Strategies and System Implementations for Secure Electronic Written Exams

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\section*{ABSTRACT} The pandemic has accelerated the process of digitization in many fields, highlighting some critical issues that have slowed the development of digital technologies in many areas. One of these is undoubtedly that of skills assessment, which on a digital platform is a more streamlined, reliable and faster process and allows some individuals from disadvantaged groups to be able to carry out the exam more easily. We present some strategies for enabling online remote secure written exams and their implementation through the open-source system LibreEOL. The system can be used for university exams (in presence or from remote locations) and training courses of all types to evaluate the effectiveness of learning in itinere, i.e., before, during and after a course, to provide quantitative data on training effectiveness. We outline the architecture of the services underpinning the system and the logical organisation of the various user roles and content relating to questions and exam delivery. We describe the algorithms that have allowed us to develop an environment that appears to be an essential aid both for teachers and students in light of the questionnaires conducted on students. The system is successfully used in the EchemTest®, promoted by the European Chemistry Thematic Network, and allows comparison of chemistry training outcomes in different European countries. Despite the importance, it has taken on in the last two years due to the pandemic, such a system makes it possible to carry out a valuable skills assessment.

\section*{INDEX TERMS} E-assessment, Cloud computing, Distributed computing, Artificial Neural networks, Human Computer Interaction, User eXperience, COVID-19

\section*{I. INTRODUCTION}

From the very beginning, the dissemination of knowledge and information has been one of the needs most keenly felt by humankind. Over time, the diffusion of ideas has adapted to technological development, taking on characteristics of structural maturity, speed of dissemination and social sharing of knowledge. Over the centuries, we have passed on knowledge orally to writing to arrive at modern times where digital information has become one of the predominant components. Nowadays, switching from traditional assessment methods to digital systems is an extraordinary leap forward in terms of modernity, respect for the student, the diversity with which different people express their skills and the enhancement of the teacher’s abilities.

The COVID-19 epidemic has hastened the digitization process in many industries, revealing several significant challenges that have hindered the development of digital technology in many domains. One of these is, without a doubt, skills testing, which on a digital platform is a more streamlined, reliable, and speedier procedure, allowing certain persons from disadvantaged groups to take the exam more readily. We discuss various ideas for facilitating online distant secure written examinations and how they may be implemented using the open-source system LibreEOL. Our experience in this direction started more than 20 years ago with our participation in a European Union initiative called Leonardo 2 and a project called DASP\textsuperscript{10},\textsuperscript{13},\textsuperscript{12}. From that embryonic system, we moved in the following years to a
full-fledged system capable of conducting computer-based written examinations for various university courses. In 2015, the system was adopted by the European Chemistry Thematic Network (ECTN) to carry out the Echemtest sessions for the certification of competencies in the various fields of Chemistry[22].

Starting from January 2020 with the advent of the Pandemic of COVID-19, the system has been completely re-engineered to afford the crucial and delicate task of carrying out written exams in a secure way from remote. The reorganisation of the platform was carried out under the following guiding principles: user-friendliness and optimal user experience, full adherence to open standards, respect for user data protection by always managing the minimum amount of data possible, maximum protection from all possible attacks, scalability and elasticity of the service to ensure adequate response times. We are confident that we have achieved our objectives in light of the data collected through the questionnaires submitted to students and thanks to the volume of examinations taken.

The paper is structured as follows: in Section II an analysis of the research work carried out on the assessment systems is presented. The analysis shows several contributions affirming the importance of e-assessment and highlighting its salient aspects and undisputed advantages. These features revealed strategic importance in the period of the COVID-19 pandemic. Section III outlines the architecture of the services forming the heart of the system, especially concerning its execution in a Cloud environment. We point out the open-source solutions available to achieve the expected efficiency of the system, currently implemented in a commercial Cloud environment. Section IV describes the logical organisation of the various user roles, the content relating to the organisation of courses and questions, the various modality to deliver exams and the available statistics that may help the teacher to monitor the students’ performances. Section V describes the algorithms implemented to validate the user’s activity while conducting the exam. This part is the most important that has been developed recently, which has required an enormous effort to try to reduce to a minimum the forcing and evident controls on the user, adopting technologies that are non-invasive for the user but at the same time warrant that the teacher can control how the exam is taken by the user, guaranteeing its veracity. Section VI describes carefully the usability of the system, underlying the strategies adopted, inspired to the minimization of operation and the transparency of the operations necessary to achieve a given task successfully. Section VII presents in detail the results obtained, both in terms of quantity of exams carried out and of the satisfaction measured from the users analysing the responses to the questionnaires. Section VIII presents the results of the Data Protection Impact Analysis (DPIA) applied to the LibreEOL platform, which is highly relevant given the very invasive strategies adopted by many commercial e-assessment solutions. Section IX outlines the main objectives achieved during the development of this system and anticipates possible future developments.

