Towards Truly Accessible MOOCs for Persons with Cognitive Impairments: a Field Study

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Highlights

What we already know about this topic

- The Convention on the Rights of Persons with Disabilities is an essential framework for promoting social inclusion, particularly with regard to the promotion of equal access to education.
- Education access is a critical lever for everyone's future, and especially for disabled people.
- There is a huge need for accessible MOOC players for people with cognitive impairment. This point was strongly reinforced by the COVID crisis.

What this paper adds

- Built from participatory design methods, a new accessible MOOC player is assessed with a field study (N=546) without equivalent in the literature, including learners with and without disabilities.
- Early interaction (with accessibility features), participation, learning and learner experience were assessed during MOOC sessions.
- Both Learning Analytics and self-rating scores confirm our contribution to designing a more inclusive e-learning environment and providing a solid base to improve the accessibility assessment methodology for MOOCs.

Implications for practice and/or policy

- Providing an accessible MOOC player is key to the inclusion of people with disabilities in distance and online learning.
- More research efforts and legal obligations are needed to narrow the digital divide between ordinary and extra-ordinary learners.

ABSTRACT. Massive Online Open Courses (MOOCs) should offer lifelong education opportunities for persons with disabilities. However, most of the current MOOCs are not fully accessible, especially for persons with cognitive impairments and limited learning capacities. To bridge this gap, we have developed an accessible MOOC player following a participatory design process and used it to deliver a course on a mainstream MOOC platform. In this article we describe a field study to evaluate the impact of the player's accessibility features on the learning experience of persons with disabilities. Following a mixed method approach, we first present the results of a quantitative assessment done with Learning Analytics methods to study the impact of the player on the retention of students with disabilities. Then we present the results of a questionnaire assessment to study the global experience of students in terms of learning performance, usability of the MOOC player, perceived cognitive load and self-determination. Both Learning Analytics and questionnaire -related results confirm our contribution to designing a more inclusive e-learning environment and providing a solid base to improve the accessibility assessment methodology for MOOCs.

KEYWORDS: Distance education and online learning ; Human-computer interface ; Special needs education ; Massive Open Online Courses ; Cognitive impairments

INTRODUCTION

The Convention on the Rights of Persons with Disabilities (PWDs) is an essential framework provided to the signatory States for improving their social inclusion, particularly with regard to the promotion of equal access to education (UN, 2017). It promotes their full participation in education systems, enabling them to define their professional project and, ultimately, to make their own choices in all areas of their lives (Ryan & Deci, 2000). It is well recognized that education is a decisive factor in shaping life-course and employability. Yet across the world, PWDs experience significantly lower employment rates than persons without disabilities, and when they are employed, have fewer opportunities to grow and develop their careers within a company or to evolve professionally in the job market (Hästbacka, 2016). One of the reasons given by both PWDs and employers is that they still face barriers to access education, and therefore have fewer professional qualifications than the general population (WHO, 2011). These difficulties are even more significant for individuals with mental health difficulties or cognitive impairments (e.g., memory disorders, attention disorders) who experience the lowest employment rates (Thornicroft et al., 2010) and are most often employed in a segregated environment (Verdonschot et al., 2009).

The overall objective of our work is to further increase the access to education for PWDs, notably those with cognitive impairments (regardless of medical conditions)[1], through new e-learning systems, to contribute to their professional and social inclusion. We focused primarily on MOOC (Massive Open Online Courses) platforms, which are playing an increasingly important[2] role in the academic and lifelong vocational training programs offered to the general population, and which are still growing strongly (Shah, 2019). Moreover, they are sufficiently flexible and adaptable to potentially ensure that content can be made accessible to as many learners as possible and that pedagogical approaches adapted to people with cognitive impairments can be used to support their learning.

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1 According to International Classification of functioning (WHO, 2001), a functional definition of disability is adopted in which the medical condition or etiology is not essential to focus on the three functional dimensions of disability, i.e., the observed deficiencies/impairments, the activity limitations and the social participation restrictions. Therefore, the disabilities related to cognitive impairments pertain a large set of neurological conditions from mental diseases (schizophrenia, bipolar disorders, depression, etc.) to cognitive syndromes due to acquired cerebral lesion (i.e., strokes, tumors, traumatic brain injuries) or neurodevelopmental (autism, ADHA, etc.) or degenerative diseases (Parkinson's or Alzheimer's disease, etc.)

2 The COVID crisis has reinforced the importance of this kind of solution.

MOOCs Accessibility

Like most online learning systems (Cinquin et al., 2019), MOOCs suffer from a lack of accessibility, which hampers the full participation of PWDs, who are therefore excluded. While sensory and motor deficits are beginning to be considered in the design of MOOC platforms, there is a paucity of results for cognitive impairments (Cinquin et al., 2019; Sanchez-Gordon & Lujan-Mora, 2018).

Several studies illustrate the accessibility issues of MOOCs. Bohnsack and Puhl (2014) showed that most MOOC platforms lack correct language markers or accessible design. Iniesto and Rodrigo (2014) used automatic tools and a visual disability simulator to analyse the educational resources of three Spanish MOOC platforms and showed significant shortcomings in terms of accessibility (e.g., absence of links for navigation, misuse of headings, images without alternative text). Sanchez Gordon and Lujan-Mora (2013) evaluated the accessibility of five Coursera courses for elderly users. They identified twenty-nine web accessibility requirements related to older users' needs. They reported that both the courses and the platform have accessibility issues that prevent elderly users from benefiting from them. In order to improve the accessibility of MOOCs, they emphasize the need to raise awareness of the web accessibility requirements of elderly users among content authors and to provide them with techniques to avoid common failures. Similar findings have been reported more recently (Martin et al., 2016; Acosta et al., 2019). All of these studies highlight the lack of consideration for accessibility in the design of MOOCs, preventing PWDs from benefiting from these new educational platforms, in contradiction to the claim that they are open to everyone.

Some projects try to overcome this lack of accessibility by offering adapted frameworks and plugins for MOOC platforms revealing an evolution in the design of MOOC systems, shifting from a technology to a human-centered approach (e.g., Boticario et al., 2012; Sanchez-Gordon et al., 2015). This shift towards user-centered design strategies for MOOCs can also be found in the study of Mendoza González and Alvarez Rodriguez (2016). They proposed the use of semi-transparent layers on top of the actual MOOC interface to assist cognitive-impaired learners by giving them indications on how to interact with the different elements of the interface using simple phrases and explicit interactions.

Challenging the evaluation methodology for MOOC Accessibility

As a direct consequence of the paucity of research on the accessibility of MOOCs, there are no concrete guidelines to guide its evaluation. As a matter of fact, Iniesto and colleagues (2017) have shown that most studies tend to limit their scope to just one single type of disability (e.g., vision impairment) or to focus on a specific platform. Moreover, the accessibility assessments they present usually follow a single methodological approach, either quantitative or qualitative, and thus are not sufficient given the complexity of the issues related to MOOCs (Gasevic et al., 2014).

As MOOCs are built upon web technologies, they are generally assessed through the scope of web accessibility. Yet, as Sanchez-Gordon and colleagues (2015) have shown, there is still no clear agreement on its definition. As a result, its assessment is still limited to compliance with standards and guidelines (W3C, 2021) through automatic tool validation or expert review. Although these methods are useful for highlighting some of the more common issues, several studies have shown that their validity and reliability are often overestimated (Brajnil et al., 2012; Power et al., 2012). As already mentioned above, accessibility issues need to be addressed at an individual level as overly generic approaches can overlook specific needs.

User-centered approaches for the design of complex websites such as MOOC platforms encourage a more holistic view of accessibility. Usability, which is a well-established concept in human computer interaction design (Caroll, 2003), is therefore a relevant measure to assess accessibility (Petrie & Kheir, 2007). In our context, its evaluation ensures that accessibility features can be used by individuals with cognitive impairments to achieve learning goals with effectiveness, efficiency and satisfaction in a MOOC context (ISO, 2019). Indeed, while instructional objectives are clearly specified by teachers, learners can engage in a MOOC for a wide range of different reasons (Iniesto et al., 2017). A high level of engagement is a fundamental goal to be achieved, especially for PWDs whose attrition rate is generally high in distance learning situations (Cooper et al., 2016).

