been carried out on the accessibility of the homepages of the websites of universities in some countries without considering videos.

In previous investigations on the web accessibility of videos and multimedia, in 2007, a summary of some elements and best practices to take into account to make a multimedia resource accessible on the web was presented [27]. In 2008, an investigation was conducted on how the WCAG 1.0 and the draft of the WCAG 2.0 could be applied to make multimedia content accessible [28]. In 2010, the results of a study showed how, by suppling rich descriptions of video content, the accessibility of web videos could be enhanced. [29]. In 2015, an investigation presented the results of a study centered on evaluating the accessibility of videos on the most commonly used websites [30]. In these works, the authors emphasized the need to generate accessible video content. In 2017, a study proposed a system to generate SignWriting for video tracks, enhancing the accessibility for deaf people [31]. In 2019, two proposals were presented to improve video accessibility for deaf and hearing-impaired people through the use of dynamic subtitles and captions [32], [33].

In 2019, we presented a study on the accessibility of 10 videos, some of which were published by Latin American universities and taken from Webometrics [34]. This study was mainly focused on photosensitivity analysis; the evaluation was performed using the automatic PEAT tool [34]. Similarly, in 2019, we presented another study with the results of the accessibility analysis of educational videos used in 30 MOOCs. These studies were based on compliance with the WCAG 2.1 [15]. These studies contributed to the gathering of solid knowledge about the accessibility requirements that people with disabilities have for videos published on the web. In addition, they gave us the possibility to propose some primary research, since in the field of accessibility, there are still many pending things to do to achieve universality of the web.

In this research, we conduct a manual evaluation of the accessibility in videos (91,421) published by 113 universities classified as the best in the world by the Shanghai Ranking Consultancy. Additionally, we performed an in-depth statistical analysis of the existence of captions (a basic accessibility characteristic that videos must meet) and 11 accessibility characteristics (5 basic levels, 1 medium level and 5 high levels) in 6,780 videos considering the WCAG 2.1.

Concerning the accessibility of video players, in 2011, the results of two studies on the accessibility of media players were presented [35], [36]. The authors of these works concluded that multimedia content does not keep pace with technological advances and that there was no fully accessible multimedia player. In 2014, research was carried out describing the design and evaluation of an accessible video player [37]. In 2017, a checklist with 23 indicators focused on the design and evaluation of the accessibility of media players was presented [38]. Likewise, in 2017, the results of 13 interviews were presented, which collected information regarding how people with disabilities interact with video players [39]. In 2018, an evaluation of the accessibility of 37 video players, both free and paid, was performed [40]. The authors of that study agreed that Able - Player and OzPlayer do not contain show-stoppers.

In 2019, we presented a detailed analysis of the accessibility requirements for video players in e-learning based on the UAAG 2.0 and WCAG 2.1 [41]. Our research concluded that the designers and developers of video players still have much work to carry out to offer accessible players to people with disabilities.

Regarding the accessibility of the websites of universities, several studies have been carried out in different countries; for example, in 2010, a study was carried out in Turkey [42]; in 2016, in the Kyrgyz Republic [43]; in 2017, in Ecuador [44]; in 2018, in Israel [45]; South Africa [46] and Latin America [47]; and in 2019, in Portugal [48], Spain, Chile and Mexico [49] and the United States [50]. In these works, the evaluation process was carried out using automatic tools such as WAVE, Web Accessibility Checker, AChecker, SortSite, or TAW and considering the WCAG 2.0 or WCAG 2.1. In the conclusions of these studies, the authors highlighted the problems faced by people with disabilities due to the lack of accessibility of web pages. However, these investigations excluded videos from their analyses. Unlike those studies, in our research, we focus on the accessibility of the videos published on the websites of the universities ranked among the best worldwide.

III. METHOD AND MATERIALS

The method we followed to achieve our study objectives is shown in Fig. 1. This method contains five phases and considers compliance with the WCAG 2.1.

Phase 1: Filtering the success criteria and techniques of the WCAG 2.1 focused on the accessibility of prerecorded videos and video players. This phase consists of two steps:

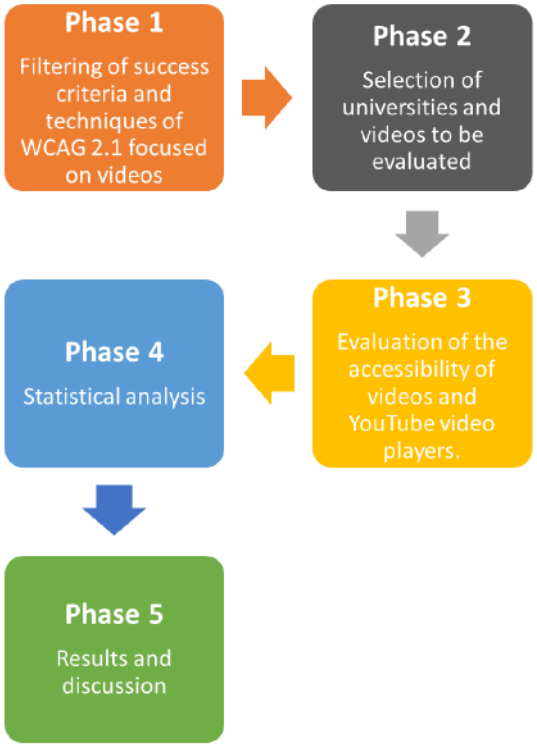

FIGURE 1. Phases of the applied method.

1.1 Filtering the principles, guidelines, success criteria, and conformance levels recommended by the WCAG 2.1 to make time-based media accessible.

1.2 Filtering the techniques proposed by the WCAG 2.1 that guide compliance with the success criteria from step 1.1.

Phase 2: Selection of universities, videos, and video players to be evaluated. This phase consists of four steps:

2.1 Selection of universities.

The selection of the universities was made considering the latest Academic Ranking of World Universities report, published by the Shanghai Ranking Consultancy in August 2019 [51]. This report presents a list of 1,000 universities that have obtained the highest academic level worldwide [51].

The sample size was calculated via a simple random procedure with a finite population (1,000 universities) applying equation (1).

$$n = \frac{z^2pqN}{e^2N+z^2pq} \quad (1)$$

n = Sample size
z = Confidence level
p = Proportion of the population with the desired characteristic
q = Proportion of the population without the desired characteristics
e = Error level
N = Population size

From the sample size calculation, the universities were randomly selected, applying the RANDBETWEEN (bottom, top) function of Microsoft Excel. The range used in the function was between 1 and 1,000. A Microsoft Excel spreadsheet was used to record the information corresponding to the name of the selected universities, the country, the region, and the URL of the website of each university.

2.2 Selection of the platform on which the videos to be evaluated are published.

An exploration of the website of each of the universities that make up the sample was carried out using the URL obtained in step 2.1. We verified that a large number of universities do not have their own platform for publishing videos. Instead, the existence of some links to social networks, such as Instagram, Facebook, and YouTube, among others, was found. However, a clear preference for the YouTube platform was confirmed. Recent studies have also demonstrated that the native video player of YouTube is one of the most accessible considering the WCAG [41], [52], [53].

Therefore, to standardize the analysis, the videos published by the universities on the YouTube platform were evaluated. Universities that did not use YouTube were excluded from the evaluation process and were not replaced by other universities for the purpose of carrying out the respective statistical analysis.

2.3 Registration of the URL of the official YouTube channel and general information of the videos published by the universities.

In the spreadsheet created in step 2.1, the URL of the university's official YouTube channel, the date of creation of the channel, the number of subscribers, the number of views and the number of videos published were recorded.

2.4 Descriptive and exploratory statistical analysis with the data obtained in steps 2.1, 2.2 and 2.3.

Phase 3: Evaluation of the accessibility of videos and YouTube video players.