II. RELATED WORKS

Many scientists and researchers in the field have long been concerned with methods that accurately allow assessing the knowledge, skills, and competencies acquired by learners at the end of a term of study [28].

From early childhood education to university studies, assessment is based on standard protocols and results, measuring the results so that educational institutions responsible for student learning can make decisions based on objective and structured data. Of course, these results must be student-centred and reflect the knowledge, skills, and well-rounded skills preferred by today’s students [6], [25]. The development of hardware and software technologies has made it possible to exchange and manage structured and complex information in an elastic way that society has undergone profoundly radical changes. Thus was born the idea of bringing new technologies into the world of teaching. The first outcomes of this attempt undoubtedly show that learning seems to be significantly facilitated by electronic technologies [18], [38], [54].

Educational institutions quickly discovered that e-assessment allowed them to drastically reduce the time it took to create and manage a student’s exam, benefiting all involved: the student, the teacher and the educational institution [2], [11]. Students prefer electronic assessments because they have more control over the situation and experience less stress throughout the exam; friendly interfaces and enjoyable environments are more appealing than the conventional ones. It is also quick and straightforward to use, with rapid feedback. The electronic evaluation may undoubtedly boost student performance by increasing motivation. The emotional component is equally crucial because it allows groups to communicate dynamically by neutralising distances [39], [9], [31]. Teachers also wink at e-assessment because it saves time in document correction, allows for the evaluation of a more significant number of students concerning the time available for this activity, aids in the monitoring of student performance and analysis of data obtained thanks to the many possible evaluations, and allows for the classification of concepts exposed to the students’ understanding. Finally, because e-assessment provides structured data valuable for management and control available in a short time, the same educational institutions can speed up the decision-making process [10], [5], [15].

With the advent of the pandemic, the level of use of remote communication technologies has suddenly and unexpectedly increased, and e-assessment has played a fundamental role in all of this [41]; educational institutions were forced to resort to the help of online lessons and tests rapidly [36], [4]. This has allowed researchers in the sector to have an enormous amount of data to study, which will allow them to learn more about the impact these technologies can have on learning [11].
Furthermore, this has made it possible to uncover some critical points of the remote assessment process, such as authentication issues [27], [29], [27], anti-cheating methods [7], [21], and described their approach to validate the exam conducted from a remote location [20], [17].

III. SYSTEM SERVICE ARCHITECTURE

The system architecture is distributed on a cloud platform through a complex subdivision of scalable and redundant microservices that guarantee very high reliability to service availability offered to users. The overall architecture is divided into different availability areas, and in particular, we have configured two availability zone, zone A and zone B, two regions far enough away to guarantee disaster recovery but still in the surroundings of the city of Milan. This means each microservice, like the file system, or the database, are replicated across multiple areas within the Milan area. This architectural model assures us that LibreEOL functions can continue to be provided to users even in case of faults. A synthetic schema of the system architecture is shown in figure 1.