It is well known that improving the intrinsic motivation of learners can lead to a decrease in their attrition rate when using online learning platforms (Zahed-Babelan & Moenikia, 2010). This is even more true in the case of PWDs, where the lack of accessibility can lead to a bigger effort to self-regulate their learning. In this perspective, the Self-Determination Theory (SDT, Deci & Ryan, 2004) has been proven beneficial in e-learning situations (Roca & Gagné, 2008) and is also considered to be a reliable indicator for technology acceptance (Lee et al., 2015). This theory refers to the psychological mechanisms involved in intrinsic motivation and autonomous decision-making that play a critical role in the perceived quality of life. The SDT proposed that three basic psychological needs, namely competence, autonomy and relatedness, are either supported or challenged by social contexts (Wehmeyer et al., 2017). In the recent reconceptualization of SDT, known as the Causal Agency Theory, evidence is provided that the more self-determination a person has, the more likely they are to identify their strengths and weaknesses, leading to an improvement in their perceived autonomy and competence. It is important to note that these causal relationships are increased in people with cognitive impairment (McDougall et al., 2010; Wehmeyer & Shogren, 2016; Wehmeyer et al., 2017). For instance, research has found self-determination to be positively related to both employment and independence for individuals with learning and developmental disabilities, one and 3 years after graduation (Wehmeyer & Palmer, 2003). As Wehmeyer and Schalock (2001) have explained, for youths with learning and cognitive impairments, being self-determined is a critial lever for causing things to change to accomplish a specific end ; and as a result, such process of agency supports the optimization of quality of life, particularly for persons with cognitive impairments. Accordingly, the evaluation of MOOC accessibility should take into account the feeling of autonomy and competence, as well as the relatedness with regard to the community-based dimension promoted by MOOC platforms.

Learning Analytics for accessibility

If improvements in student retention has always been a hot topic in MOOC Learning Analytics (Hone & El Said, 2016), few studies have taken into account disability and accessibility. This is a significant omission as several studies have demonstrated that disability can be a significant factor in academic and MOOC attrition (Cooper et al., 2016; Lipka et al., 2020; Murray et al., 2000). Cooper and colleagues (2016) tried to move forward the field of Learning Analytics by studying the retention rates of disabled and non-disabled students. To this end, they performed a comparison between the odds ratios of completion rates of disabled and non-disabled students for 1338 learning modules from the Open University. Their results made it possible to determine the reliability of this metric as a measure of accessibility and demonstrated how Learning Analytics can improve the field of e-learning accessibility.

Since video lectures are one of the main media used for delivering MOOC content, analyzing video interactions has also received a lot of attention (Seidel, 2017). Video-based

Learning Analytics is used to study a macro-level of learning activity with the use of metrics such as the number of videos watched (Anderson et al., 2014), the time a student is engaged (Guo & Reinecke, 2014) or student navigation styles (Guo et al., 2014). A more in-depth level analysis can also be used for MOOC instructors to closely examine how a student interacts with each video lecture, e.g. what types of video interactions are performed, when they happen and how intense they are (Kim et al., 2014). This can help to determine if students are encountering any issues for a particular part of the course (Sinha et al., 2014), and in the end present MOOC content providers with opportunities to improve students' learning experience. Unfortunately, the video players involved in the above-mentioned studies are all mainstream players, and few research articles discuss accessibility issues.

All the above Learning Analytics based studies use indirect measures of MOOC accessibility. Indeed, the possible outcomes of low technology accessibility are dropouts and a low level of interaction with video materials. Direct Learning Analytics measures of accessibility could be the tracking of use behaviors of accessibility features available into technology. According to the Rogers' theory of diffusion (Rogers, 1995) which offers a comprehensive view regarding the processes involved in accepting or discontinuing use of technology, prior trialability is a key dimension for the continued use of technology, particularly for PWDs (e.g., Parette & VanBiervliet, 1992; Riemer-Reiss & Wacker, 2000). Trialability is the degree to which the user has prior use experiences with the technology for its long-term adoption. From this key concept, it could be assumed that first experiences of accessibility features in a MOOC player are decisive for continuing the MOOC in PWDs. In other words, the PWDs who fully complete the course should exhibit greater use behaviors of accessibility features from the first minutes of interaction with the MOOC player compared to PWDs who have discontinued. Consequently, it is likely fruitful for Learning Analytics -related accessibility purpose to track the early uses of accessibility features (i.e., interaction logs), in particular for detecting MOOC dropout risks in PWDs.

Design of an accessible MOOC player (AMP)

As the overall objective of our work is to further increase the access to education for PWDs through new e-learning systems, we have initiated a research program aimed at enhancing the accessibility of MOOCs, with a particular focus on persons with cognitive impairments. To achieve this objective, we have firstly chosen to adopt a multidisciplinary approach and engage PWDs as stakeholders, involving them throughout the design, tests and field-study evaluation of the proposed solutions. In line with user-centred design approaches (ISO, 2010) the participatory process was initiated with a requirement elicitation phase to clarify the context of use and specify user needs and preferences (Cinquin et al., 2020). We held meetings with specialists from various fields of expertise (including experts in multimedia learning and MOOCs, special education, human factors, accessibility and assistive technologies), and conducted interviews with university students with cognitive impairments (i.e., ADAHD, dysexecutive syndrome, dyslexia, schizophrenia, *etc.*).

From the needs, guidelines and co-design sessions, a first prototype of an accessible MOOC player was developed and evaluated in a multiple-case study. The results and discussions helped us to identify problems that we were not aware of, allowing us to improve the design in the next iteration, and refine the experimental protocol in a small scale environment ahead of a larger field study. Finally, ideas selected at the end of the all processes were implemented into a first version of AMP, our MOOC player (see Figure 1) .

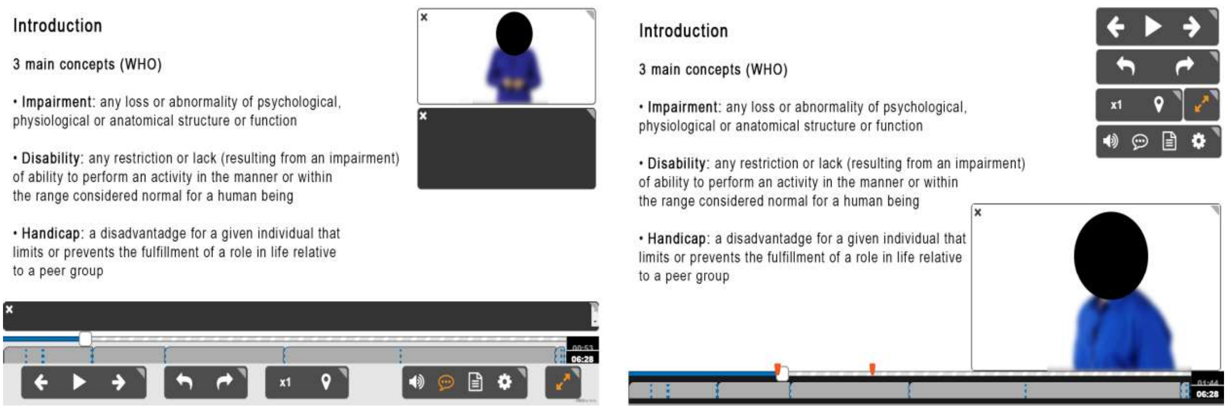

Figure 1: Two configurations of AÏANA

The design of AÏANA was based on a fundamental principle: *the fragmentation of pedagogical content into independent elementary streams* (e.g., video, audio, subtitles, *etc.*) synchronized in time. This change in content organization has allowed us to define a set of self-configuration features for users to dynamically configure their learning experience according to their wishes and abilities:

- **Selection of useful streams:** Users can configure their work space by selecting the streams they want to watch, read and listen to.
- **Spatial organization:** Users can either keep a default layout or modify it as they please. They can resize and move each of the content element windows.
- **Profiles management:** The layout configuration is automatically saved on the server-side and proposed as an individual user profile. If a user's needs evolve due to personal or contextual changes, they can reconfigure the player interface accordingly and save it as a different profile.
- **Social learning:** Users can export their profile and therefore share it, for instance with people who have disabilities close to their own. On a voluntary basis, this could contribute to strengthening the social bond between learners and promote the emergence of a supportive community.

All the modifications can be made at any time (before starting or during perusal) and can be renewed whenever users wish to do so.