Since there are no automatic tools that allow evaluating all the web accessibility features of videos and video players, the evaluation process was carried out manually. Manual evaluation involves a considerable amount of time and intense work by experts [54]. The application of this evaluation method allowed us to accurately determine the level of compliance with the accessibility of the videos and the YouTube player based on the WCAG 2.1. The 11 success criteria selected in Phase 1 were evaluated (6 focused on video accessibility and 5 focused on video players). This phase consists of 3 steps:

3.1 Evaluation of compliance with success criterion 1.2.2.

Given the importance of captions, compliance with success criterion 1.2.2 (Captions) was evaluated for all the videos published by the universities that made up the sample. Because YouTube has cannot show all the videos published on a channel (approximately 2,800 videos are shown), in the cases that warranted it, the following procedure was carried out to allow determining and evaluating the total number of videos published by each university:

3.1.1 Access the university's YouTube channel and order the videos from the most recent

3.1.2 Evaluate compliance with criterion 1.2.2 of all videos published up to k-1 years ago, where k corresponds to the last year for which YouTube displays videos.

3.1.3 Order the videos from the oldest date of publication.

3.1.4 Evaluate compliance with criterion 1.2.2 of all videos published up to k years ago.

3.2 Evaluation of the accessibility of the videos.

Considering the time and effort involved in carrying out the manual evaluation of the accessibility of the videos, 60 videos published by each of the universities that make up the sample were evaluated (a total of 6,780 videos). The 60 videos were selected under the following criteria:

Criterion 1: The 20 oldest videos.

Criterion 2: The 20 most recent videos.

Criterion 3: The 20 most popular videos.

3.3 Evaluation of the accessibility of the YouTube video player

Evaluation of the compliance with the 5 success criteria that the WCAG 2.1 recommend for video players was carried out.

Phase 4: Statistical analysis in IBM SPSS release 23 of the results obtained in Phase 3.

Phase 5: Results and discussion. This phase consists of two steps:

5.1 Presentation of the results on the accessibility of videos published on YouTube in accordance with the WCAG 2.1.

5.2 Discussion about the accessibility level of videos and the YouTube video player.

The described method was applied from January 26 to 29, 2020. It is worth highlighting that the proposed method can be applied to evaluate the level of accessibility of all videos published on the web, regardless of the video player. In this research, the YouTube platform was selected since, based on the result of step 2.2, approximately 80 % of the videos published by the universities analyzed share their videos through YouTube.

IV. RESULTS

As a result of the first phase, Table 3 shows the principles, guidelines, success criteria and levels of conformity that the WCAG 2.1 suggest compliance with so that videos and video players are accessible on the web. These success criteria were selected from Tables 1 and Table 2. Additionally, Table 3 shows the techniques proposed by the WCAG 2.1, which guide compliance with the success criteria.

In phase 2, the sample size was calculated, applying equation (1) to consider the statistics for population proportions. The parameters used were as follows: population size N = 1,000 universities, confidence level z = 99 %, margin of error e = 10 %, probability of success p = 50 % and probability of failure q = 50 %. The sample size obtained was n = 142 universities.

As an example, Table 4 presents an extract of a dataset that contains information from 142 randomly selected universities. This table contains information about the world rank, acronym, university name, country, region and URL of the website of each university. Table 4 is arranged in ascending order by the world rank. All information and results of this study are available in our dataset in the Mendeley repository.[2]

TABLE 3. Success criteria for prerecorded videos -WCAG 2.1.

Principles - Guidelines	Success Criteria - Level	Techniques
Perceptible - Time-based Media	1.2.2 - A	G93, G87
	1.2.3 - A	G8, G69, G78, G173, G203, H53
	1.2.5 - AA	G8, G78, G173, G203, H96
	1.2.6 - AAA	G54, G81
	1.2.7 - AAA	G8
	1.2.8 - AAA	G58, H53, G159, H46
Perceptible - Distinguishable	1.4.2 - A	G60, G170, G171
	1.4.3 - AA	G18, G145, G148, G174
	1.4.4 – AA	G87, G93
Operable - Keyboard Accessible	2.1.1 - A	G90, G202
Operable - Enough Time	2.2.2 - A	G4, G11, G152, G186, G187, G191

P=Prerecorded, G=General, H=HTML

TABLE 4. Extract of the dataset listing the best universities worldwide taken from the shanghai ranking.

World Rank	Acronym	University	Country	Region	URL
1	Harvard	Harvard University	USA	Americas	http://www.harvard.edu
8	Columbia	Columbia University	USA	Americas	http://www.columbia.edu
23	Imperial	Imperial College London	UK	Europe	http://www3.imperial.ac.uk/
35	UBC	University of British Columbia	Canada	Americas	http://www.ubc.ca
42	UMN	University of Minnesota, Twin Cities	USA	Americas	https://twin-cities.umn.edu/

Fig. 2 shows the percentages by region to which the universities that make up the sample correspond and the percentages by region of the 1,000 universities considered in the Shanghai Ranking. As can be seen in Fig. 2, the sample is representative, which allows inferring properties over the entire population from the results of our analysis.

Table 5 shows the 37 countries to which the 142 universities that make up the sample correspond. It can be seen that 30 universities are located in the USA, which is the country with the highest number of universities evaluated, followed by China with 17 and the United Kingdom with 12, and with the 34 remaining countries having numbers of universities ranging from 1 to 7. Table 6 shows the number of universities that make up the sample and their percentages according to their positions in the Shanghai Ranking, being classified into five categories.

As a result of an exploration of the websites of the universities that make up the sample, based on the platform they use

[2] https://doi.org/10.17632/k6zjz5wx2n.1

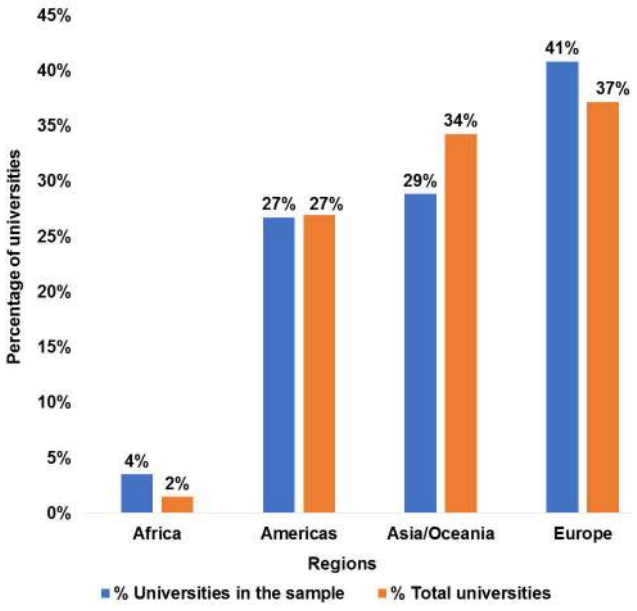

FIGURE 2. University distribution by region in the sample and in the Shanghai Ranking.

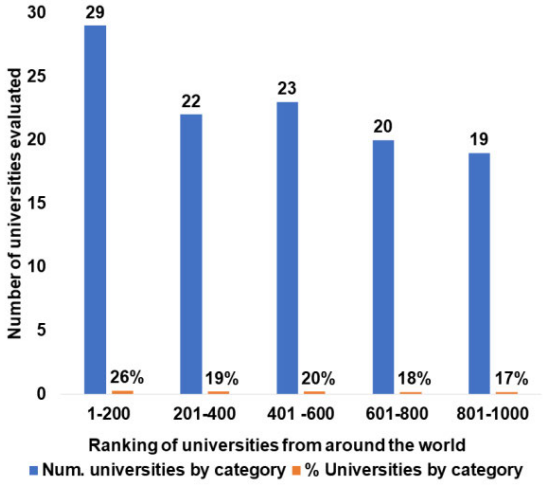

FIGURE 3. University distribution by range according to the Shanghai Ranking.

TABLE 5. Best universities worldwide taken from the Shanghai ranking.

