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Learning ecologies in online students with disabilities

Ecologías de aprendizaje en estudiantes online con discapacidades

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ABSTRACT

E-Learning environments are enhancing both their functionalities and the quality of the resources provided, thus simplifying the creation of learning ecologies adapted for students with disabilities. The number of students with disabilities enrolled in online courses is so small, and their impairments are so specific that it becomes difficult to quantify and identify which specific actions should be taken to support them. This work contributes to scientific literature with two key aspects: 1) It identifies which barriers these students encounter, and which tools they use to create learning ecologies adapted to their impairments; 2) It also presents the results from a case study in which 161 students with recognised disabilities evaluate the efficiency and ease of use of an online learning environment in higher education studies. The work presented in this paper highlights the need to provide multimedia elements with subtitles, text transcriptions, and the option to be downloadable and editable so that the student can adapt them to their needs and learning style.

RESUMEN

Los entornos de aprendizaje en línea están mejorando sus funcionalidades y la calidad de los recursos, facilitando que estudiantes con discapacidad puedan crear y adaptar sus propias ecologías de aprendizaje. Normalmente, el número de estudiantes con discapacidad matriculados es tan residual y sus discapacidades tan particulares, que resulta difícil identificar y cuantificar qué medidas de asistencia son relevantes para este colectivo en general. El objetivo de este trabajo es hacer entender cómo aprenden los estudiantes en entornos en línea dependiendo de su discapacidad y de las características del entorno. Consistentemente, se definen cinco ecologías de aprendizaje que son más frecuentes. Este trabajo contribuye a la literatura científica en dos aspectos fundamentales: 1) identificar qué barreras se encuentran, qué herramientas de apoyo utilizan los estudiantes online con discapacidad y cómo las combinan para formar ecologías de aprendizaje adaptadas a discapacidades específicas; 2) presentar los resultados en los que 161 estudiantes con discapacidad reconocida evalúan la eficiencia y facilidad de uso de un entorno de aprendizaje online en el ámbito universitario. Se resalta la necesidad de proveer elementos multimedia con subtítulos, transcripciones de texto, y la opción de que sean descargables y editables para que el estudiante pueda adaptarlos a sus necesidades y estilo de aprendizaje.

KEYWORDS | PALABRAS CLAVE

Learning ecology, accessibility, e-learning, disability, PLE, transcripts, assistive technology, students.
Ecología de aprendizaje, accesibilidad, enseñanza virtual, discapacidad, entorno personal de aprendizaje, transcripciones, tecnología de asistencia, estudiantes.

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1. Introduction

Learning Content Management Systems (LCMS) provide access to learning content and services independently of time and location barriers. In the new paradigm of ubiquitous learning, academic services are extending their accessibility through technologies and devices (Díez-Gutiérrez & Díaz-Nafría, 2018; Tabuenca, Ternier, & Specht, 2013; Virtanen, Haavisto, Liikanen, & Kääriäinen, 2018), offering new opportunities to scaffold learning ecologies that may be especially favourable for people with disabilities (Bryant, Rao, & Ok, 2016; Perelmutter, McGregor, & Gordon, 2017). People with disabilities can eliminate barriers, thus ensuring an efficient and easy use of ICT. Exclusion from ICT applications has implications beyond remaining outside the information society, it also means being ostracized from an autonomous and independent life. Recent reports refute the fact that people with disabilities are large users of new technologies, and mobile devices in particular (Vodafone Spain Foundation, 2013; Zubillaga-del-Río & Alba-Pastor, 2013; Gutiérrez & Martorell, 2011). Educational systems have difficulties converting ICTs into learning and knowledge technologies. Therefore, it becomes necessary to guide teachers in this transition (Sancho, 2008).