The main goal of these self-configuration features is to enhance task-relevant information, especially crucial to people for whom little information can be processed such as in cases of cognitive slowing-down or decrease in divided-attention, sustained attention or higher-level cognitive functions as described in ICF-CY (WHO, 2007), and covering executive functions involved in complex goal-directed behaviours such as decision-making, abstract thinking, planning and carrying out plans, mental flexibility, and deciding which behaviours are appropriate under what circumstances (e.g., time management, cognitive flexibility, inhibition, judgement, *etc.*). By offering the user the possibility of customizing the layout himself, these features can enhance the user's perception of self-determination, especially with regard to autonomy, which is known to be an essential factor behind success in online education. Another positive outcome of these features is the opportunity to directly and easily adjust the cognitive load induced by instructional flow by limiting the amount of content displayed on the MOOC player and configuring the way the learning material is displayed[3].

[3] Keeping in mind that the compensatory mechanisms used by PWDs result in significant cognitive costs (Morrow & Rogers, 2008), added to the cost incurred by the processing of irrelevant information that can be provided during a teaching sequence (e.g., teacher's gesture, Paas et al., 2003), it is a critical asset that needs to be addressed to optimize cognitive processing.

All these first functionalities mainly address how the learning content can be organized and displayed, but it was also necessary to consider features that maximize the way users interact with the learning material. To this end, AÏANA proposes several functionalities to assist students with cognitive impairments to navigate and get meaningful information throughout the courses:

- **Semantic structure:** Each MOOC sequence is divided into several instructional units, each representing all the information that must be considered in order to understand a given concept. Each unit can itself contain several slides depending on the complexity of the concept. The overall structure is visually displayed close to the time progression bar and consists of tabs whose size varies according to their length.
- **Levels of navigation:** As our content is highly structured, the use of standard video player functions appears limited. In addition to the standard time navigation, we added specific features to navigate sequentially between instructional units or slides, or choose to return to the beginning of a selected instructional unit.
- **Time markers:** Instead of pausing the video when they want to take notes, users can use time markers to bookmark specific parts of a sequence. The markers are visible on the timeline and can be selected to play back the video from their exact position. By doing so, they avoid the buffering that can make the course hard to follow.
- **Additional window:** Additional information such as the description of important terms, acronym definitions or icons that visually support the teacher's speech can be displayed to assist users in their understanding or to draw the user's attention to a particularly important part of the course.
- **Different teacher displays:** Different views of teachers can easily be added and offered to the learners. For instance, they can choose between several viewing angles of the teachers display, such as a classic frontal view or a profile view so that it appears as if the teacher's gaze is oriented towards the content of the slides.

Most of these functionalities allow users to externalize the non-relevant sub-tasks and optimize processing opportunities and thus can serve as environmental support, for instance for persons with working memory and/or long-term memory impairments, persons that need specific repetitions or for persons with difficulties in achieving simultaneous tasks (i.e., listen and write) as in cases of a cognitive slowing-down or attention disorders.

Field Study Objectives

The present study aims to evaluate the main concepts of AÏANA and assess the impact of its features on accessibility in a real context of use. Consequently, the primary goal is to provide an evidence-based study investigating the learning experience of PWDs (with and without cognitive impairments) vs. non-disabled persons (NODs) when using our accessible MOOC player. The main expected results are that AÏANA will allow the PWDs to:

- Reduce their more frequent drop-outs across MOOC sessions;
- Achieve an equal level of learning performance compared to NODs;
- Maintain a sustainable cognitive load level;
- Experience feelings of self-determination as high as those of other learners.

METHOD

We used a causal comparative study design, a more ethically appropriate research method in our educational settings, as a classical (control-observed) experimental design would have led us to randomly force some users to use a traditional player and force others to use ours.

Over a period from November 2016 to April 201, data collection was performed during four consecutive sessions of a MOOC about Digital Accessibility delivered on a French MOOC platform (FUN-MOOC, https://www.fun-mooc.fr/fr/) that is widely used and open to the public. The entire course consists of 32 modules that are spread over 5 weeks. Each module contained one or two videos as well as a quiz used for learning assessment. All data was collected anonymously using an external registration process managed by the MOOC platform.

Procedure and participants inclusion criteria

In order to give learners the opportunity to be more familiar with the player, an instructional session (Preparation Week) was included. During this session, a tutorial presented the different features available and users were invited to test them and configure their interface according to their specific preferences, needs and/or abilities. In addition, participants were also informed that they could share their personal configuration in a dedicated forum thread and engage in discussions with the pedagogical team.

Prior to the first module, participants were asked to fill in a profile questionnaire composed of demographic questions (including gender, age, and education level) in which they could self-declare a disability from a questionnaire derived from the standardized ICF's function disabilities taxonomy (for instance: *I have difficulty reading text*, *I have difficulty staying focused*, *I have problems with memorization*, *etc.*). Participants that declared at least one disability belonged to the PWD group while the others formed the non-disabled Persons (referred to as NODs) group. Two series of research questionnaires were proposed, one at the mid-point and one at the end of the MOOC. Interaction logs were also collected for each user in the form of a set of traces recorded at each interaction with a functionality (e.g., the user clicks on a button on the interface, moves one of the elements, *etc.*).

In the following sections, we present the field study methodology in two consecutive parts: Part 1 describes the Learning Analytics assessement (module completion, attrition and participation rates, interaction logs with the MOOC Player) while Part 2 presents the questionnaire assessement (Learning score, usability, cognitive load and self-determination measures).

Part I: Learning Analytics assessment

In order to have a preliminary understanding of the participation of PWDs and NODs in the course, we first compared the number of learners who completed the surveys for the two groups. Then especially to test whether accessibility is a dominant factor in determining the retention of disabled students in this MOOC, we analyzed the course completion by: *a.* performing a comparison of the 32 modules' odds ratios (OR) of completion rates in our MOOC with the dataset in (Haynes, 2013); *b.* performing a comparison of participation and attrition between the two groups of learners (PWDs and NODs); *c.* analysing the early interaction behavior of the two groups regarding their use of AÏANA accessibility functionalities.

Participants

To be included in the Learning Analytics assessment, participants had to have filled in the profile survey and to have taken part in only one of the four sessions of the MOOC. After the exclusion of 32 participants enrolled more than once, a total of 646 participants were included (87 PWDs and 559 NODs).

Measures & Statistical Treatment

Modules Completion. In this part, we drew on the analytic method presented by (Cooper et al., 2016) to evaluate accessibility, using a relative odds ratio (OR) value to reflect the impact of disability on course completion according to the following formula (1):

$$OR = \frac{odds_{NOD}}{odds_{PWD}} = \frac{p/(1-p)}{q/(1-q)} \tag{1}$$

Where: p is the completion rate of NODs, then $odds_{NOD} = p/(1-p)$;
q is the completion rate of PWDs, then $odds_{PWD} = q/(1-q)$.

The OR value assesses whether the variable of disability significantly affects the completion rate of the course: when OR $>$ 1, NODs perform better than PWDs. The larger the OR is, the greater the disparity between the two groups. The authors defined a threshold of 3.0 for the OR value so as to filter out cases where factors other than disability would have an impact on student performance. Therefore, when OR $>$ 3, disability has a significant effect on student performance.

We first calculated 32 modules' odds ratios (OR) of completion rates, then compared them to the dataset in Cooper and colleagues (2016) through a visualization analysis. To avoid distortion, modules with less than 25 PWDs were not considered.

Participation and Attrition. To give us an outline of PWDs' global participation in the course, we counted the number of NODs and PWDs that filled in the profile survey, the mid-course survey and the end-course survey, and compared the proportion of PWDs at each stage with the results provided by Iniesto and colleagues (2017) who studied PWDs participation in 8 MOOCs with a similar procedure.

Participation in each module was defined by the proportion of active learners (i.e., learners who watched videos or completed the quiz in the corresponding module). Given that most students tend to follow MOOC courses by video sequence (Qu & Chen, 2015) and that, as the course progresses, the number of active people declines (Belanger et al., 2013), we chose the module sequence order as the time measure, and drew the attrition curves for PWDs and NODs. To compare their respective attrition rates, we calculated the Frechet distances of the two normalized curves. The Frechet distance is a measure of similarity between curves that takes into account the location and ordering of the points along the curves (Alt et al., 1995). When the Frechet distance is less than 1, it indicates that the two trajectories are similar, which means the attrition rates of the two groups are the same.