The client requests are managed by an Application Load Balancer [35], [14], which is a significant application operating at level 7 on the ISO/OSI stack. Its task is to sort the number of active connections among the various Apache nodes, distributing the load over them in the most homogeneous way possible. The algorithm used for load sharing is Least Outstanding Requests (LOR) which assigns new HTTPS connections to nodes with fewer outstanding requests. Nodes are Docker containers running within a cluster managed by an orchestrator, which ensures that these are always properly functional and efficient. If a container no longer responds to requests or has saturated the RAM because of a memory leak, it is immediately restarted. The containers are all identical, running the Ubuntu Linux OS and an Apache webserver. HTTPS requests reach one of the apache servers and are then handled by returning, for example the LibreEOL homepage. The container cluster uses horizontal autoscaling. Autoscaling increases or decreases the number of active containers in the Docker cluster based on CPU utilization percentage and makes user requests get handled correctly even during peak hours (i.e. when there are many exams simultaneously). If the CPU usage reaches a global average value of 60% on all the containers, the newly incoming requests will be routed to a new container created to empower those already present. As soon as the exams finish, the CPU goes back to lower usage levels and therefore, the autoscaling brings the number of active containers progressively back to a lower quantity, reducing platform costs and keeping the system efficiency at the highest levels all the time. In order to preserve the consistency of the data saved on the storage, the system uses a Network File System distributed throughout mount points individually hooked by each container. In this way, data written on container 1 located in availability zone A can also be correctly processed by container N in the availability zone B. Correct data redirection can only be done in real-time by tracking the PHP session. A user could start his interaction with the system on node 1 of Availability Zone A and continue to use the contents through another node thanks to the load balancing performed by the load balancer. A Redis database is used to manage the user session, to assure consistency and reliability. That allows making computational processes’ movements transparent to the user between one container and another. Further strength for the architecture created is the possibility of distributing the computation cost due to the SQL requests on the database. The database is a cluster of MySQL servers created through the use of a horizontally scalable architecture that includes a Writer (Master) node and N Reader (Slaves) nodes. The cluster is replicated on both Availability Zones to guarantee fault-tolerance and High Availability (HA).

LibreEOL is a Web App structured with a PHP-based backend, a JavaScript-based FrontEnd and MySQL is used as RDBMS. We have always tried to adopt standard solutions in developing the code, preferring HTML5 native approaches and respecting good practices in Human Computer Interaction and User eXperience. So, the languages used to create and develop LibreEOL have been JavaScript, PHP, SQL and Bash. A student’s test execution is not needed to download additional components or install other software to the web browser, except technical cookies; this guarantees immediacy and ease in using the contents without introducing further overhead to the computer.

IV. SYSTEM LOGICAL ARCHITECTURE

LibreEOL is a web application based on the Model-View-Controller (MVC) architectural pattern [24] that allows the management of electronic examinations for individual courses and enables the collection of statistical data that can be used to improve the quality of teaching.

A. USER ORGANIZATION

Users and content are divided into groups (i.e. Universities) and subgroups (i.e. Departments). Users are divided into the following roles: students, examiners, teachers and administrators. The examiner role is designed to support the teacher in conducting the examination sessions of a course. This role does not have any authority over the information content of questions relating to the course itself. The operations that a user can carry out within the system are determined by the role to which they belong. Each profile is associated with different interfaces with functionalities consistent with the operations allowed within the specific role. It is possible to connect it to an Identity Management service to assign roles automatically, to enhance the platform’s usability.

B. CONTENT ORGANIZATION

Each teacher can create one or more courses made up of a set of questions classified according to the level of difficulty and topic.
Several teachers and examiners may be associated with each course. The teacher is allowed to express his questions using a set of 11 different types: Multiple choice, Multiple choice with a score, Multiple responses, True/False, Yes/No, Essay, Hotspot, Numerical, Text match, Text match case sensitive and "QR code". While Multiple Choice supports one answer as true and the others as false, in Multiple Choice with a score it is possible to assign a positive/negative floating point value to all answers. The Hotspot type allows selecting a portion of the image to indicate the answer. The Essay type allows answering by entering free text. A Numerical question allows providing a numerical result (an answer with a tolerance of 3% of the value given by the teacher is accepted). The "QR code" typology allows the upload of the images acquired with a smartphone of a free-written paper, as happens in in-person examinations.