Online courses are usually structured by computer engineers and hosted in LCMS. Teachers then add their subjects and activities according to the curriculum. Each teacher must have a minimum level of digital competence that allows them to enhance these sections with texts, images, assessments, videos and other multimedia content. When teaching students with disabilities, it is not necessary for every educator to become an accessibility expert. However, they should have a clear vision of the existing barriers and a general idea of how these students can make effective use of their computer (Copper, 2006). Almost everyone with disabilities can be taught how to make effective use of the computer with the help of assistive technologies provided by the operating system or specialized software (and/or hardware) (Williams, Jamali, & Nicholas, 2006).

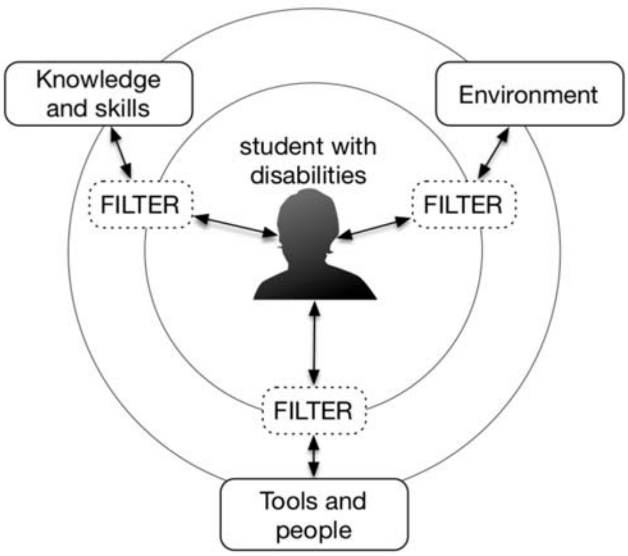
1.1. Resource ecologies in the learning context

A learning ecology is defined as the set of physical or virtual spaces that provide opportunities to learn (Barron, 2004). Jackson (2013) developed a definition indicating that the learning ecology of a specific individual includes the processes, contexts, relationships, and interactions that give rise to opportunities and resources for learning. Indeed, each person has a wide and diverse range of possibilities for training and learning, which requires individuals to take more and more control of their own learning process (González-Sanmamed, Sangrà, Souto-Seijo, & Estévez Blanco, 2018; Caamaño, González-Sanmamed & Carril, 2018).

Ubiquitous technology is encouraging students to learn how to use tools beyond the software and resources that are commonly available to teachers and students. Luckin (2008) designed the Ecology of Resources (EoR) model to cover the need to consider a broader spectrum of learning resources beyond the student's desktop. This model represents how existing tools in the student's usual context can offer new ways of assistance (Luckin, 2010). The fact that students have a wide variety of resources available is not enough. It must be ensured that for each particular environment, the resources are organized and activated in an appropriate manner for each student who may need to access them. In a learning scenario, Luckin distinguishes the following elements that make up an ecology of learning resources. This paper highlights the specialized EoR model in the context of students with disabilities (Figure 1):

- Environment. Usual learning context. For example, the desk and the computer where the student normally studies.
- Tools and people. Tools or people that (added to the usual environment) facilitate student learning. For example, headphones that facilitate adapted listening, or transcripts of videos that allow the student to read the transcripts.
- Knowledge and skills. Capacities or content that the student is interested in acquiring. For example, learning a programming language.
- Barriers or filters. They prevent access to any of the aforementioned elements. For example, in the case of a student with a hearing impairment, there are videos that do not contain subtitles or transcripts.

Figure 1. Learning ecologies online for students with disabilities



The working hypothesis is that, according to the Universal Learning Design paradigm (Meyer & Rose, 2000), e-Learning environments must provide a variety of multi-format resources in the form of accessible collections. Specifically, the objective of this study is to answer the following research questions:

- RQ1: Which learning ecologies can be identified in online students with disabilities? And more specifically, what barriers does this group encounter, and what tools do they rely on? A related work study is carried out to represent the ecologies in the EoR model (Luckin, 2010)
- RQ2: How to assess whether the support tools provided in online environments are sufficient and suitable for students with disabilities to learn. The results of a study are presented in which students with certified disabilities evaluate these tools. Furthermore, the creation of ecologies is confirmed.