Survival analysis. To model the probability that learners dropped out the course, we conducted a survival analysis, a method used to examine how specific factors influence the rate of a particular event happening at a particular point in time, in our case, dropping out. More specifically, we used a Cox proportional hazard model (Cox, 1972) that can be expressed by the hazard function denoted by $h(t)$ (2):

$$h(t) = h_0 \times exp(b \times x_{disability}) \quad (2)$$

Where: t represents the time of participation in the course

h_0 is the baseline hazard

$exp(b)$ is the hazard ratio (HR)

The hazard ratio represents the effect size of disability: being in the PWD group reduces the hazard of dropping out when HR is less than 1, but increases the hazard when HR is more than 1. Finally, we conducted a Wald test to evaluate the effect of disability on dropping out (Agresti et al., 2011).

Early interaction. It is well known that accessibility barriers lead to dropouts in the first moments of service use. To further investigate AÏANA efficiency, we analyzed the use of its functions during the first five minutes. After the exclusion of participants with no interaction logs, 537 participants (76 PWDs, 461 NODs) were included in this analysis.

To compare the potential effect of the first five minutes of use behavior on the course completion, we divided each group into two categories according to their course completion: Completers and Dropouts. To be identified as a completer, a participant had to meet at least one of the following criteria: 1. Obtain a final learning score greater than or equal to 0.55, which corresponds to the lowest grade for obtaining a completion certificate ; and 2. Watch at least 90% of the videos (i.e., at least 34 videos).

There were 40 completers and 36 dropouts out of 76 PWDs, and 236 completers and 225 dropouts out of 461 NODs.

AMP's functions fall into two main types. The first one includes the mainstream functions, available in mainstream players, including play, pause, adjust volume and play rate, seek bar, turn on/off the subtitles and enter full-screen mode. The second one includes accessibility functions, which are specifically added to improve accessibility, including fast-forward or rewind according to slides or notion, add/remove/delete bookmarks, adjust size and position of interface elements, export or import user preferences. For each learner, we calculated the total number of clicks on accessibility functions within five minutes using the first interaction trace generated as the starting time. Since the number of clicks on the accessibility functions did not conform to the normal distribution by Kolmogorov-Smirnov test, and considering the large sample size gap between PWDs and NODs (PWDs:NODs ≈ 1:7), we chose to use type-III sums of squares, recommended for unbalanced designs, to compute a two-way ANOVA analysis.

Part II: Questionnaire assessment

Participants

To be included in the questionnaire assessment, participants had to have completed a profile questionnaire, have had a recorded score and have completed all research questionnaires. A total of 277 participants, with 46 PWDs and 231 NODs met these eligibility criteria. Two subgroups were formed from the PWD group: 21 persons with at least one cognitive disability (designated COG group) and 25 persons with at least one sensory or motor disability and no cognitive disability (designated NCOG group). Socio-demographic information for the different groups can be found in Table 1.

	COG	***NCOG***	***All PWD***	***NOD***
N	21	25	46	231
Age Mean	41.8 (sd = 12.4)	41 (sd = 10.8)	41.4 (sd = 11.5)	39.8 (sd = 10.9)
Age Min-Max	21-66	21-67	21-67	18-71
Gender	10M 11F	7M 17F 1o	17M 28F 1o	102M 125F 4o
≤ *Bachelor*	10 (47.6%)	13 (52.0%)	23 (50%)	60 (26%)
≤ *Master*	7 (33.3%)	6 (24.0%)	13 (28.3%)	91 (39.4%)
PhD	4 (19.0%)	6 (24.0%)	10 (21.7%)	80 (34.6%)

Table 1: Participant characteristics.

sd = Standard deviation; M = Male, F = Female, o = Other.

Measures & Statistical Treatment

To qualitatively assess the accessibility and probe the effectiveness of AÏANA independently from learners' conditions, multiple outcomes were analyzed (Cinquin et al., 2020): **learning score** from repeated multiple-choice questions quizzes ; **Usability score** (the standardized questionnaire System Usability Scale SUS, Bangor et al., 2008; Brooke, 1996; Lewis & Sauro, 2009); **Cognitive load** (CL) score (measured using the raw version of NASA-TLX (Hart & Staveland, 1988); and **Self-Determination** (SD) scores (Vallerand, 1997), distributed into the three main concepts of Self-Determination Theory: Autonomy, Competence and Relatedness (SDT, Ryan & Deci, 2000).

The qualitative results of the study are reported in three successive sections (for details see Appendix). The first section presents the differences between the NOD and PWD groups. The second section presents the differences between the COG and NCOG groups. The third section examined the correlations between the learning score, the usability score, the perceived cognitive load and the different components of self-determination for NOD and PWD groups, respectively.

RESULTS

Part I – Learning Analytics assessment

Module Completion. The average module completion rate was 90.40% for PWDs and 90.48% for NODs. In comparison with the study performed by Cooper and colleagues (2016) where the module completion rate was 69.5% for PWDs and 75.3% for NODs, in our MOOC the vast majority of learners complete a module as long as they participate in it. From the 32 modules in our MOOC, there are 15 modules with an OR value inferior to 1 (52%) and two with an OR value equal to 0 (i.e., all PWDs completed the module). As no module exhibits an OR value above 3 (max OR = 2.43), we can conclude that accessibility is not a dominant factor in determining the completion rates of PWDs (Cooper et al., 2016).

Figure 2 presents a visualization of the distribution of the OR of completion rates obtained from our dataset ($N = 32$), overlaid with dataset[4] from Cooper and colleagues (2016) ($N = 668$).

[4] As we did not get the complete data from Cooper and colleagues (2016), it was not possible to compare the two datasets with statistical methods.

Firstly, any OR value above the threshold of 3.0 would indicate that a module is presenting accessibility issues that significantly impact on the performance of students with disabilities (Cooper et al., 2016), but we observed that no OR values obtained exceeded this threhold. Secondly, we can observe that our results are basically located in the middle and lower part of the distribution, which means that our MOOC shows better accessibility than most other MOOCs. Although there may be some differences between modules, considering the high average completion rate of PWDs, we can suppose that our MOOC gives PWDs a relatively equal and more inclusive e-learning environment.

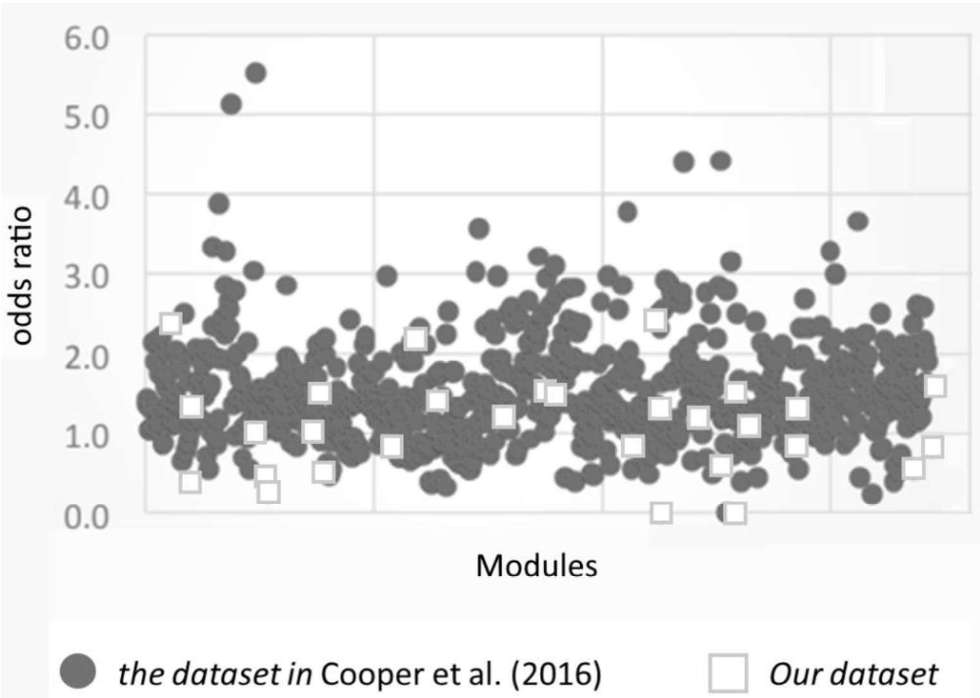

Figure 2 : Distribution plot of odds ratios of completion rates. Each dot represents a module presentation (distributed along the x-axis in no particular order); the y-axis is the odds ratio value; the gray dots represent the dataset in Cooper and colleagues (2016) and the blue dots represent our dataset.