Country	Region	Num. Univ
Argentina	Americas	1
Australia	Asia/Oceania	5
Belgium	Europe	1
Brazil	Americas	3
Canada	Americas	3
China	Asia/Oceania	17
China-Taiwan	Asia/Oceania	4
Czech Republic	Europe	1
Denmark	Europe	2
Estonia	Europe	1
Finland	Europe	2
France	Europe	4
Germany	Europe	7
Greece	Europe	2
India	Asia/Oceania	1
Iran	Asia/Oceania	2
Israel	Asia/Oceania	2
Italy	Europe	9
Japan	Asia/Oceania	4
Luxembourg	Europe	1
Mexico	Americas	1
Netherlands	Europe	2
New Zealand	Asia/Oceania	1
Nigeria	Africa	1
Norway	Europe	2
Portugal	Europe	1
Romania	Europe	1
Russia	Europe	3
Saudi Arabia	Asia/Oceania	1
South Africa	Africa	4
South Korea	Asia/Oceania	3
Spain	Europe	5
Sweden	Europe	1
Thailand	Asia/Oceania	1
Turkey	Europe	1
UK	Europe	12
USA	Americas	30
Total:		**142**

to publish their videos, the statistics show that approximately 80 % of universities publish on the YouTube platform. The universities that do not publish their videos on YouTube (29 universities) were excluded from the research process. In other words, 113 universities were finally considered for data collection in this investigation.

The excluded universities (20 % of the sample) include universities in the Republic of China (15 %) and universities in Argentina, Greece, Iran, Nigeria, Saudi Arabia, South Korea, and the USA (5 %). In the case of China, it is important to highlight that the websites of some social networks, such as YouTube, Facebook, Twitter, Blogspot, and Vimeo, have been blocked since 2009 [55]. In the case of China, the most commonly used video platforms are Youku, Tuodu, and iQiyi.com.[3]

Fig. 3 shows the distribution of the 113 universities evaluated according to their position in the ranking. It is observed that category 1, which is made up of the universities located in the first 200 places, comprises 29 universities, while in the other categories, the number of universities ranges between 19 and 23.

Table 7 shows, as an example, an extract of the information detailing the URL of each university website, the URL of each YouTube video channel, the number of subscribers, the YouTube join date, the number of views and the number of videos shared by the university. All the data were gathered from January 26 to 29, 2020. All information is available in our dataset in the Mendeley repository.[4]

[3]Actually, five Chinese universities and a USA university offer a link to YouTube on their websites. However, the numbers of videos and views are minimal (e.g., Northwestern Polytechnical University (NPU) has only 1 video, 187 views, and 28 subscribers); thus, they were excluded from this study.

[4]https://doi.org/10.17632/k6zjz5wx2n.1

TABLE 6. Number and percentage of universities by world rank.

Category	World Rank	Num. universities	Average
1	1-200	33	23.24 %
2	201-400	28	19.72 %
3	401 -600	31	21.83 %
4	601-800	25	17.61 %
5	801-1000	25	17.61 %
	Total:	142	100 %

TABLE 7. Extract of The Information from the official YouTube channels of the universities studied.

Acronym	URL of university website	URL of video channel	Num. subscribers	Join date	Num. views	Num. videos
Harvard	http://www.harvard.edu	https://www.youtube.com/user/Harvard	1,080,000	2005	101,787,584	3,460
Columbia	http://www.columbia.edu	https://www.youtube.com/user/columbiauniversity	61,800	2006	9,147,140	1,626
Imperial	http://www3.imperial.ac.uk/	https://www.youtube.com/user/imperialcollegevideo	98,000	2008	14,073,586	1,769
SJTU	http://www.sjtu.edu.cn/	University does not use the YouTube platform to publish its videos				

TABLE 8. Universities by region and total information from their official YouTube channels.

Region	Num. university	Num. videos	Num. subscribers	Num. views
Americas	36	36,623	1,444,892	105,715,631
Africa	4	3,968	16,330	5,992,562
Asia/Oceania	16	15,541	205,317	76,125,186
Europe	57	35,289	474,213	102,048,145
Total:	**113**	**91,421**	**2,140,752**	**289,881,524**

Information about the number of subscribers and the number of views or reproductions was taken from the YouTube channel of each university. The total number of videos published by each university was obtained from a search carried out directly on the YouTube platform using the search string ''videos name of university''.

Table 8 shows the distribution of the 113 universities by region, as well as the total numbers of videos published, subscribers and views by region. It is observed that the 113 universities have published a total of 91,421 videos. The total number of views was 289,881,524, and the total number of subscribers was 2,140,752.

In Fig. 4, it can be seen that American universities had the highest average of published videos (1,017), while European

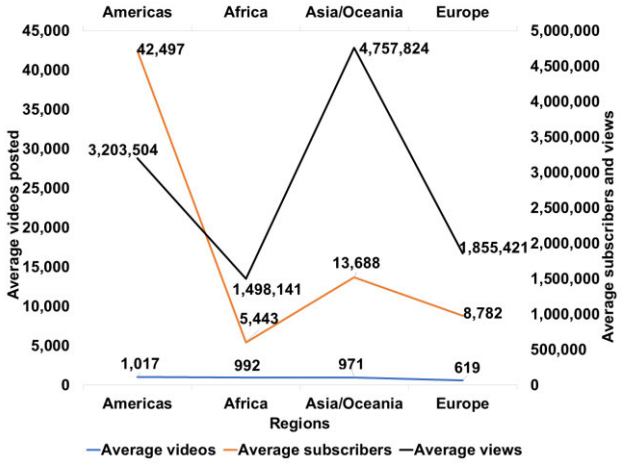

FIGURE 4. Average numbers of published videos, subscribers and views by region.

universities had the lowest average of published videos (619). The following are also observed:

Universities in the Americas region rank first in the average number of subscribers, with 42,497 subscribers, while with respect to the number of views, it is in second place, with 3,203,504.

The universities in Africa rank fourth with respect to the average number of subscribers and the average number of views, with 5,443 subscribers and 1,498,141 views.

Asia/Oceania universities rank second in terms of the average number of subscribers, with 13,688, and first with regard to the average number of views, with 4,757,824.

Universities in Europe rank third with respect to the average numbers of subscribers and views with 8,782 and 1,855,421, respectively.

Table 9 shows the results of a descriptive statistical analysis with a confidence level of 98 % with respect to the distribution of the total number of videos published by the 113 universities considered in this study. The average number of videos published per university is 809 videos. The median is 615, the minimum number of videos published is 2, and the maximum number is 4,206. The kurtosis k = 5.19647456 and skewness = 2.121518448 demonstrate that there are one or more values far from the mean or the presence of outliers.

The result showed a variance = 649,290.8916; thus, the Kolmogorov-Smirnov normality test ($p > 0.05$) was performed. This test indicated that the number of videos published does not have a normal distribution because of the significance Sig = 0.0. Thus, we reject the null hypothesis and accept the alternative hypothesis (H1: The number of videos published on the website of the best universities in the world does not have a normal distribution) proposed in this study. In the same way, in Fig. 5, the histogram shows that the data do not have a normal distribution. Consequently, the tests for nonparametric data were applied.

An exploratory statistical analysis was performed to determine the distribution characteristics of the total number of

TABLE 9. Descriptive analysis of the number of videos published.

Published videos	
Mean	809.0353982
Standard Error	75.8019597
Median	615
Mode	833
Standard Deviation	805.7858845
Sample Variance	649,290.8916
Kurtosis	5.19647456
Skewness	2.121518448
Range	4,204
Minimum	2
Maximum	4,206
Sum	91,421
Count	113
Confidence Level (98.0 %)	178.9005062

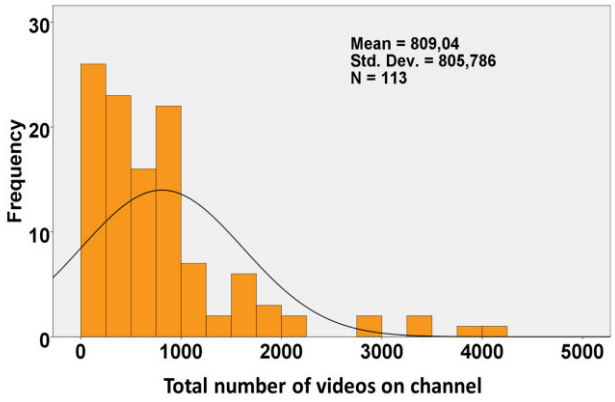

FIGURE 5. Normality curve of the number of videos published.

videos published by the 113 universities, which were classified into 5 categories (1-200, 201-400, 401-600, 601-800, 801-1000) according to the position they occupy in the Shanghai Ranking. Fig. 6 shows the median, concentration, and dispersion of the data, outliers, and extremes and the asymmetric distribution of the data. Additionally, 50 % of the total number of videos published are more dispersed in relation to the other categories of universities, since their interquartile range (IQR) is equal to 1,281. In the same way, two outliers are observed: 3,460 videos published by Harvard University (USA) and 3,931 videos published by Vanderbilt University (USA).