1.2. Classification of learning ecologies in students with disabilities

Students with disabilities may need more than just one tool to carry out their activity in online environments. The ecologies defined here are not separate, they can combine learning objectives, environments, tools, and barriers. The classification has been made from the perspective of Copper (2006), which considers that, in general, it is not appropriate to consider medical classifications of disability when seeking to identify the means for people with disabilities to make efficient use of the computer. It is preferable to consider the person's abilities and disabilities with respect to what they should do to make more effective use of their computer, adopting a functional approach. Learning ecologies bring together the limitations suffered by people with a certain sensory limitation. This may be a visual, auditory, motor, cognitive, psychic limitation or even suffer specific learning difficulties, such as dyslexia and dysgraphia, or attention deficit hyperactivity disorders (ADHD) and autism. On many occasions the same person suffers from functional and sensory limitations of various types, the casuistry being very diverse.

Five learning ecologies can be distinguished mainly in students with disabilities based on sensory differences and the limitations that each disability presents (Carbó-Badal, Castro-Belmonte, & Latorre-Dena, 2017; Rodríguez-Martín, 2017). In presenting the ecologies, the difficulties inherent in each functional diversity are summarized. Furthermore, technological solutions are presented that help to address these barriers.

1.2.1. Learning ecology in online students with a hearing impairment (EHI)

This group comprises students who suffer from a mild hearing loss or difficulty in hearing to a substantial loss in both ears or deafness. People who wear hearing aids can be included. The barriers are mainly access to audio and video content (e.g. voices and sounds) when reproducers are not equipped to play subtitles or do not provide volume controls (Fuertes, González, Mariscal-Vivas, & Ruiz, 2005). Another barrier is enriched text without the option to adjust the text size, and colors of the subtitles, and web applications that do not allow multimodal interaction (e.g. only with a mouse, without a voice option). Below are some of the main relevant tools to provide an optimal access:

- Transcripts and subtitles of audio content, including audio-only content and multimedia audio tracks.
- Media players that display subtitles and provide options to adjust the text size and subtitle colors.
- Options to stop, pause and adjust the volume of audio content (regardless of system volume).
- High quality audio with the lowest possible background noise.
- See representation of EHI in (Tabuenca & Rodrigo, 2019b).

1.2.2. Learning ecology in online students with a visual impairment (EVI)

This category includes users with severe visual impairments, such as blindness, other moderate visual impairments, such as glaucoma or even color blindness.

People with visual disabilities need to adapt the representations of the data according to their tools. This group mainly faces barriers in accessing multimedia content when they lack adequate audio or textual transcriptions, or if they are only accessible using the mouse (ONCE, 2019). The audio description for visual content, both static (i.e. images) and dynamic (i.e. videos) is very important. In terms of formulas, the fields that are poorly arranged and not accessible by tabulators give rise to a serious difficulty in use. Similar barriers are disorganized contextual menus or menus that are inaccessible via the keyboard (Venegas-Sandoval & Mansilla-Gómez, 2010).

Below are some of the main relevant tools to provide optimal access:

- Enable an option to enlarge or reduce the size of text and images.
- Define font sizes with relative units so that the font size can be enlarged or decreased using the graphic interface options.
- Provide a link to select a high contrast color palette. It is important to provide the possibility to customize text fonts, colors and their distribution on the screen.
- The structure must be clear both for the user who can see the whole content and for anyone who accesses the information through a screen reader.
- Sections must be marked as section headings. Thus, users of screen readers can easily move between the different sections using voice synthesis (pressing the letter "H").
- The HTML and CSS code used must include formal grammars to ensure the correct display of content in different browsers.
- Provide textual transcripts for audios and videos.
- Provide audio descriptions for videos or movies.
- See representation of EVI in Tabuenca and Rodrigo (2019b).