C. EXAM ORGANIZATION

Each teacher can create examination sessions according to the settings they have configured. In this way, it is possible to create complete examination sessions or mid-term evaluation tests covering a subset of the topics. Creating an exam call requires the teacher to indicate which exam settings to use. These include the possibility of activating or not activating the algorithms for conducting examinations remotely. Once the exam session has been created, students can register and eventually take some demo tests provided by the teacher. On the day of the exam at the scheduled time, the teacher will provide the password to allow students to access the exam and take the test. If the exam session is held remotely, the teacher can monitor all the students through the "Live view" tool, which allows him/her to observe all the students taking the exam.

At the end of the examination, the teacher will access a panel summarising the tests taken and listing the candidates. This panel allows the teacher to view the individual tests and set the grade, either by accepting the value proposed by the system or by defining it, as is the case with "QR code" or open-ended questions (Essay).

Once the exam has been completed, the teacher archives the exam. The results could be sent by email to the students if the teacher enabled the option while creating the exam.

D. STATISTICAL ANALYSIS

The system provides various statistics and reports, and it is in this ability, one of the central added values of conducting examinations on an electronic platform is hidden. The teacher can monitor the frequency of correct answers among the various students within a course and between courses of different years. Careful evaluation of these indicators allows...
the teacher to calibrate the content delivered and the mode of delivery.

Administrators obtain a distribution of the tests by day and month, enabling them to proactively calibrate the resources made available to the system to carry out horizontal scaling (increasing active resources initially in anticipation of high usage peaks). It is also possible to plan vertical scaling of the infrastructure (switching to more powerful hardware in anticipation of high usage peaks).

V. ALGORITHMS IMPLEMENTED TO VALIDATE STUDENTS’S ACTIVITY

The central aspect that deserves serious consideration when one decides to take exams remotely is to ensure that the test measures the actual skills, quality and quantity of a student’s knowledge. Furthermore, it is also essential to ensure that the test has legal validity, i.e. it is necessary to prevent the student from receiving suggestions or information from the outside. The technology developed by us is divided into various components that analyze the ambient audio, the video stream captured by the webcam, the mouse movements and the keyboard. In the design phase, we took particular care of efficiency, and we intended to focus on a code capable of running on inexpensive devices with low computational power. Students often own old laptops and smartphones. Therefore, our technique is completely based on geometry and basic mathematical operations that make our algorithm fast and executable on most of the hardware used by students. Neither a dedicated graphics accelerator is required. All the algorithms presented have properly been run on dual-core CPUs produced since 2010.

A. ALGORITHM FOR VIDEO STREAM ANALYSIS

Our objective is for the student to take the test without being distracted or receiving illicit assistance. The system requires a camera and microphone to verify how the test is being carried out remotely; thus, the test may be conducted from remote locations. The images captured by the camera represent sensitive data and are rich in information. We built our algorithm to keep the number of photographs and sounds saved on the server to a bare minimum and keep the server’s information for as little time as possible. Each student had to provide permission for this sensitive data to be processed before taking the exam.

1) Identification of the face movements

A very significant aspect for identifying a student misbehaviour concerns the identification of video distractions, intended as too wide and sudden movements of the head. In figure 2, the 68 landmarks produced by the neural network that we use for this function are shown. Neural networks perform the task of automatically classifying classes of objects in the most varied fields of application [32], [33]; in our specific case, the network has been developed in such a way that it can recognise the landmarks of the user’s face.

![Image](image_url)

FIGURE 2: The identification of the landmarks computed by the neural network from the collected webcam flow of images.

Starting from analysing the subject’s face and its movements in space, we can assume with high reliability whether his/her conduct has been inappropriate. This is obtained using a neural network that provides landmarks extraction and detects 68 points on the subject’s face representing them by X, Y coordinates in a Cartesian plane.

In figure 3(a), we can graphically analyze the algorithm computation. The photograph shows explicitly a student who is staring at the monitor. It is possible to notice that the face is contained within two red-bordered rectangles, an inner and an outer one. The blue rectangle represents the polygon tangent to the outermost points of the student’s face and represents our centre of gravity. These rectangles represent the tolerance of the system. The algorithm computes as follows: in the beginning, the neural network computes the landmarks, and the algorithm evaluates the relative tolerance threshold so that the student can move, breath, yawn. These two rectangles are periodically recalibrated over the student’s face in order to ensure that they are always consistent with his/her position. It is, in fact, taken into account that during an exam that can even last 2 hours, the student can move slightly to get more comfortable. If the learner turns away from the screen and does not look at it, the blue square will touch or even exceed the boundaries set by the red rectangles’ corners.