The universities located in rankings 201-400 and 401-600 reach medians of 513.50 and 430, respectively. These universities present a higher concentration of their data, with IQRs equal to 541 and 609, respectively. An extreme value of 4,206 videos published by the Bar-Ilan University of Israel belonging to the category of universities ranked 401-600 is observed.

With respect to the universities located in the ranking 601-800, their median is 640.50, 50 % of the videos are located in the IQR of 767 videos and no atypical values are present. Finally, the median value of the universities located

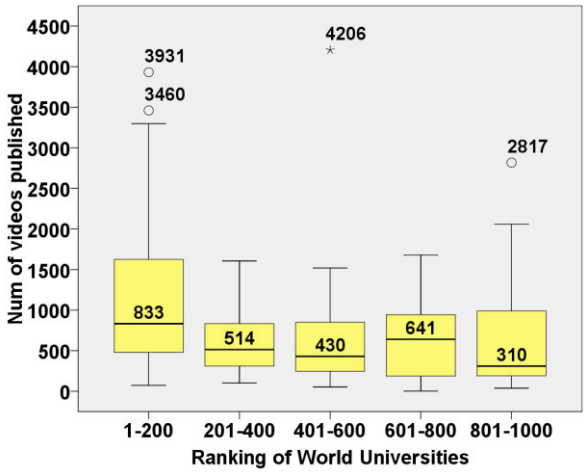

FIGURE 6. Boxplots of the distribution of published videos based on the rankings of universities.

in the 801-1000 ranking is 301, the lowest value of all. It is also observed that their data are scattered, reaching an IQR of 815 videos. In this case, an outlier corresponding to 2,817 videos published by the Federal University of Santa María of Brazil is recorded. Additionally, it is observed that in all groups of universities, there is a greater dispersion of their data from quartile 3.

In phase 3, the evaluation of compliance with success criterion 1.2.2 (Captions) was carried out for the 91,421 videos published by the 113 universities. The results show that 12,257 videos have associated captions, which corresponds to approximately 13 % of the total videos. Table 10 and Table 11 show the results of the descriptive analysis of these videos. These tables include the maximum and minimum numbers of videos published and measures of the central tendency and dispersion such as the mean, the median, the standard deviation, the range of variation, the skewness, and the kurtosis. These measurements allow us to complement the information displayed in Fig. 7, in which the distribution and dispersion of the videos that have associated captions are displayed.

Fig. 7 shows that of the total videos published by the universities ranked in places 1 to 200, 201 to 400 and 401 to 600, approximately 25 % of their videos were published with captions. The universities ranked in places 601-1000 published much less than 25 % of the videos with captions. Regarding the total number of videos published, in the case of universities that occupy the first 200 places, the median is 883 videos, while the median of videos with captions is 513.5 videos. Likewise, 1 outlier is observed that corresponds to the 751 videos published with captions by Harvard University, and 1 extreme value corresponding to the 1,261 videos with captions published by Brown University can be seen. For universities ranked 201-400, the median is 38.5 captioned videos; Curtin University presents an extreme value with 972 captioned videos. For the universities located in places 401-600, their median is 15 videos published with

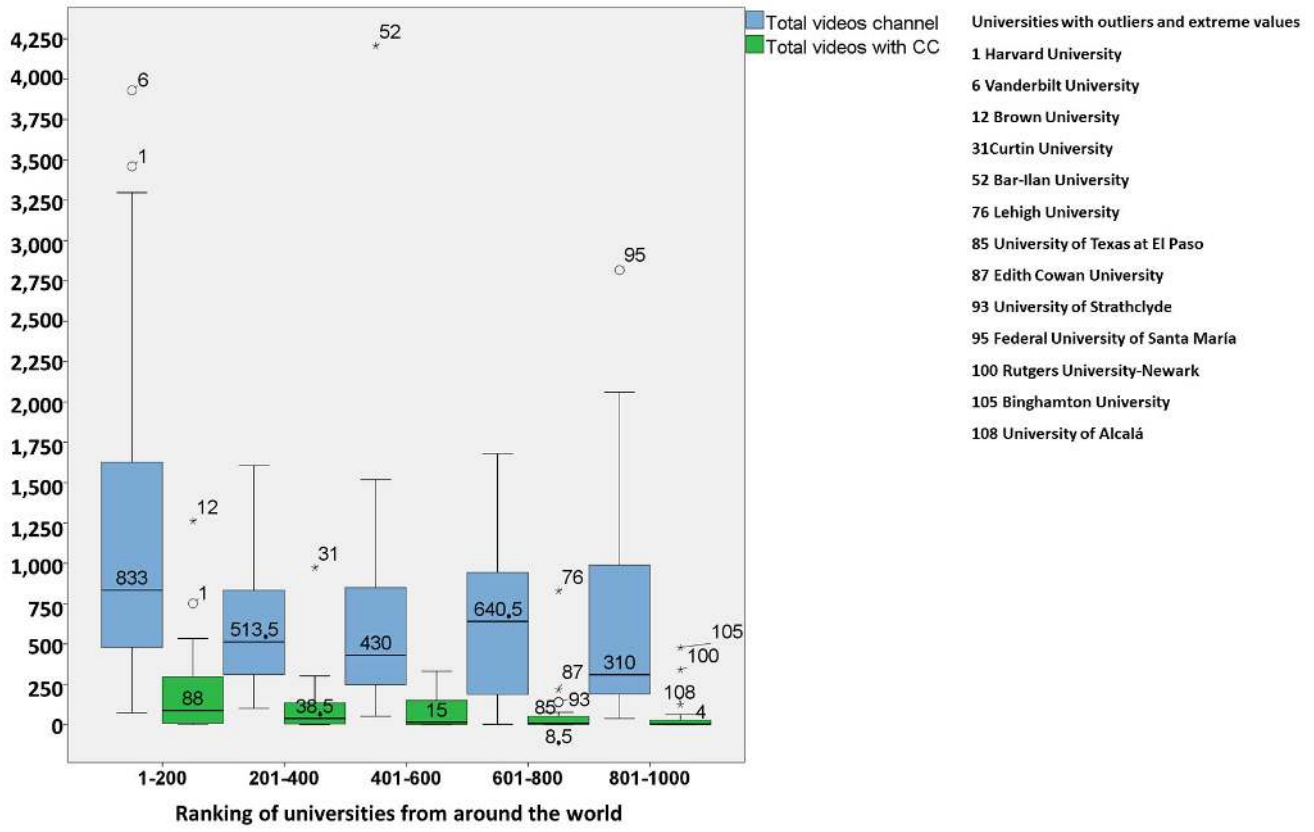

FIGURE 7. Cluster boxplot distribution of the total number of videos in a channel and videos with captions with respect to the world ranking.

TABLE 10. Descriptive analysis of the total number of videos published.

Measures of central tendency and dispersion	University rankings				
	1-200	201-400	401-600	601-800	801-1000
Num. universities	29	22	23	20	19
Mean	1,189.90	619.68	702.17	647.45	746.42
Median	833.00	513.50	430.00	640.50	310.00
Standard deviation	1,066.049	373.361	844.259	492.643	810.532
Minimum	73	101	52	2	38
Maximum	3,931	1,606	4,206	1,679	2,817
Range	3,858	1,505	4,154	1,677	2,779
Interquartile range	1,281	541	609	767	815
Skewness	1.255	0.982	3.510	0.588	1.322
Kurtosis	0.783	0.703	14.389	-0.308	0.968

TABLE 11. Descriptive analysis of the videos published with captions.