1.2.3. Learning ecology in online students with a physical/motor impairment (EPI)

A motor disability is a series of alterations that affect the carrying out of movements. There are people with complete paralysis and others with motor difficulties in their lower limbs (difficulty in displacement) or higher (difficulty in speech or manipulation problems).

This group mainly faces barriers when using the keyboard and mouse (Sanz-Troyano, Torrente, Moreno-Ger, & Fernández-Manjón, 2010).

Below are some of the main relevant tools to provide optimal access:

- Hardware support (e.g. ergonomic keyboards, keyboard housings, one-hand keyboards, adapted mice, joystick, head pointers and stylus integrated into caps or helmets, mouth rods, page turning devices, armrests, supports and mechanical stands).

- Software support (e.g. predictive virtual keyboard, voice recognition programs and transcribers, digital recorder).
- Provide the student with extra time to complete oral / written activities or assessments.
- Mechanical elements and adaptations in keyboards and mice or pointing pencils.
- See representation of EPI (Tabuenca & Rodrigo, 2019b).

1.2.4. Learning ecology in online students with mental impairment (EMI)

People with mental disabilities are characterized by alterations in cognitive and affective processes. This group faces barriers related to information reasoning and communications skills (Cuesta & Ramos, 2012). The lack of specific information or ambiguous statements can cause a lot of anxiety in these students. They can suffer alterations in their reasoning, difficulty in recognizing reality, processing information, difficulties in adapting to a specific environment, and elaborating contextualized information. They may suffer paranoia or stage fright, which reduces their ability to communicate. They may even suffer cognitive limitations. The pharmacological treatments they receive can affect their attention span, concentration, memory, verbal and written comprehension, and the management of information.

Below are some of the main relevant tools to provide optimal access:

- Provide precise instructions for carrying out the assessment tests and exam modalities.
- Make flexible delivery deadlines for assignments and evaluation tests.
- Use simple and illustrative iconographies with bright colors and simple shapes that help their understanding and memorization.
- Offer alternative types of evaluation tests (e.g. multiple-choice questions or short questions). This adaptation should ideally not affect the evaluation of the skills required to pass the course.
- See representation of EMI in (Tabuenca & Rodrigo, 2019b).

1.2.5. Learning ecology in online students with specific attention or hyperactivity difficulties (EAD)

There is a group of disorders connected with significant difficulties in the acquisition and use of reading and writing, or attention deficits. They are usually caused by neurological alterations or dysfunctions that affect perceptual, psycholinguistic processes, working memory and strategies of learning and meta-cognition (Romero & al., 2005). Dyslexia (difficulty reading) may exist in isolation, but it is usually accompanied by dysgraphia (difficulty in writing), as both processes are cognitively linked.

On the other hand, attention deficit hyperactivity disorders cause dysfunctions in the mechanisms of executive control and behavior inhibition, which directly affects work memory, concentration, the self-regulation of motivation, the organization of tasks, the internalization of language and the processes of analysis and synthesis (Faraone, Biederman, & Mick, 2006).

In general, all of the disorders explained here can give rise to greater impulsiveness, lack of concretion in completing tasks. Consequently, they may have greater possibilities of failing answers as they usually present poorly readable spelling, crossings out and a lack of organization in their ideas. Below are some of the adaptations that might help these students:

- Computer or tablet with assistive apps, and digital recorders.
- Text-to-speech conversion software (which read, for example, the texts on the computer screen or mobile devices).
- Provide extra time to complete individual activities (e.g. tasks, assignments).
- Receive contextual information of what is being displayed in the blackboard or any presentation document. The instructor must make an extra effort to verbalize aloud what he is pointing at in each moment.
- See representation of EAD in (Tabuenca & Rodrigo, 2019b).

This work is structured as follows: In this first section, RQ1 has been addressed by classifying learning ecologies according to each particular disability, with the aim of clearly identifying the needs to be taken into account when creating learning contents and structuring them in adapted LCMS.