The above results suggest that the use of AÏANA allows PWDs to engage in the MOOC in a similar way to NODs without any additional barriers to their participation. It should be noted that the only study on MOOC accessibility with this analytics method was not able to assess this indicator over an entire MOOC session due to an insufficient number of PWDs on certain modules

($N < 25$) (Cooper et al., 2016). In our study, the number of PWDs participating meets statistical requirements, thus it does not cause a large fluctuation in the proportion of active learners because of the retention or attrition of individual students whose data are presented hereafter.

Participation and Attrition. Figure 3 shows the number of PWDs and NODs along with the proportion of PWDs who completed the pre-course, mid-course, and post-course surveys. About half of the learners that filled in the pre-course survey did not fill in the mid-course survey. After that, most learners who filled in the mid-course survey also filled in the post-course survey. The result of a chi-square test shows no significant correlation between disability and survey completion ($\chi^2 = 2.9786,\ p = 0.2255$).

At the beginning of the course, we observe a slightly higher rate of PWDs in our MOOC (13.47%) than in other MOOCs (10.75%) (Iniesto et al., 2017). At the end of the course, the difference is more significant: 16.29% in our MOOC *versus* 11.30% in other MOOCs. This result suggest that our MOOC displayed by AÏANA effectively promotes the participation of PWDs.

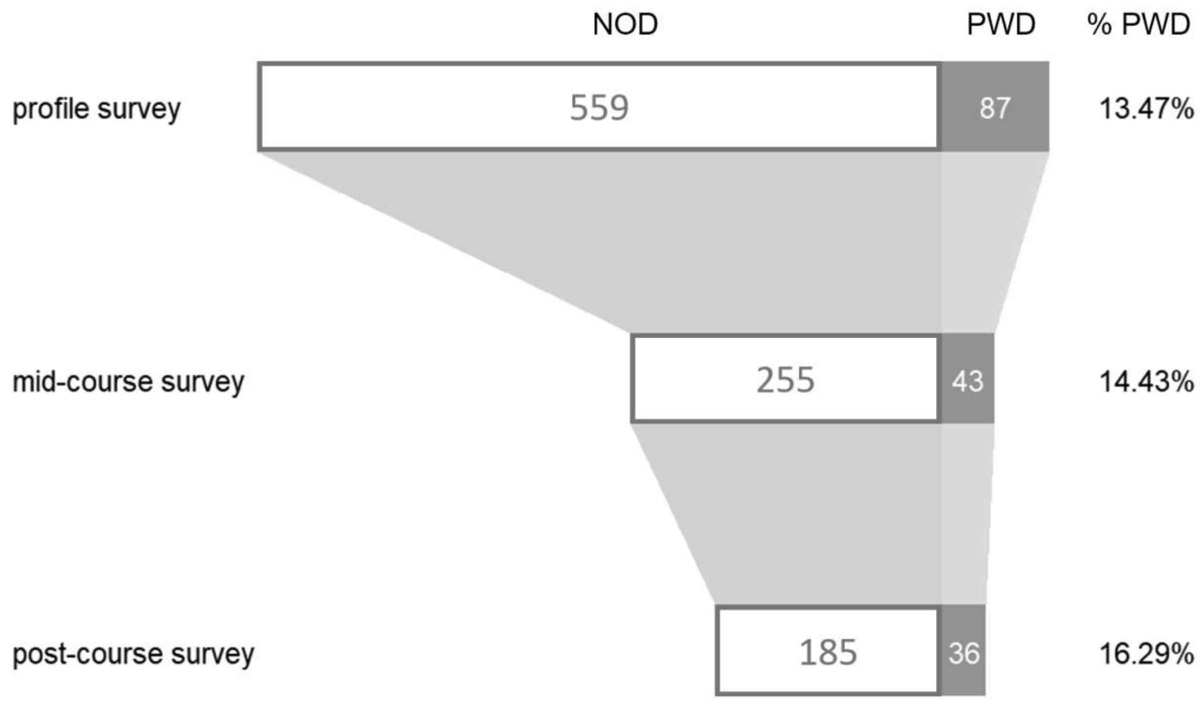

Figure 3: PWD proportions in surveys

Regarding participant attrition, the proportion of active learners was about 83% of the total number of participants (85.06% in PWDs and 83.18% in NODs) in the first module, indicating that nearly 17% of learners abandoned the course after the preparation week. As the course progresses, the proportion of active learners gradually decreases (see Figure 4). The Frechet distance between PWDs and NODs attrition curves is 0.242 (< 1), which indicates that the two trajectories are similar. Consequently, the attrition rates of PWDs and NODs are equivalent.

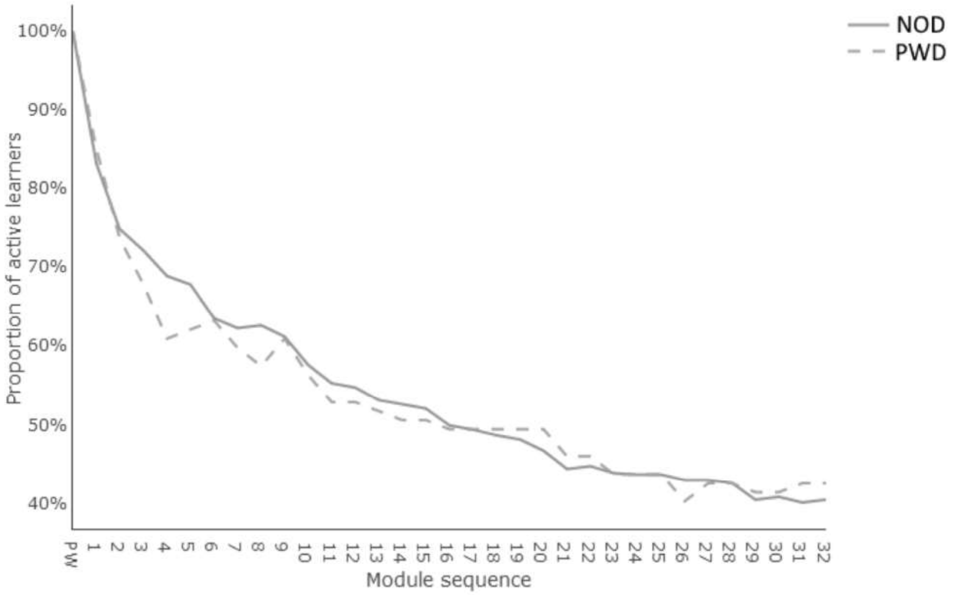

Figure 4: Attrition curves across the module sequences
for non-disabled Persons (NOD) and Persons with disabilities (PWD)

Survival Analysis. In our resulting survival model, the Hazard ratio of disability is equal to 1.02, suggesting that PWDs are 2% more likely to drop out of the course than NODs. Furthermore, the result of the Wald test shows that disability had no significant effect on the probability of dropping out ($z = 0.176,\ p = 0.86$). When plotted together, the survival curves of PWDs and NODs present a similar trajectory (see Figure 4). Although the proportion of active PWDs is slightly lower, the attrition rates of the two groups are not significantly different. As such, these results suggest that the use of AÏANA enables PWDs to attend a MOOC in a similar way to persons without disability and that it does not present any additional barriers to their participation.