Measures of central tendency and dispersion	University rankings				
	1-200	201-400	401-600	601-800	801-1000
Num. universities	29	22	23	20	19
Mean	196.07	105.27	71.22	76.15	57.58
Median	88.00	38.50	15.00	8.50	4.00
Standard deviation	277.516	207.590	99.982	186.886	129.435
Minimum	1	0	0	0	0
Maximum	1261	972	331	828	477
Range	1260	972	331	828	477
Interquartile range	313	131	166	64	38
Skewness	2.443	3.799	1.290	3.793	2.701
Kurtosis	7.190	15.872	0.479	15.429	6.783

captions. For the universities that occupy positions 601-800, their median is 8.5 videos with captions, with 2 outliers and 2 extreme values that correspond to the University of Texas at El Paso, University of Strathclyde, Edith Cowan University and Lehigh University, with 138, 142, 216 and 828 videos, respectively. Finally, for the universities that occupy places 801-1000, 3 extreme values are observed corresponding to the University of Alcalá, Rutgers University-Newark, and Binghamton University, with 124, 340 and 477 videos published with captions, respectively, while the median is 4 videos published with captions.

Fig. 8 shows the result of the evaluation of criterion 1.2.2 carried out on a total of 6,780 videos corresponding to the 20 oldest videos, the 20 newest videos and the 20 most popular videos published by each of the 113 universities. The most recently posted videos have the highest percentage of captions, followed by the most popular videos, while the oldest videos have the lowest percentage of captions. In the case of the newest published videos, the data fit the linear regression model with a decreasing slope $p = -0.0578$ and coefficient of determination $R^2 = 0.7637$. The top 200 universities posted 34 % of the newest captioned videos. This percentage decreases to 24 % for the universities located in the 201- 400 ranking, followed by the universities located in the 401- 600 ranking, with 20 % of the videos with captions, the universities located in the 601- 800 rankings, with 24 % of their videos with captions, and the universities located in the ranking 801-1000, with 11 % of their videos

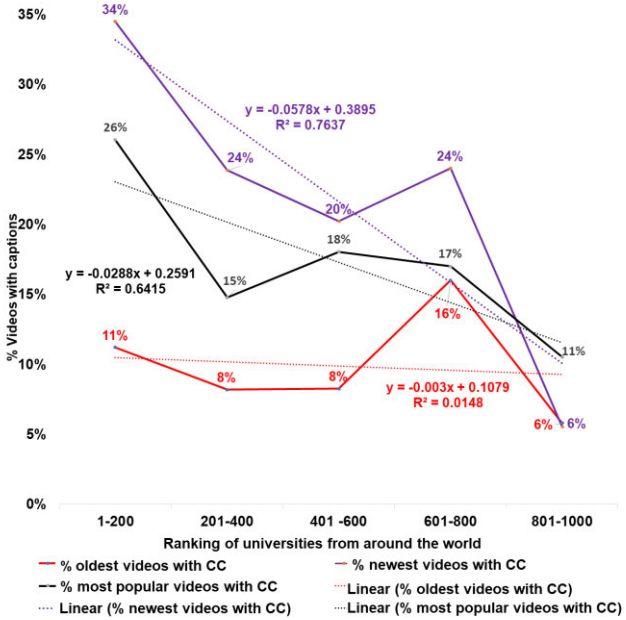

FIGURE 8. Trends of the newest, most popular and oldest videos with captions by their world ranking.

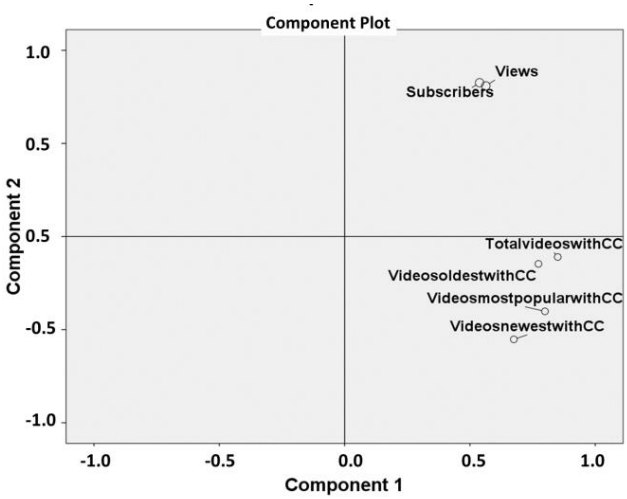

FIGURE 9. Correlation of the analyzed variables.

TABLE 12. KMO and bartlett tests.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.668
Bartlett´s Test of Sphericity	Approx. Chi-square	503.543
	df	15
	Sig.	0.000

with captions. Similarly, it is observed that the distribution of the most popular videos adjusts to a linear regression model with a decreasing slope $p = -0.0288$ and coefficient of determination $R^2 = 0.6415$, which reveals a greater variability of the data.

In the case of the oldest videos, the coefficient of determination $R^2 = 0.0148$, that is, a value very close to 0, which shows that these data would not fit a linear regression model. The percentage of old captioned videos at most universities is approximately 8 % and 11 %, with the exception of universities ranked 601-800, which published approximately 16 % of their videos with captions.

Fig. 18 in the appendix shows the 113 universities evaluated and the numbers of the oldest, newest and most popular videos published with captions.

To determine the correlations between the variables: number of subscribers, total views, total number of videos with captions, and the oldest, most popular and most recently published videos with captions, the KMO and Barlett tests were applied, as shown in Table 12. Among the results, $p = 0.000$, which shows that the dimension reduction model is optimal. The measure of simple adequacy $= 0.0668$ shows that there is an acceptable correlation. Fig. 9 is a component plot, which shows that the number of views of the videos is correlated with the number of subscribers. The total numbers of the most recent, oldest and most popular videos with subtitles have less relevant correlations.

To analyze the distribution of videos that have associated captions according to the region in which the universities are located, a statistical analysis applying the Kruskal-Wallis independent sample test was performed. We considered 4 degrees of freedom (corresponding to the n-1 regions considered in this analysis) and the 6,780 videos (2,260 most recently published plus 2,260 most popular plus 2,260 oldest). In the case of the most recently published videos, the value of the asymptotic significance Sig = 0.00. Therefore, we reject the null hypothesis and accept the alternative hypothesis (H2: The distribution of videos with captions varies according to the region of the world where the universities are located) proposed in this study. That is, the distribution of the newest published videos with captions varies according to the world region of each university. Fig. 10 clearly shows the difference in the interquartile range by region; there is a significant difference among the five analyzed regions. The presence of 2 outliers is observed in the Asia/Oceania region, and 8 outliers, in Europe. Additionally, it is observed that the median of the newest published videos with captions in the Americas region is much higher than in the other regions of the world.

In the case of the most popular videos that have captions, an asymptotic significance $p = 0.00$ was obtained, with which we reject the null hypothesis (H2) and conclude that there is a significant difference between the regions in the distribution of the most popular videos with captions published by the best universities in the world. This result is clearly seen in Fig. 11, highlighting that the median in the Americas region is much higher than in the other regions.

In the case of the oldest videos that have captions, an asymptotic significance $p = 0.00$ was obtained, with which we reject the null hypothesis (H2) and conclude that there is a significant difference between the regions in the distribution

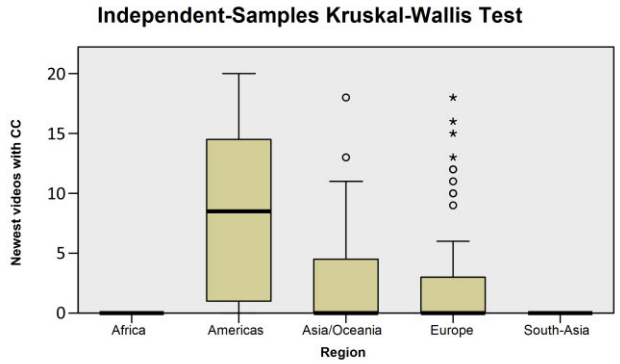

FIGURE 10. Boxplots of the distribution of the newest videos with captions by region.