In the next section, RQ2 is addressed by presenting an evaluation study of an online learning environment and its support tools. Section 3 presents the results of the study from the perspective of

161 students with certified disabilities. Finally, in section 4 the conclusions are presented based on the results obtained.

2. Method

This study uses the Technology Acceptance Model (TAM) as a reference to explore how users accept and use technology (Davis, Bagozzi, & Warshaw, 1989). This tool is effective in predicting the acceptance of systems by users (Robles-Gómez & al., 2015). The model has been extended by adding constructs to complete it with additional psychological factors related to the use or intention to use the system: an e-learning system (Liaw, 2008), online lifelong learning (Suh & Lee, 2007), digital skills and Internet (Yi & Hwang, 2003), online social networks (Liu, Chen, Sun, Wible, & Kuo, 2010), cognitive absorption (Venkatesh, 2000), etc.

However, there are no previous models measuring the acceptance of a technological system by exploring its accessibility features. This study proposes to explore improvements in accessibility that influence the willingness to use a specific technological system. In this case, the system is a repository of e-learning audio-visual resources at UNED (CadenaCampus). CadenaCampus allows live broadcasting from the university's videoconference classrooms. There are more than 700 classrooms equipped with video-conference studios. They provide the option of connecting with users via chat and shared desk. The system is integrated into the university's LCMS and also functions as an external repository. The portal features a tagged semantic structure with specific metadata to enable content searches with different criteria.

Table 1. Socio-demographic stats

Current status	n	%
Studying	64	43.84%
Employed	54	36.99%
Pensioner	45	30.82%
Unemployed	25	17.12%
Self-employed	5	3.42%
Current studies		
Social sciences, trading & law	53	36.99%
Humanities & arts	32	21.92%
Health & wellbeing	26	17.81%
Education	21	14.38%
Sciences	13	8.90%
Engineering, industry & construction	10	6.85%
Services	5	3.42%
Agriculture	1	0.68%
Type of disability		
Reduced handling capacity and strength	78	53.42%
Limited cognitive capacity	26	17.81%
Limited vision	26	17.81%
Limitation in the ability to hear	21	14.38%
Limitation in the ability to hear	6	4.11%
No vision	4	2.74%
No ability to hear	2	1.37%
No colour sensibility	0	0%
Disability recognized by the Spanish government*		
Between 33% and 65%	102	69.86%
More than 65%	38	26.03%
Did not answer	5	3.42%
Did not know	1	0.68%

*optional answer.

This study aims to identify which learning ecologies students with disabilities actually use, assessing the accessibility of the resources provided by the CadenaCampus system and focusing on two key characteristics: 1) The accessibility of the content search engine; 2) The accessibility of the audio-visual content player. The following constructs have been added to measure the degree of acceptance and use of resources that improve system accessibility:

- Availability of textual transcriptions.
- Availability of subtitles.
- Availability of subtitled videos.
- Audio availability.
- Availability of the option to download the aforementioned elements to use in offline mode.
- Semantic labelling to support the search system and recommendation of educational resources.

2.1. Participants

At the end of the academic year an email was sent to the students with recognized disabilities (n=7,397) in which they were invited to evaluate the accessibility characteristics of the CadenaCampus system. A total of 161 students agreed to participate in the study by accepting informed consent.

The participants in this study were people with recognized disabilities (assigned to the student attention services department for students with disabilities at the university), with an average age of 46.2 years old (SD=11.06), 51.37% being men.

The sociodemographic results (Table 1) confirm that people with disabilities usually have more than one disability due to the diseases or accidents suffered. The most frequent disabilities are reduced manipulation and strength (EPI), limited cognitive ability (EMI), limited vision (EVI), and limited hearing ability (EHI). A large part of the respondents was studying (43.84%), but many others were working as employees (36.99%), were pensioners (30.82%), or unemployed (17.12%).