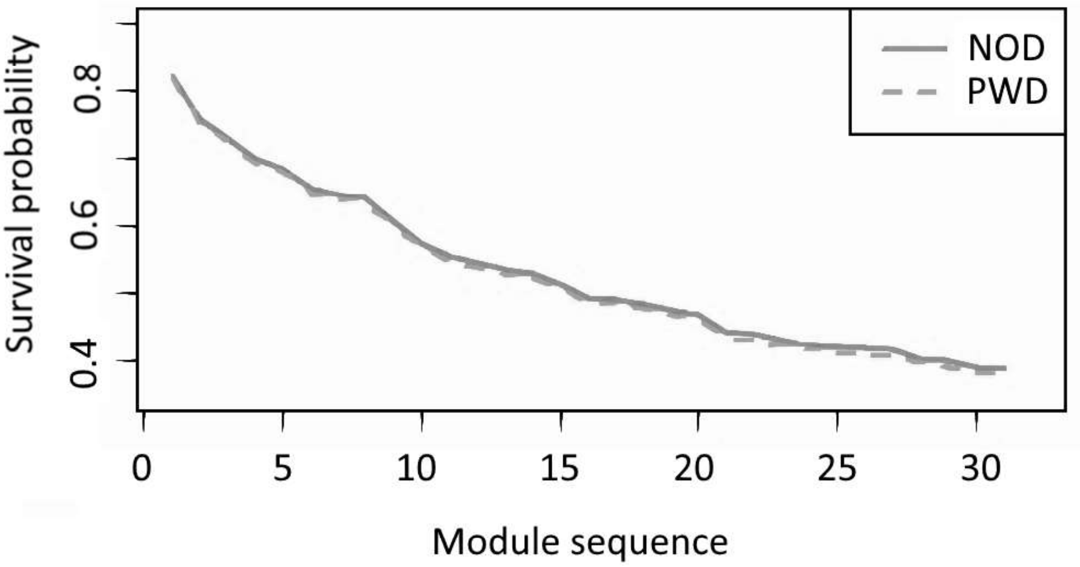

Figure 5: The predicted survival proportion by module
for non-disabled Persons (NOD) and Persons with disabilities (PWD)

Early use. As shown in Figure 6, in the first five minutes, the average number of clicks for NOD dropouts is 1.49 ($sd = 4.11$) and 1.34 ($sd = 3.15$) for NOD completers. In comparison, the average number of clicks for PWD dropouts is 0.61 ($sd = 1.69$) and 2.30 ($sd = 4.15$) for PWD completers. The result of a two-way ANOVA shows that there is an interaction between disability and course completion ($F(1,1,533) = 4.2608,\ p = 0.039,\ \eta^2 = 0.008$), which indicates that the difference in the use frequency between PWD completers and the PWD dropouts is significantly larger than that between NOD completers and NOD dropouts. A further Mann-Whitney U test indicates that there is a significant difference between PWD completers and PWD dropouts in the average number of clicks on accessibility functions ($U = 534.5,\ Z = -2.29,\ p = 0.023,$ $Cohen's\ d = 0.523$). However, this is not the case when comparing NOD completers and NOD dropouts ($U = 25866,\ Z = -0.579,\ p = 0.563, Cohen's\ d = 0.0411$).

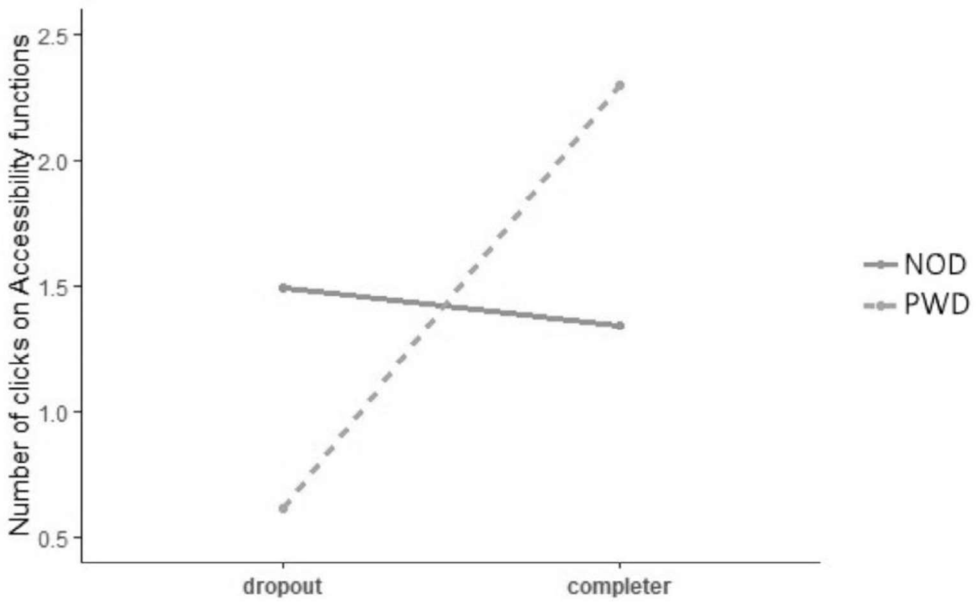

Figure 6: Interaction plot between disability and course completion on the use of accessibility functions in the first five minutes of use for non-disabled Persons (NOD) and Persons with disabilities (PWD)

A comparative analysis using a self-determination questionnaire shows that the motivation of PWD completers and PWD dropouts does not differ significantly (PWD dropouts = 2.97 out of 5 and PWD completers = 3.16 out of 5, $p > .05$). Consequently, if the intrinsic motivation at the beginning is equal for each group, the above series of results indicates that PWDs who dropped out are those who did not use the accessibility features during the first five minutes, showing that the attendance of PWDs on the course is strongly associated with their rapid appropriation of accessibility functions. Table 2 shows the distribution of accessibility features most used by the PWD completers.

	Fast-forward or rewind		**Add/remove/delete**	**Adjust size and Position of Interface elements**	
	Notion	Slide	Bookmark	Window place	Window Size
Number of use (5 mins)	35	6	8	28	10
Percentage %	40.23	6.90	9.20	32.18	11.49

Table 2. Distribution of accessibility features used by the PWD completers during the first five minutes.

Part II - Questionnaire assessment

NOD vs PWD comparisons

Learning performance. Both groups reached a similar learning performance with a similar progression all along the course. The results of the statistical analysis show a significant main effect of time ($F(1{,}275) = 4.81,\ p = .029,\ \eta^2 = .002$), such that the overall learning score was slightly higher at mid-term than end-term (Learning score mid-term = 0.885, Learning score end-term = 0.870) for both groups. There is no main effect of Group on assessments scores ($p = .095$) and no significant interaction between Time and Group ($p = 0.502$) (see Table 3 in the Appendix).

Usability. All users perceived the system as highly usable, with an average SUS score above 70 (Bangor et al., 2008)]. Moreover, a significant main effect of Time ($F(1{,}275) = 3.95,\ p = 0.549,\ \eta^2 = .002$), revealed that the overall SUS score was slightly better at the end of the MOOC (Usability mid-term = 76, Usability end-term = 78.2) for both groups. The analysis revealed no significant effect of Group on SUS score ($p = .549$) and no significant interaction between Time and Group ($p = .296$) (see Table 3 in the Appendix).

Cognitive Load. All users perceived a low impact of the player on their cognitive workload over the whole duration of the course, exhibited by the low average NASA-LTX scores obtained for both groups (CL mid-term = 28.6, CL end-term = 26.7). There was no significant effect of Group on NASA-LTX score ($p = .352$), no significant effect of Time ($p = .220$) and no significant interaction between Time and Group ($p = .274$) (see Table 3 in the Appendix).

Self-Determination. There was a significant main effect of SDT ($F(2{,}550) = 69.041,\ p < 0.001,\ \eta^2 = .37$), such that the level of perceived self-determination differs according to the component, with the feeling of autonomy being higher than the feeling of competence, which in turn is higher than the feeling of relatedness. In addition, the analysis revealed an interaction between SDT and Time ($F(2{,}550) = 3.598,\ p = .028,\ \eta^2 = .001$) exhibiting an increase in the perception of autonomy and competence between mid-term and end-term for all users, while the perception of relatedness remains stable. For both groups, the overall SDT scores obtained are rather high, indicating a high level of perceived competence, autonomy and relatedness. In this respect, the analysis revealed no significant main effect of Group on SDT scores ($p = .462$)

indicating that both groups reached a good level of perceived self-determination globally (see Table 4 in the Appendix).

COG vs NONCOG comparisons

Learning performance. Both groups achieved a good level of performance with the same progression (Learning score mid-term = 0.858, Learning score end-term = 0.849). The analysis revealed no main effect of Group on assessments scores ($p = .095$), no main effect of Time ($p = .506$) and no significant interaction between Time and Group ($p = .244$) (see Table 5 in the Appendix).