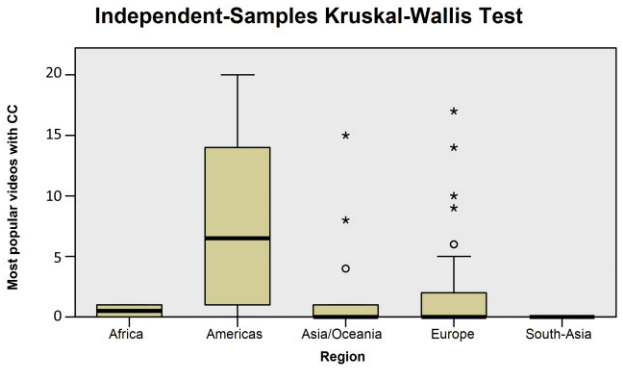

FIGURE 11. Boxplots of the distribution of the most popular videos with captions by region.

of the most published videos by the best universities in the world, as shown in Fig. 12.

To analyze the distribution of the videos with captions according to the university ranking, we also applied the independent samples Kruskal-Wallis test with 4 degrees of freedom. Concerning the newest published videos, a bilateral significance p = 0.07 was obtained. Thus, the p-value is very close to statistical significance; hence, the results are almost compatible with the alternative hypothesis (H3: The distribution of videos with captions has significant differences according to the ranking of the universities) proposed in this study. That is, the distribution of the newest videos with captions varies according to the position of the universities in the ranking. Fig. 13 shows how the median of the newest videos published with captions by the universities located in the top 200 places in the ranking is much higher than that of the universities that occupy other positions.

Concerning the most popular videos with captions, a bilateral significance Sig = 0.110 was obtained, which corresponds to the null hypothesis. In other words, the distribution of the most popular videos with captions is the same among the five ranking categories analyzed. Fig. 14 shows that there are no significant differences between the medians of each of the ranking categories analyzed.

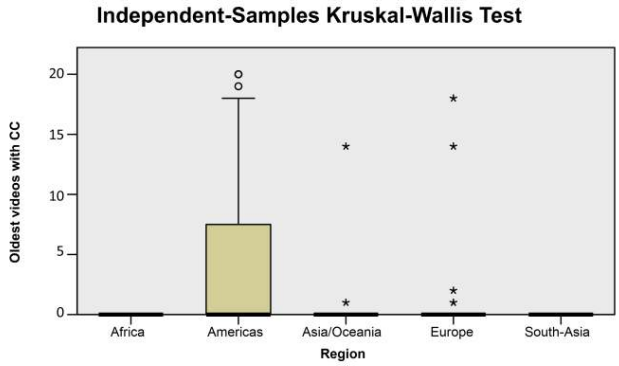

FIGURE 12. Boxplots of the distribution of the oldest videos with captions by region.

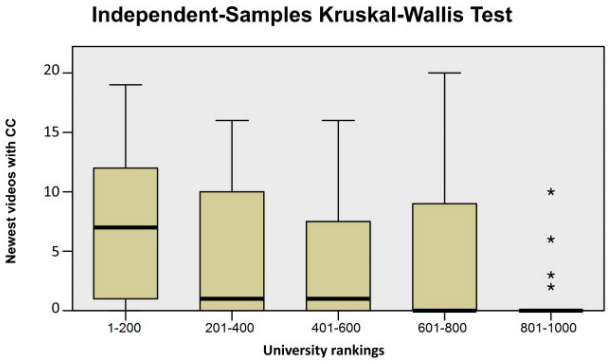

FIGURE 13. Boxplots of the distribution of the newest videos with captions by the world ranking of universities.

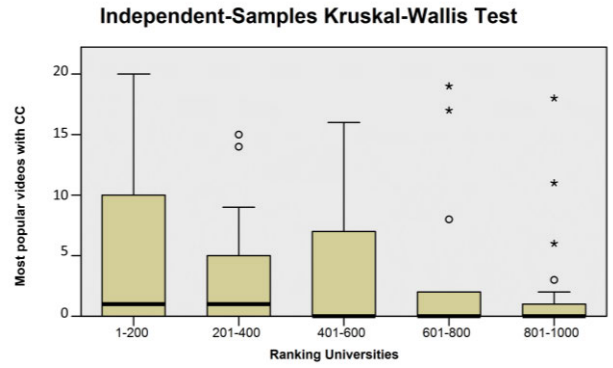

FIGURE 14. Boxplots of the distribution of the most popular videos with captions by the world ranking of universities.

The oldest videos with captions had a bilateral significance Sig = 0.862. Therefore, the null hypothesis is accepted, which means that the distribution of the oldest videos is the same in the 5 ranking categories analyzed, as shown in Fig. 15.

As an example of the analysis performed, Table 13 includes an extract of the evaluation results of the 6 success criteria of accessibility level A (1.2.2, 1.2.3), level AA (1.2.5) and level AAA (1.2.6, 1.2. 7, 1.2.8) from Harvard University. This evaluation process was carried out on the 6,780 videos published by the 113 universities that make up the sample.

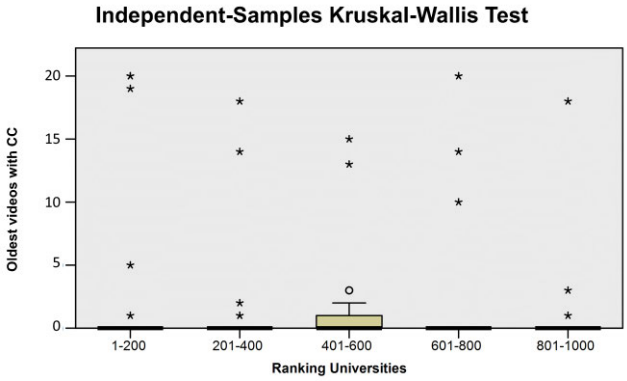

FIGURE 15. Boxplots of the distribution of the oldest videos with captions by the world ranking of universities.

TABLE 13. Accessibility evaluation of videos - harvard university.

Video	Success criteria						Compliance levels of accessibility			Errors by accessibility level		
	1.2.2	1.2.3	1.2.5	1.2.6	1.2.7	1.2.8	A	AA	AAA	A	AA	AAA
VP1	1	0	0	0	0	0	1	0	0	1	1	3
VP2	0	0	0	0	0	0	0	0	0	2	1	3
VP3	0	0	0	0	0	0	0	0	0	2	1	3
VO1	1	0	0	0	0	0	1	0	0	1	1	3
VO2	1	0	0	0	0	0	1	0	0	1	1	3
VO3	1	0	0	0	0	0	1	0	0	1	1	3
VN1	1	0	0	0	0	0	1	0	0	1	1	3
VN2	1	0	0	0	0	0	1	0	0	1	1	3
VN3	1	0	0	0	0	0	1	0	0	1	1	3

VP = Most popular videos, VO = Oldest videos, VN = Newest videos

The results show that 10 % of the oldest videos have captions, while 24 % of the most recently published videos have captions. In the case of the most popular videos, 18 % contain captions. In summary, the results obtained show that the level A criterion 1.2.2 (Captions) is met by 17 % of the videos, while the level A success criterion (1.2.3), level AA success criterion (1.2.5), and level AAA success criterion (1.2.5, 1.2.6, 1.2.7 and 1.2.8) have a 0 % accessibility compliance. Noncompliance with these criteria of success occurs because YouTube does not have implemented functions that allow users to associate sign language, audio description or extended audio description with videos. On the other hand, although YouTube offers the possibility of uploading files with textual transcription, the videos evaluated in this research counted only the interactive textual transcription generated automatically by YouTube, which is undoubtedly helpful but not sufficient to meet success criterion 1.2.3 or 1.2.8.