These data are consistent with the current status of the group of people with disabilities issued in Spain that reflects that this group is poorly integrated into the labor market (Jiménez-Lara & Huete-García, 2018).

2.2. Materials

The self-developed questionnaire was shared with students using a link to an accessible online platform. The wording of the questions (ease of reading and being understood) was reviewed and contrasted by three university academics, experts in the areas of psychology, sociology and technological accessibility. Two technicians with motor and mental disabilities respectively, and an external collaborator with poor vision participated in the writing.

The level of accessibility to the online questionnaire was automatically validated with the TAW tool (Web Accessibility Test) and manually validated by a blind collaborator associated with this research group. The questionnaire is shared in Tabuenca & Rodrigo (2019b) and the results are shown below.

3. Results

3.1. Compliance with audio-visual recordings

The first question explored the degree of student satisfaction with specific characteristics of video and audio recordings, which are very beneficial resources for groups with disabilities (Table 2). Cronbach's alpha was calculated to obtain a good internal consistency (α=0.91).

Table 2. Satisfaction with audio-visual recordings (n=113)

Feature	Very satisfied (5)	Satisfied (4)	Neutral (3)	Unsatisfied (2)	Very unsatisfied (1)	M	SD
Quality	24(21.24%)	47(41.59%)	15(13.27%)	18(15.93%)	9(7.96%)	4.4	0.91
Usefulness	32(28.32%)	50(44.25%)	15(13.27%)	11(9.73%)	5(4.42%)	3.82	1.08
Accessibility	26(23.01%)	51(45.13%)	16(14.16%)	12(10.62%)	8(7.08%)	3.66	1.15

The results were satisfactory despite the recordings being produced by inexperienced users in communications, both live and without post-production.

Table 3. Specific features in audio-visual materials (n=109)							
Usefulness of tools (n=109)	Extremely useful (5)	Very useful (4)	Neutral (3)	Slightly useful (2)	Not at all useful (1)	M	SD
Downloadable videos	85(77.98%)	11(10.09%)	12(11.01%)	1(0.92%)	0(0%)	4.65	0.71
Downloadable audios	80(73.39%)	14(12.84%)	13(11.93%)	1(0.92%)	1(0.92%)	4.56	0.80
Downloadable transcripts	71(65.14%)	18(16.51%)	18(16.51%)	2(16.51%)	0(0%)	4.45	0.83
Literally translated transcripts	54(49.54%)	36(33.03%)	17(15.60%)	2(1.83%)	0(0%)	4.30	0.79
Audio-visual materials enriched with transcripts	52(47.71%)	37(33.94%)	18(16.51%)	2(1.83%)	0(0%)	4.27	0.80
Audio-visual materials enriched with subtitles	54(49.54%)	30(27.52%)	19(17.43%)	5(4.59%)	1(0.92%)	4.20	0.95
Ease to use supporting tools (n=110)	Extremely easy (5)	Easy (4)	Neutral (3)	Difficult (2)	Extremely difficult (1)	M	SD
Accessible & easy to find download-video-feature	41(37.27%)	35(31.82%)	18(16.36%)	11(10%)	5(4.55%)	3.87	1.15
Accessible & easy to find download-audio-feature	39(35.45%)	35(31.82%)	18(16.36%)	12(10.91%)	6(5.45%)	3.80	1.19
Accessible & easy to find download-transcript-feature	36(32.73%)	36(32.73%)	22(20%)	11(10%)	5(4.55%)	3.79	1.14
Accessible & easy to find subtitles in audio-visual materials	27(24.55%)	40(36.36%)	27(24.55%)	10(9.09%)	6(5.45%)	3.65	1.11
Accessible & easy to find transcripts in audio-visual materials	28(25.45%)	37(33.64%)	26(23.64%)	15(13.64%)	4(3.64%)	3.63	1.11

3.2. Textual transcriptions as a support tool

Textual transcripts are very important for deaf people, people with cognitive deficits, and old people. They are an intermediate product for subtitling and facilitating the production of abstracts and concept maps easily.