In figure 3(b) an example about this behaviour has shown.

In that case, a photograph of the event is taken, and a distraction is counted.

2) Monitoring of all students taking the exam

Low-resolution images are extracted from the webcam images at 2-second intervals and displayed on the exam’s associated Live View page so that the teacher can monitor the progress of the exam as a whole. Based on the images shown, the teacher can send Chat messages to individual
students or all the participants. This tool has an enormous impact and power on the teacher and allows them to establish important contact with students during the exam. The images shown in the “Live View” panel are also displayed on the page dedicated to each student, showing the various video distractions, any audio recorded, the times the client was disconnected from the server and for how long, and the number of times the exam page was reloaded. This page is essential for assessing the correctness of the test taken by the student. Figure 4 shows the Live View environment described above while the exam is in full swing. Figure 5 shows a student’s summary page with indications of the events that characterized the test and allow the teacher to make a final decision on the correctness of the test.

**B. ALGORITHM FOR ANALYSING ENVIRONMENTAL AUDIO**

Through JavaScript code we obtain the audio stream from the microphone. The audio is analysed with a sampling rate of 48K times per second and a bit rate of 64KBps. The audio we capture is stereophonic. We first calculate the average value of the ambient sound pressure. If we detect a peak, i.e. a sound with an intensity more remarkable than the average of the last period, then, for the duration of the event, we record an audio file that in this first phase will be stored in the RAM memory of the computer. The audio file is recorded in OGG format. This is an open format, open-source and released under a BSD licence.

The OGG format can store audio encoded using the lossy compression algorithm ‘Vorbis’, also released under a BSD licence. The recording phase, monitoring of ambient sound pressure and coding of the audio flow, takes place entirely on the client, i.e. it is carried out by the student’s computer, with a low expenditure of computational resources. An example that graphically shows the variation of the ambient sound pressure during a speech can be seen in figure 6. The system then checks the length of the recorded audio file. If it is less than 1 second long, it is not uploaded to the server. If, on the other hand, its duration is greater than or equal to one second, then it is securely stored in the system, and the audio event associated with the student is recorded in the database. Monitoring takes place throughout the examination.

**C. MOUSE AND KEYBOARD MONITORING ALGORITHM**

To prevent students from obtaining content and information on the Internet, we built algorithms that ensure that they only sit the test with the knowledge they have gained throughout their studies. The examination screen is enlarged and displayed in full-screen mode when the test is started. Any windows that may have been open are then covered by the application screen, which will occupy the entire visible area of the student’s screen. At the same time, mouse monitoring is started; in particular, we want to prevent the mouse from leaving the examination screen and clicking on external areas, such as on a second monitor. To do this, we first install an event listener on the web page that will monitor the property “focus”. This property tells us whether or not the web page is in the foreground, or whether the user is clicking or acting on elements in the background or on other monitors. The loss of focus, in fact, guarantees that the student has clicked outside the examination window.

If a student clicks outside the examination window, a picture of the event is taken, and the timestamp of the event is stored in a server-side counter. Before starting an exam, the teacher can define the maximum number of times a student can click outside the exam window. It is essential to provide a certain margin from our tests, and not be too strict on this aspect. We think it is correct to set the ‘focus lost’ parameter to 3. It is, in fact, possible that during the exam, the student has notification from the antivirus program requesting an interaction, or he has audio problems and needs to click on the headset control panel, or it is possible that he accidentally clicks out of the exam. In any case, once the occurrences the student loses focus on the page exceed the parameter set by
the teacher, the exam is closed and the student is ejected from
the session. In addition to this, a series of checks are carried
out on the keyboard and on the mouse’s interaction with the
page. These controls prevent the copying/pasting of text to
and from the examination page.