Compliance with success criterion 1.2.2 by region is shown in Fig. 16. It can be seen that 36 % of the videos published by the universities of the Americas region have associated captions, while 29 % of the videos posted by Asian/Oceanian universities have associated captions. Universities in Europe

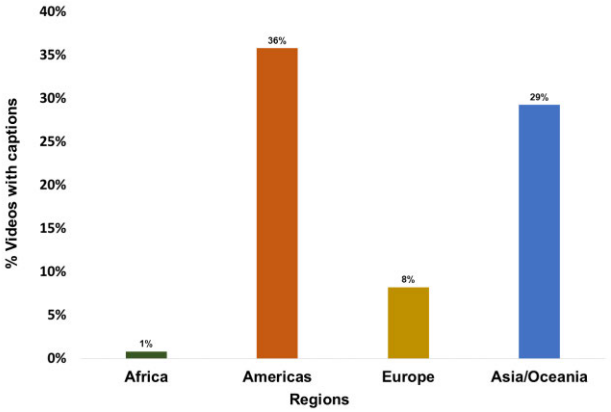

FIGURE 16. Percentage of compliance with success criterion 1.2.2 by region.

TABLE 14. Universities that achieved the highest percentage of compliance with accessibility Level A.

World Rank	Country	Region	University	TVP	C-1.2.2	C-1.2.3	C-LA
633	USA	Americas	Lehigh University	59	98 %	0 %	49 %
682	USA	Americas	University of Nevada - Reno	58	97 %	0 %	48 %
80	USA	Americas	University of California, Irvine	57	95 %	0 %	48 %
692	UK	Europe	University of Strathclyde	49	82 %	0 %	41 %
1	USA	Americas	Harvard University	47	78 %	0 %	39 %
396	UK	Europe	University of York	47	78 %	0 %	39 %
405	USA	Americas	Boston College	45	75 %	0 %	38 %
479	USA	Americas	University of North Texas	42	70 %	0 %	35 %
210	Australia	Asia/Oceania	Curtin University	40	67 %	0 %	33 %
84	USA	Americas	Brown University	35	58 %	0 %	29 %

TVP = Total number of videos with captions, C-1.2.2 = % Conformance with success criterion 1.2.2, C-1.2.3 = % Conformance with success criterion 1.2.3, C-LA = % Conformance Level A

and Africa achieve the lowest percentages of compliance with this success criterion, with 8 % and 1 %, respectively.

Table 14 shows the 10 universities that achieved the highest percentages of compliance with accessibility level A. It can be seen that 7 of the 10 universities belong to the Americas region, 2 universities to Europe and 1 university to the Asia/Oceania region.

Similarly, based on the WCAG 2.1, we consider five success criteria (1.4.2-A, 1.4.3-AA, 1.4.4-AA, 2.1.1-A and 2.2.2-A) to carry out the evaluation of the YouTube video player accessibility. The results showed that YouTube meets these criteria for success in 100 % of the cases.

V. DISCUSSION

In this research, we manually evaluated the accessibility of 91,421 videos published on the YouTube official channels of 113 universities considered among the best in the world according to the Shanghai Ranking. These videos include all those published by each university through January 29, 2020.

For these universities, the regions and countries where they are located and the dates on which they joined YouTube were identified. In the case of videos, characteristics such as the number of subscribers, number of views and number of videos shared by each university were identified. Furthermore, considering the time and effort involved in carrying out the manual evaluation of the accessibility of videos, 60 videos published by each of the universities that make up the sample were evaluated (total 6,780 videos). The 60 videos were selected under three criteria: the 20 oldest videos, the 20 most recent videos and the 20 most popular videos.

This platform was selected because 80 % of the best universities in the world according to the Shanghai Ranking use this platform to share their videos. That is, 20 % of the universities have developed a proprietary platform or use other platforms such as Vimeo, Dailymotion, Metacafe, Veoh, Youku, and Tudou (the last two used in China), among others. The massive publication of videos on YouTube could be due to the fact that it is one of the most accessed websites on the internet since its creation in 2005 [56]. However, in some countries, the use of YouTube has been blocked, temporarily or permanently, such as in Saudi Arabia, Bangladesh, the People's Republic of China, Turkey, Thailand, and Pakistan, among others [57].

The universities that occupy the first 200 places in the ranking are those that publish the greatest number of videos, their median being equal to 833; that is, 50 % of these universities have published more than 833 videos.

A. COMPLIANCE WITH WCAG 2.1 LEVEL A SUCCESS CRITERIA

The results obtained concerning compliance with success criterion 1.2.2 (Captions) are alarming because 87 % of the videos published by the 113 universities considered in this study do not meet one of the basic accessibility requirements. YouTube was created in 2005, and the first accessibility-oriented recommendations of the WAI regarding the requirement to incorporate captions in videos were published in the WCAG 1.0 in 1999 [58]. Currently, the YouTube platform offers the possibility to upload files with captions in different languages. Furthermore, YouTube includes built-in support for captions, and many videos have automatic captions generated by machine learning algorithms in English and nine other languages [59]. These captions are not perfect and can be edited to correct errors and include additional information, such as music or sound effects. In other cases, automatic captions may not even be available for certain videos, depending on the complexity of the audio [59].

The results of this study show that although only 17 % of the total videos published have associated captions, compliance with this success criterion has improved over the years. Thus, 10 % of the oldest videos have captions, compared with 24 % of the newest published videos and 18 % of the most popular videos.

It is possible that the complaints filed against some prestigious universities in the USA by organizations that defend the rights of people with disabilities to access the captions of the videos published on their websites and virtual platforms [19] may be causing these institutions to become increasingly aware of the responsibility and obligation they have to provide accessible and inclusive videos for all their students.

The results obtained for the relationship between the rankings of the universities and the fulfillment of the requirement to publish videos with captions in the case of the most popular and newest published videos could be related. Thus, we accept the hypothesis proposed in this study (H4: The Shanghai Ranking is a good indicator of the level of accessibility of videos published by universities considered the best worldwide).

This result differs from the results obtained in the study of 10 videos related to universities in Latin America, in which it was concluded that being in a high position in the ranking does not necessarily mean that the multimedia resources comply appropriately with the WCAG 2.1 [34]. The difference in this result could be attributed to the fact that in this study, we considered 6,780 videos published by 113 universities in 37 countries of the world, while in the study carried out on videos related to Latin American universities, we considered only 10 videos and 4 countries.

Likewise, it is important to take into account that, for the results we have obtained in this research of the accessibility of all the videos published (91,421) with captions (success criterion 1.2.2) in the case of universities in the Americas region, their compliance is 36 %, a figure that reflects the reality of North American and not of Latin American universities, which reached only 0.12 % compliance with this success criterion. This occurs because in the Shanghai Ranking and in this study of the 27 % of universities that make up the universities of the Americas, 23.4 % are North American and only 3.6 % correspond to Latin American universities.

Additionally, 23.4 % correspond to North American universities, 20.6 % are US universities and 2.8 % are located in Canada. Therefore, the results show that North American universities publish the highest number of videos with and without captions. Furthermore, the oldest videos reached the lowest percentage of accessibility compliance, which indicates that probably around 2005 (the date YouTube was created), there was a lack of knowledge of accessibility laws and standards by the university authorities, designers and developers of web content, such as the creators of the YouTube platform. Advantageously, in August 2008, YouTube implemented a feature that allows users of this platform to upload files with subtitles in different languages [60]. This feature

was implemented with the aim of reaching a broader audience that included people with disabilities [60].

On the topic of the fulfillment of accessibility level success criteria 1.4.2 (Audio Control), 2.1.1 (Keyboard) and 2.2.2 (Pause, Stop, Hide), the YouTube platform has implemented functions that allow them to be met by 100 % of videos. Success criterion 1.2.3 (Audio Description or Media Alternative), however, has 0 % compliance. This inaccessibility occurs, on the one hand, because YouTube does not allow the association of a track with the audio description of the video. On the other hand, although YouTube provides the option to upload a file with a textual transcription of the video, the videos evaluated in this study had interactive automatic transcripts (with or without timestamps) generated by YouTube. Transcripts generated by the YouTube platform contain basically the same information as do automatic captions.