Usability. Both groups perceived the system as highly usable throughout the course (Usability mid-term = 76.7, Usability end-term = 80.2). The analysis revealed no significant effect of Group on SUS score ($p = .225$), no significant effect of Time ($p = .116$) and no significant interaction between Time and Group ($p = .990$) (see Table 5 in the Appendix).

Cognitive Load. Both groups perceived the cognitive load induced by the player as rather low, with no significant change from mid to end-term (CL mid-term = 28.3, CL end-term = 27). Although the group effect did not reach significance ($p = .083$), examination of the means suggested that the perceived cognitive load is slightly higher for the COG group compared to the NCOG group, although it remains low (mean = 35.2). There was no significant effect of Time ($p = .548$) and no significant interaction between Time and Group ($p = .761$) (see Table 5 in the Appendix).

Self-Determination. A significant main effect of SDT ($F(2,88) = 23.662,\ p < .001,\ \eta^2 = .059$) indicates that the level of perceived self-determination differs according to the component, with the feeling of autonomy being higher than the feeling of competence, which in turn is higher than the feeling of relatedness (see Table 6 in the Appendix). There was no significant main effect of Group on SDT scores ($p = .770$) and no significant main effect of Time ($p = .174$), indicating that both groups reached a good level of perceived self-determination globally. Finally, there was no interaction between the different factors.

Correlations

As the COG *vs.* NCOG group effect was not significant across the qualitative measures, the correlational analyses were performed for the overall PWD sample and the NOD sample, respectively (see Table 7 in the Appendix).

For both groups, a strong perceived usability was associated with a higher level of perceived autonomy, competence and relatedness and less perceived cognitive load. The results of a Z test for independent measures exhibited no significant differences in the correlation values between the two groups, indicating that the perceived usability is an important co-variable of SDT regardless of any disability conditions. In addition, strong positive correlations can be observed between the three components of SDT in both groups, in particular between Autonomy and Competence scores.

The perceived cognitive load was associated with the learning performance only among the NOD group and not the PWD group. However, this correlation is rather low ($\tau_b = -.149$). For the PWD group, the Kendall's τ_b revealed a statistically significant relationship between the NASA-LTX score and the Self-Determination autonomy and competence component score showing that a lower level of perceived cognitive load is associated with a higher level of perceived autonomy and competence for PWDs.

DISCUSSION

These results are the first to provide an extended quantitative and qualitative accessibility assessment in a field study setup that includes a large sample of PWD learners. The results provide a promising way of supporting the effectiveness of AÏANA to improve MOOC accessibility. Regarding the Learning Analytics assessment, AÏANA enables a good retention of PWDs throughout the MOOC, with an equivalent attrition rate of non disabled persons corroborating the odds values for module completion across MOOC sessions. Moreover, the analysis of the first five minutes of use revealed that PWDs that demonstrate the most early interaction behaviors with accessibility features are the most likely to persist until the end. The comparison of participation between PWDs and NODs for each module and the inclusion of a disability variable in the measurement of learner attrition appear to be two new interesting indicators to strengthen MOOC accessibility assessment methodology that MOOC platforms could easily implement to conduct a rapid assessment of their content. In addition, as stressed in the Rogers' theory of diffusion (Rogers, 1995) through the trialability concept, the analysis of the first minutes of interaction confirms that the rapid adoption of accessibility features is a decisive factor in the persistence of PWDs, irrespective of the initial level of intrinsic motivation (i.e., self-determination scores) for using the AÏANA player to follow the MOOC (that was high in both the PWD completers and the PWD dropouts). Taken together, these observations suggest that the first interactions with accessibility features provide a promising way of direct measurement in evaluating the implementation of accessibility solutions.

As mentioned, amongst the PWDs, the completers and dropouts did not differ in their initial motivation, so factors other than motivational ones are thus involved in the relationships between the early uses of accessibility features and the completion of the MOOC. Several non-exclusive one-to-other factors could be advanced. Firstly, as for the NODs, the PWDs may discontinue due to traditional reasons for dropping out of MOOCs, such as those related to the learner's perception of the course content, or to the learner's ability to find and manage time effectively in respect of his/her social constraints (work, care, family, etc.) (e.g., Eriksson et al., 2017). Secondly, it is possible that the prior learning phase was insufficient for some PWDs to understand and to master the accessibility features of the player, leading them to discontinue the MOOC learning. This pintpoints the need to reinforce instructional support when inviting PWDs to make use of accessibility features.

Regarding the questionnaire assessment, all learners achieved equivalent learning outcomes regardless of their disability condition, and the overall usability performance of AÏANA was high for every participant. The use of AÏANA is not perceived by users as generating a significant cognitive load, and that is the case for all users. While the cognitive load perceived by users who reported at least one cognitive impairment could have been expected to be higher, it remains relatively low and does not significantly differ from other PWDs. Such a finding is noteworthy in light of previous findings which report that cognitive load is a critical learning barrier for PWDs, especially those with cognitive impairments (Greer et al., 2013). The results of the Self-Determination questionnaire show that AÏANA provides a good support to PWD needs in terms of autonomy and competence, known to be important components for learners' intrinsic motivation (Roca & Gagné, 2008), and more particularly for PWDs with and without cognitive impairments (Wehmeyer et al., 2017). Moreover, correlational analyses revealed that SDT measures are co-variable of learning rate in NODs and of cognitive load, especially for PWDs. As such, these results can serve as a guide for a more qualitative evaluation of a MOOC, with the consideration of perceived autonomy and competence as valuable accessibility hallmarks for all learners.

To complement these initial results, it is important to keep in mind the importance of having self-reported measures that shed light on some of the limitations associated with Learning Analytics measures. Indeed, in the absence of a control condition providing attrition-related behaviors in PWDs when the player is without accessibility features, it could be that the PWDs are more resilient in their attendance regardless of accessibility quality (similar dropout curves for all accessibility conditions). Or, conversely, they may have more adverse reactions to poor accessibility quality (increased dropouts for low accessibility conditions). In the former case, this would mean that similarities in attrition rates between PWDs and NODs are to be expected whatever the accessibility conditions; and, in the latter case, it would be obtained after a decreased number of PWD dropouts. While the latter case would remain supportive of the accessibility effectivenes of our MOOC player, the former case would not. Consequently, demonstrating the attrition similarity between PWDs and NODs is a valuable indicator for accessibility-related Learning Analytics within the hypothesis that PWDs' and NODs' behavior is really comparable in terms of attendance and dropout in MOOCs. Such a limitation highlights the interest of an in-depth exploration by multiple (Learning Analytics and questionnaire) measures regarding MOOC player accessibility experience in PWDs. Indeed, both interaction behaviors and self-rating scores are congruent with a suitable accessibility quality associated with the AÏANA player.

Limitations and Future Work

Although the field study has led to the encouraging results above, some limitations need to be discussed or to be resolved in future work.

Data collection. More information related to interaction has yet to be collected to gradually improve the data collection framework. For example, interaction traces with some accessibility functions (such as switching the player theme or downloading subtitles) are not recorded. It should also be important to complete our dataset with data from the MOOC platform (e.g., learners' login/logout time, quiz submission time and page views, *etc.*) to provide more information to understand engagement patterns. In addition, matching the anonymous profiles with MOOC user-names could be useful to obtain the learner's behavior data in the forum, such as the frequency of posting and commenting on quantitative aspects, and the sentiment analysis of comments on qualitative aspects.

Attrition. Comparing the impact of disability on attrition is a groundbreaking attempt in MOOC accessibility research. Nevertheless, our conclusions have yet to be further validated. Indeed, in the absence of an available benchmark of PWD attrition rates, we used the NOD attrition rate as our baseline. It is well documented that NOD attrition in online learning is generally higher than in traditional settings (Kizilcec & Halawa, 2015), but we have no certainty that PWDs usually exhibit similar attrition-related behaviors. Consequently, demonstrating the similarity in attrition between PWDs and NODs is a valuable indicator within the hypothesis that PWDs' and NODs' behavior is genuinely comparable in terms of attendance and dropout in MOOCs.

Interaction. For the first time, this field study has reported the relationship between the use-related interaction behaviors on a MOOC player and the retention of PWDs, revealing that the initial experience of PWDs using an accessible MOOC system has a crucial impact on their subsequent sustainable attendance. In order to further improve AMP's design, it could be beneficial to integrate self-adaptive properties into the player following the ability-based design approach (Wobbrock et al., 2011), to detect PWDs who are not using the accessibility functions within the first 5 minutes and to provide them with functions adapted to their self-declared needs through system suggestions.