In this case, the transcripts were provided to students as a learning resource and can be downloaded to be used offline. To the question "Do you think that the transcripts helped you to acquire the knowledge better?", 85.5% answered affirmatively (n=113).

Table 4. Most frequently searched terms on disability (n=113)							
Term	Never (5)	(4)	(3)	(2)	Frequently (1)	M	SD
Accessibility	20	18	23	19	20	2.99	1.41
Accessible	22	15	26	13	24	2.98	1.46
Disability	17	15	27	18	23	2.85	1.38
Adaptation	14	19	26	15	26	2.80	1.38
Adapted	14	15	27	15	29	2.70	1.39
Transcript	8	18	21	16	37	2.44	1.35
Functional diversity	12	13	18	20	37	2.43	1.40
Transcribe	8	18	20	16	38	2.42	1.36
Subtitled	8	12	24	15	41	2.31	1.33
Diverse functional	7	13	15	20	45	2.17	1.31
Subtitle	4	12	22	16	46	2.12	1.23
Re-talked	4	10	20	19	47	2.05	1.20

3.3. Usefulness of the support tools

Students with disabilities may require more time to visualize, listen to and process the information. They appraise very positively the availability of resources in download mode to be able to work with these elements more quietly and offline (Table 3). Cronbach's alpha was calculated to obtain a good internal consistency (α=0.89).

3.4. Ease of use in the support tools

Resources in CadenaCampus are visually arranged next to the corresponding video with an iconography designed for this purpose and including contextual information. This question explores the ease of identifying audio-visual materials and their option to download files (Table 3). Cronbach's alpha was calculated demonstrating good internal consistency (α=0.94).

3.5. Folksonomy of accessibility

Students with disabilities (like any other student) use search engines to find learning objects adapted to their specific needs. These platforms add metadata to learning objects to make them easier to find by using certain terms. In this research, we have explored the possibility of enriching metadata with terms related to the accessibility of resources. Several experts identified 12 folksonomy terms that could be used to allocate resources in specific formats, taking both the (infinitives and participles of the) verbs and the most similar nouns (Table 4). For each of the terms, students were requested to indicate how often they used them. In addition, they were offered the option of reporting an additional term.

The results confirm the suitability of using a social indexation by means of simple labels on a flat namespace, without predefined hierarchies or kinship relationships. Likewise, they confirmed the use of the terms previously identified by the experts. Alternative terms suggested by the participants of the group studied were "inclusive", "audiobook", "outline", "summary", "video-class", "functional diversity", "exams" and "download". The indexation of learning objects with these metadata implies a valuable support tool for educators and designers when embedding learning objects in any LCMS.

4. Discussion and conclusions

Educators and designers of educational content should have an overview of how students with disabilities can use a computer and what technological tools facilitate the construction of learning ecologies according to their limitations. In this work, five learning ecologies for online students have been set out, classifying them according to the type of disability (RQ1): students with hearing impairment, visual impairment (EVI), physical / motor disability (EPI), psychic disability / mental disorder (EMI), and students with specific attention difficulties or hyperactivity (EAD) (Section 1.2). Inspired by the model proposed by Luckin (2010), we have identified barriers and support tools that can help students with disabilities in their learning activities.

In this work, 161 students with recognized disabilities have evaluated some of the support tools based on their experience throughout their university course. The results confirm that the system being studied includes all the elements raised by Luckin (2010) as necessary to satisfy an accessible and quality learning environment (RQ2). To corroborate these conclusions, the main tools and the access barriers are summarized below:

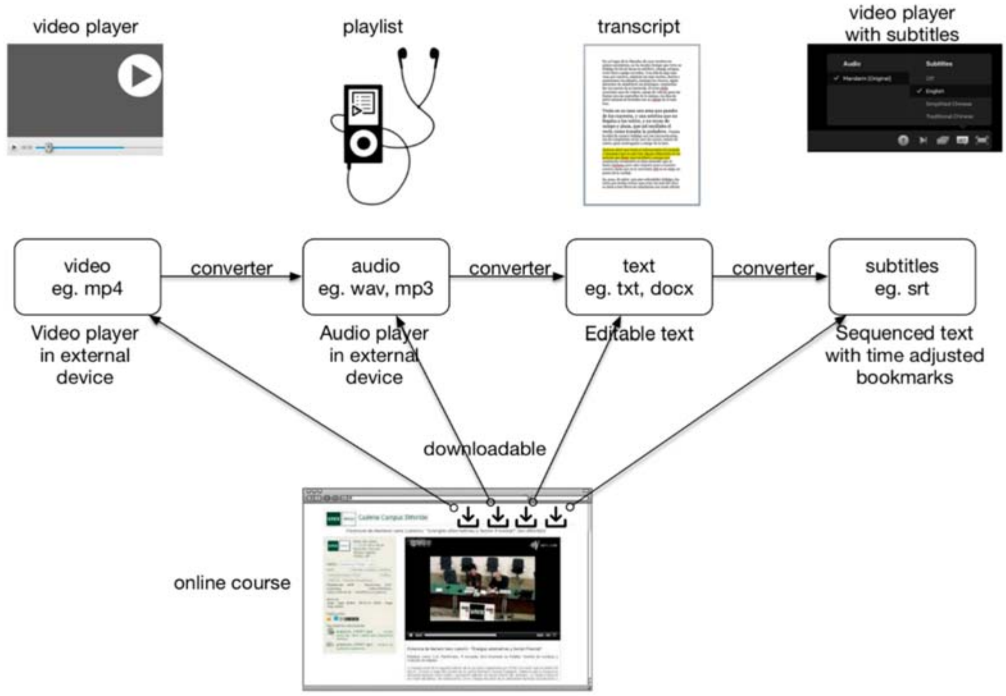
- Audio-visual recordings. This is one of the main elements in e-learning environments. It was commonly defined in all ecologies (EHI, EVI, EPI, EMI and EAD). The assessment obtained has been good in terms of accessibility, quality, and usefulness of the recordings offered (Section 3.1).
- Textual transcripts. They are essential, not only for students with hearing problems (EVI), but also as an element of assistance for any student. They can be modified to create summaries, concept maps, or to add notes with comments and doubts. 85% of the participants confirm this assertion (Section 3.2).
- Textual enrichment of audio-visual elements through transcriptions and subtitles. This feature supports students with both hearing and visual impairment (EHI and EVI). Participants rated transcripts more positively followed by subtitles. Likewise, they rated very favourably that the transcripts fitted literally with what the teacher had said.
- Downloading materials. This feature allows students to customize contents and organize their study without sequencing or depending on an Internet connection. This tool is key since 53% of the students had reduced handling capacity (EPI), and 21% had some visual limitation (EVI). The LCMS under study offered different support tools to students with disabilities.

The results show that downloading videos was the support tool they found in an easier and more accessible way (M=3.87), followed by audio download (M=4.56), downloading transcripts, and finally the subtitles (Section 3.4).

With all of the aforementioned, the results reinforce the working hypothesis. Learning environments must have a wide variety of related multi-format resources in the form of accessible collections (Meyer & Rose, 2000). With the convenient semantic labelling and a good profile of registered users, the systems can offer each student the resources that best suit their needs (González-Sanmamed & al., 2018).

Figure 2 illustrates a holistic representation that includes the main support tools, how they can be extracted from each other, and what associated interface the student with disabilities can use in their learning.

Figure 2. Tools to support students with disabilities in online environments



The results presented in this study are exploratory and should be taken with caution as they are based on a sample of 161 out of 7,397 students with recognized disabilities. Important aspects such as the assessment of the effect on gender learning and age that have been included as tasks for future work have been omitted from this study.

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