B. COMPLIANCE WITH THE WCAG 2.1 LEVEL AA SUCCESS CRITERIA

For the fulfillment of success criteria 1.4.3 (Contrast) and 1.4.4 (Resize Text), YouTube allows changing the size of the captions and contrast so that these criteria are met 100 % of the time. Additionally, YouTube includes functions that allow the user to change the font family, font color, background color, background opacity, window color, character edge style, and font opacity. For the fulfillment of success criterion 1.2.5 (Audio Description, level AA), as previously mentioned, YouTube does not have this functionality, which is why the YouTube platform does not allow compliance with this accessibility requirement, which makes it a video player that is not accessible.

C. COMPLIANCE WITH THE WCAG 2.1 LEVEL AAA SUCCESS CRITERIA

Despite the fact that universities want to meet the success criteria of level AAA, i.e., 1.2.6 (Sign Language), 1.2.7 (Extended Audio Description) and 1.2.8 (Media Alternative), the YouTube platform does not have these accessibility functions implemented. Hence, the AAA accessibility level has 0 % compliance. Given these results, universities could use another video player that is accessible or develop a proprietary platform that allows them to meet all accessibility requirements.

VI. CONCLUSION

Due to the technological advancements that we are currently experiencing, we have at our disposal countless tools that facilitate the process of creating and publishing videos on the web. Unfortunately, this process can be carried out without any control over the level of accessibility of the videos. This lack of accessibility has caused millions of people around the world to have their rights of access to information, education, and inclusion violated. Therefore, web designers and developers must provide accessibility features to video content such that they are accessible to all people with disabilities. The accessibility features that have become standard and that we recommend for implementation are the WCAG 2.1 proposed by WAI of the W3C.

The level A accessibility proposed by the WCAG 2.1 is considered the minimum level that videos should meet so that people with disabilities can access information published on the web. One of the essential requirements is that videos have captions (success criterion 1.2.2). The results of this research show that only 13 % (12,257 videos) of the total videos published (91,421) by the 113 universities considered among the best in the world have captions. Another minimum accessibility requirement is to provide an audio description or alternative media to videos (success criterion 1.2.3). This requirement has 0 % compliance because YouTube does not have a function that allows uploading a track with audio description (making it an inaccessible video player) or because the evaluated videos did not have a file associated with their textual transcription. In the educational field, these results reflect the level of affectation that millions of people with disabilities face in the learning process due to noncompliance with the minimum accessibility requirements for videos. On the other hand, these results show the urgent need for university authorities to become concerned with changing this reality. The AA and AAA levels focus on the accessibility of videos, and the compliance percentage is 0 % because YouTube does not provide the possibility of associating tracks with audio descriptions or extended audio descriptions, sign language or textual descriptions from the videos. However, it should be noted that the YouTube platform has some potential; for example, voice recognition algorithms have been incorporated that allow YouTube to automatically generate captions in the original language of the video. Automatically generated captions can be edited, providing the possibility to make corrections. YouTube also offers an automatic translation service for captions into multiple languages. Additionally, the caption tracks generated by YouTube can be downloaded in different formats. These characteristics are undoubtedly very positive and beneficial for people with or without disabilities, but they do not exempt YouTube from compliance with the basic requirements established in the WCAG.

Regarding compliance with accessibility levels A (minimum), AA (medium), and AAA (high) related to video players, we evaluated five success criteria (1.4.2-A, 1.4.3-AA, 1.4.4-AA, 2.1.1-A, and 2.2.2-A), which were met by YouTube 100 % of the time. This result coincides with those offered by other previous analyses [52], [53] and supports the decision made by the analyzed universities to use YouTube as the platform for their videos. As a future work, we plan to evaluate the accessibility of the videos published by these universities on platforms other than YouTube and compare the results with those obtained in this research; in another future work, we could evaluate the accessibility of the videos in MOOCs offered by higher education institutions. Another future work could be to extend this study to all the universities included in the Shanghai Ranking as well as in other rankings such as Webometrics. Since there is still much to do to achieve

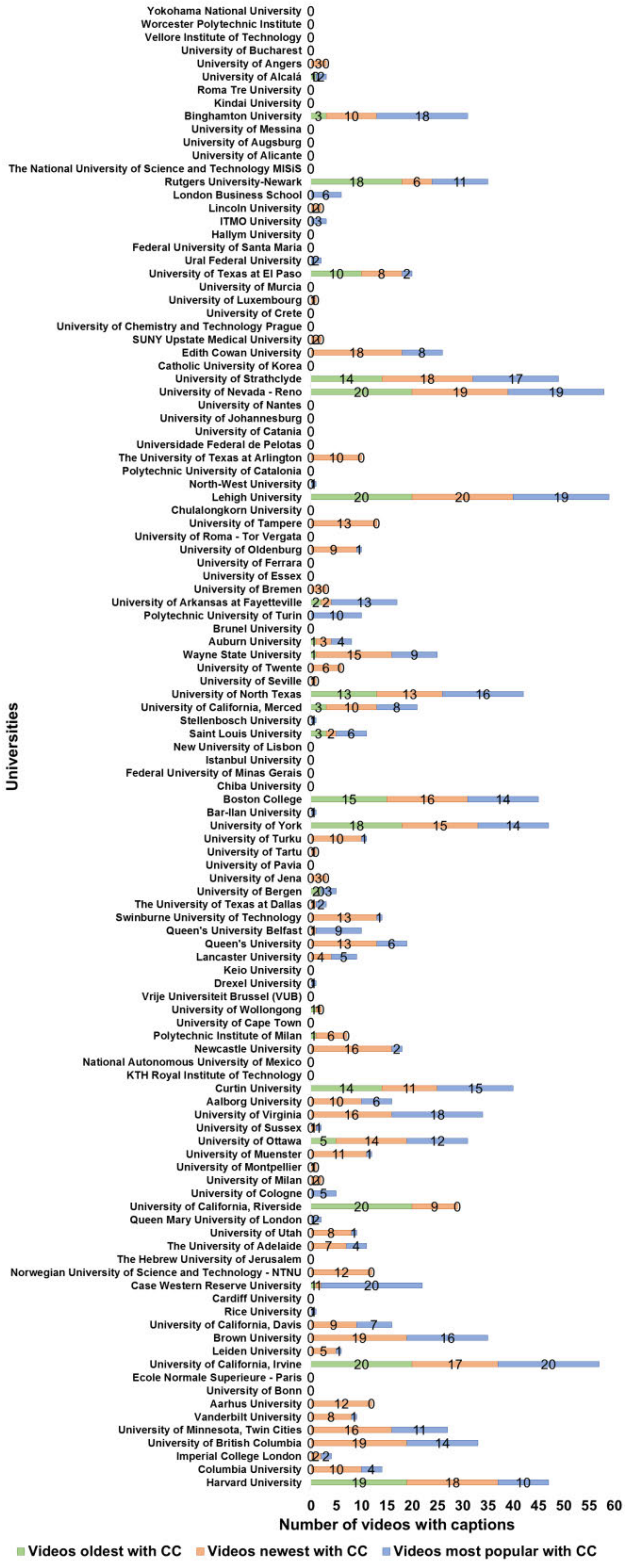

FIGURE 17. **Total numbers of the oldest, newest and most popular videos with captions.**

fully accessible videos published on the web, especially concerning the lack of captions, in another future work, we could carry out a study on the relationship and dependency that exists between the videos that have captions and their duration times. Despite the fact that YouTube is one of the most used platforms by the best universities in the world, this platform does not allow videos to meet the WCAG 2.1 level AAA accessibility success criteria. Level AA accessibility is met by 63 %. Nevertheless, currently, there is no other video player more accessible than YouTube [52], [53]. We recommend that universities join efforts to create a common but customizable platform for each university that is fully accessible to ensure compliance with the right to education established in the Convention on the Rights of Persons with Disabilities [18].

APPENDIX

Fig. 17 shows the 113 universities evaluated and the numbers of the oldest (green), newest (orange) and most popular (blue) videos published with captions. Additionally, it is seen that some universities over time publish a greater number of videos with captions in compliance with this accessibility requirement. However, it is also shown that a large number of universities do not meet this success criterion, which translates into the exclusion of people with disabilities from accessing the content of their videos.

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