Mixed method Learning Analytics and Questionnaire. The evaluation of AMP's efficiency requires further Learning Analytics analyses in conjunction with the questionnaires (Viberg et al., 2018). Through studying learners' actual use of AMP, we concluded that the attendance of PWDs on the course is associated with their rapid appropriation of accessibility functions. If the appropriation is related to the good usability of AMP, the early consideration of AÏANA accessibility functionalities could be related to a strong intrinsic motivation, resulting in more interactions. Additionally, results from the Learning Analytics assessment enabled us to gather information about a more global user experience, showing that the player was well valued for its usability and elicited good self-determination perception. The conjunction between actual use of AÏANA and subjective data gathered through the research questionnaires could be used as a complementary means of accessibility evidence.

More in depth interaction analysis to determine behavior. In this study we analyze each interaction independently. Following Sinha and colleagues (2014), it would be interesting to explore patterns of functionality interaction (i.e., chains of actions that occur during a specified time frame) to define a taxonomy of behavior use for AÏANA that could be used to provide users with personalized shortcuts, based on the analysis of their own usage.

CONCLUSION

The outcomes of the field study support the positive impact of our design decisions and provide positive feedback about the benefits of AÏANA for PWDs to engage in a MOOC, in particular with regard to people with cognitive impairments that are often insufficiently addressed. As a consequence, it supports our inclusive design approach, showing that AÏANA facilitates the removal of barriers to PWDs to engage in MOOCs, which is promising in terms of providing new opportunities for the inclusion of people with disabilities in educational technologies. The use of both quantitative analytics and qualitative assessment allowed us to obtain a more complete evaluation of accessibility, confirming the need for a mixed-method approach to assess online learning accessibility.

From a broader perspective, the present study provides the e-learning accessibility community with new metrics that can be used to explore different levels of participation (attrition rate *vs.* early interaction analysis) or to evaluate the valence of different learner experience components (cognitive load *vs.* self-determination). We believe that such research efforts will contribute to providing PWDs with equal opportunities for their personal and professional development, a fundamental condition for them to exercise their right to choose and realize their life project.

STATEMENTS

The authors declare that they have no conflict of interest. The entire study design, as well as data management, has been approved by the ethics committee of our national research institute and each participant gave informed consent before participating in the study. As the informed consent did not include open-data storage of individual data, the data are available on request to researchers who would like to consult them within the legal deadline for authorising their storage (10 years after harvest).

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List of Tables and figures (Appendix)

Appendix
Statistical designs and descriptive data from qualitative assessment

The qualitative results of the study are reported in three successive sub-parts. The first sub-part presents a statistical analysis of the differences between the NOD and PWD groups. For learning performance, usability and cognitive load measures, we conducted mixed ANOVAs (2 (Group: NOD, PWD) x 2 (Time: mid-term, end-term)) with group as a between-subjects factor, and time as a within subjects repeated measure factor. For Self-Determination we conducted a mixed ANOVA (2 (Group: NOD, PWD) x 2 (Time: mid-term, end-term) x 3 (SDT component: Autonomy, Competence, Relatedness)) with group as a between-subjects factor, time as a within subjects repeated measure factor and SDT component as a within-subjects factor. Levene's tests were conducted for each dependent variable and confirmed the equality of variances between the two groups. The chosen statistical significance threshold is $p = .05$.

The second sub-part presents a statistical analysis of the differences between the COG and NCOG groups. The statistical analysis procedure is identical to that used when comparing the NOD and PWD groups, only with a change of related group for the independent variable to COG and NCOG. The third section presents an exploratory correlation analysis on the measures obtained at end-time for NOD and PWD groups. To examine the relationship between the learning score, the usability score, the perceived cognitive load and the different components of self-determination, we performed correlational analysis on the measures obtained at end-time for NOD and PWD groups. An examination of the scatterplots (not presented) suggested the presence of monotonic nonlinear relationships between each pair of variables in both groups. Accordingly, a nonparametric procedure, the Kendall's tau-b correlation coefficient (i.e., Kendall's τ_b) was performed (Kendall, 1948; Newson, 2002). The chosen statistical significance threshold is $p = .05$. Due to the large number of correlations, we applied the Bonferroni correction (Bonferroni, 1936) and included the Benjamini & Hochberg correction (Benjamini & Hochberg, 1995) as an alternative to the highly conservative aspect of Bonferroni's correction (Haynes, 2013). Correlation coefficients between groups were then compared using the Fisher r-to-z transformation, with a statistical significance threshold of $p = .05$.

		NOD M (SD)	PWD M (SD)
Learning score	mid	.892 (.090)	.858 (.110)
(max. score = 1)	end	.872 (.128)	.848 (.133)
Usability score	mid	76.3 (18.4)	76.7 (18.7)
(max. score = 100)	end	77.4 (17.7)	80.2 (17.4)
Cognitive Load Score† (max. score = 100)	mid	27.3 (20.0)	32.2 (19.8)
	end	27.1 (20.3)	28.5 (17.6)

Table 3: Means (and standard deviations) of learning, usability and cognitive load scores across time according to group condition (NOD vs. PWD).
†*Cognitive Load Score was only measured for MOOC sessions 2, 3 and 4 (180 NOD, 33 PWD).*

		NOD M(SD)	PWD M(SD)
Autonomy	mid	3.44 (1.10)	3.48 (1.15)
(max. score = 5)	end	3.59 (1.05)	3.72 (1.17)
Competence	mid	3.19 (1.08)	3.15 (0.98)
(max. score = 5)	end	3.27 (1.02)	3.46 (1.19)
Relatedness	mid	2.82 (1.15)	2.91 (1.09)
(max. score = 5)	end	2.76 (1.07)	2.96 (1.07)

Table 4: Means (and standard deviations) of each SDT component according to condition groups (NOD vs. PWD)

		COG M (SD)	NCOG M (SD)
Learning score	mid	.819 (.127)	.891 (.090)
(max. score = 1)	end	.825 (.117)	.867 (.144)
Usability score	mid	73.5 (19.0)	79.5 (18.3)
(max. score = 100)	end	76.9 (17.5)	82.9 (17.3)
Cognitive LoadScore †	mid	36.2 (18.6)	28.5 (20.7)
(max. score = 100)	end	34.2 (17.1)	23.1 (10.8)

Table 5: Means (and standard deviations) of learning, usability and cognitive load scores across time according to group condition (COG vs. NCOG).

† Cognitive Load Score was only measured for MOOC sessions 2, 3 and 4 (16 COG, 17 NCOG).

		COG M (SD)	NCOG M (SD)
Autonomy	mid	3.48 (1.03)	3.48 (1.26)
(max. score = 5)	end	3.76 (1.04)	3.68 (1.28)
Competence	mid	3.10 (0.88)	3.20 (1.08)
(max. score = 5)	end	3.57 (0.92)	3.36 (1.38)
Relatedness	mid	2.62 (1.07)	3.16 (1.07)
(max. score = 5)	end	2.90 (1.14)	3.00 (1.04)

Table 6: Means (and standard deviations) of each SDT component according to condition groups (COG vs. NCOG).

Table 7 shows the correlations among the 6 measures in the PWD group above the diagonal and in the NOD group below the diagonal.

Measure	1	2	3	4	5	6
1. Learning Score		.248	-.092	.193	.247	.200
2. SUS Score	.082		**-.453** [a,b]	**.492** [a,b]	**.489**[a,b]	**.458**[a,b]
3. NASA-LTX Score	**-.149**[a,b]	**-.258**[a,b]		-.393[a,b]	-.325[b]	-.186
4. SDT Autonomy	.033	**.445**[a,b]	-.092		**.684**[a,b]	**.391**[a,b]
5. SDT Competence	.043	**.353**[a,b]	-.07	**.656**[a,b]		**.605**[a,b]
6. SDT Relatedness	-.113	**195**[a,b]	.078	**.459**[a,b]	**.489**[a,b]	

Table 7: Correlations for participants in the PWD group (n=46) are presented above the diagonal, and correlations for participants in the NOD group (n=231) are presented below the diagonal.

[a] *Significant correlation with the Bonferroni correction.*

[b] *Significant correlation with the Benjamini-Hochberg correction. p <.05*