1 $(document).mouseleave(function () {
    console.log("Focus lost !");
  });
2 $(document).mousemove(function () {
    console.log('Focus in');
  });
3 $(window).blur(function () {
    if(!document.activeElement instanceof HTMLIFrameElement ){
        console.log("Focus lost !");
    }
  });

Listing 1: Mouse control code

Furthermore, the page printing functionality, the screen
recording functionality and the print screen functionality are
inhibited.

VI. SYSTEM’S USABILITY

The system’s usability is one of the essential aspects of
designing a software application. A modern web application
must be easy to use, must not require lengthy explanations of
how the graphical interface works, be respectful of minorities
and consider users’ disabilities. Furthermore, applications of
this type should not require any special skills on the part
of the users. We have also considered the different types of
users, and the disabilities that people using the system may
have.

For example, some students have difficulty using the
mouse or carrying out drag and drop operations, so we
have designed an interface that does not require the mouse,
drag and drop movements or operations requiring complex
motor coordination. A low percentage of students also have
Specific Learning Disorders (SLD) to varying degrees. An e-
assessment system allows the teacher to offer these students
a test tailored to their needs, including more time for the
test and questions formulated to facilitate comprehension or
mathematical calculations.

When developing the user interface, we took the impor-
tance of colours seriously, so we chose a colour palette
that would not cause confusion or problems for people with
colour blindness. According to the most recent estimates,
4.2 per cent of the world’s population is colour blind, and
in Italy itself there are 2.5 million people affected by this
In many disciplines such as mathematics, chemistry, physics or the humanities, it is crucial to write by hand on sheets of paper, carry out calculations better, prove theorems, and make graphs or drawings. To this end, a particular type of question has been created that allows students to securely upload photographs of the paper they have produced, through
a QR Code using a smartphone. The smartphone is necessary to take high-resolution photos of the paper produced by the student. Once the camera has framed the QR Code, this is decoded and the web page dedicated to uploading the images appears. Each QR Code uniquely associates the paper produced by the student with his examination.

We submitted a questionnaire to the users, allowing them to voluntarily express a series of considerations on the qualitative assessment and problems encountered during the use of the system. We obtained a satisfaction index of 81.4% of the sample, indicating an important general appreciation level. Thanks to an agile programming approach and constant interaction between developers and end-users, the system’s usability is continuously improved.

VII. DISCUSSION OF RESULTS

From 21 February 2021 to 21 September 2021, we kept a direct communication channel open between the platform and the students by delivering an online questionnaire. That allowed us to collect valuable information directly from the primary users of the platform. The students voluntarily participating in the anonymous questionnaire were 1423, expressing their opinions and views on the system we have developed. The questionnaire consisted of eleven questions divided into eight sections. The preliminary questions were technical and aimed at understanding the tools used by the students to access the examination platform. The first question asked which browser the student was using, while the second asked about the operating system. The results show that 79.4% of the students use Google Chrome, 8% use Firefox, and 5.8% use Safari. The remaining 6% of the students use less popular browsers such as Brave, Chromium, Microsoft Edge, Internet Explorer, Opera and Samsung’s Browser Internet. The second question got the following responses: 62.5% of the students use Windows 10, 11.9% of the students use macOS, in the third position we find Windows 7, used by 8.2% of the students. The results obtained from these first two questions are highly significant as they show us that the development environment on which to program and develop the software code must first be tested on the Google Chrome browser. As far as the functionality of the application we have created is concerned, the operating system is of less importance since we do not use any particular APIs that would make Windows rather than other systems decisive. In the preliminary software’s development, we have tried to devise a code that runs on as many devices as possible.

The next question asked the students whether they experienced particular events during their examination, such as unexpected notifications, irrelevant error reports or unexpected behaviour. 84% of the students answered that they had not experienced any particular events, while 16% answered that they thought the system had behaved unexpectedly. These students, in particular, were asked, employing an open-ended question, to describe the event that had occurred during the examination session. We collected a total of 228 answers. Some of them explained that the cause of the problems they experienced was slow internet line at home, which delayed the loading of images and texts. Others described that notifications from the operating system, not caused by LibreEOL, had appeared in the foreground and distracted them, such as notifications of antivirus software, new emails or system updates. The most interesting answers are related to the algorithm we programmed for face tracking. In fact, some students reported that they had received warnings following small movements of the face that are part of the natural behaviour in concentration situations. These latter responses were precious to us, as we immediately took them into account and made adjustments, corrections and calibrations to the system to address these issues. In particular, we calibrated the face at the start of the test and at regular intervals to ensure that the face tracking also took into account the natural posture adjustments that people make when they sit in front of the computer for one or more hours. In addition, we have made sure that the distraction notifications we give to students are even better calibrated. These notifications are important because they allow the student to be warned if the system detects incorrect conduct. Nevertheless, it is essential to consider that the number of notifications and warnings that an automated system can give to a person while he or she is taking an exam must be wisely limited. There may be situations that are not caused by a person’s failure to comply with the most basic behavioural rules but are caused by other problems, such as a webcam with poor resolution, or poor room lighting, or an incorrect framing of the face that could generate a high number of alerts. In this case, we stop sending notifications to students when a certain threshold is exceeded. According to our tests, the optimal maximum number of alerts per person is 6. More warnings could only be counterproductive and lead to the person becoming impatient. It should also be borne in mind that the teacher is responsible for monitoring the students’ video streams throughout the exams. So, the teacher can also view the counters for the number of facial distractions, and the number of audios detected and analyse them in real-time via a secondary browser window. Thanks to these measures that we have implemented in the platform, we have not received any further reports of inappropriate warnings given to students.

The next question asked the students whether they experienced any additional discomfort during the examination. This question was answered by 100% of the students. Among them, 75.9% answered that they had not experienced any discomfort, while 24.1% (343 students) stated that they had experienced further problems. These students were then asked to express what kind of discomfort they had experienced while using the system through an open-ended text field.

The students answered that they had experienced anxiety were 76, while 12 students stated they had experienced stress during the examination. Students who experienced anxiety represented 5% of the total number of students interviewed, while those who experienced stress represented 0.8% of the total. Their valuable evaluations and the relevant advice pro-
vided to us by this small percentage of students contributed to an highly significant improvement in the usability and characteristics of the system. We realized that to reduce the students’ stress and anxiety levels, we needed to implement a series of algorithms to help them feel less alone. The algorithms we introduced provide visual and textual feedback to the student, reassuring them that they are progressing well.

The first algorithm relates to the auto-saving function of the exam, which occurs automatically at periodic intervals. This function allows the student’s answers to be stored in the system’s database before the exam is finally handed in. Auto-saving allows the exam to be retrieved if the student’s computer crashes, the power goes out, a network disconnection occurs, or other problems prevent the exam from continuing. Each time the exam is auto-saved, a small green text appears to the student informing him that the test has been correctly saved in the database.

The second algorithm implemented carries out a periodic check on the photographs that are loaded into the system relating to the QR codes displayed on the student’s exam page. When the system detects that the student has uploaded a photograph via QR code, a photograph relating to an exercise that he had to carry out on paper, the system will inform him that the photograph has been saved correctly on the exam page and not only on the smartphone screen.

The third algorithm we implemented allows direct communication via chat messages between the student and the teacher. One of the reasons that caused the most anxiety was the lack of communication between the teacher and student during the exam. This feature allows students to feel part of a community and not just an individual mechanically assessed by a software programme.

The next question asked for an overall assessment of the system’s quality: 81.4%, i.e. 1158 students, said that the system has a high level of quality and praised its features; 10.3% of the students considered the software invasive from the point of view of privacy; 8.3% of the students felt that the system was not appreciated and that it should not be used.

Thanks to the data collected, we received a confirmation of the goodness of the solutions adopted to manage better and protect personal data. In fact, through application’s design, only a minimal amount of sensitive data (photos, sounds, text of chats) are collected. They are saved on the file system only for the time needed by the teacher to carry out the examination procedures.

We have met with student representatives several times, collected suggestions and objections, and publicised the guides we have produced and all the documentation available on the website. We have explained to them the techniques adopted to protect personal data, receive their active collaboration and calm the students’ spirits.

All facial detection and tracking algorithms only work on the student’s computer, and no biometric data is processed or sent from the clients to the server.

The last question was an open-ended one. We asked the students to express any criticism or constructive proposals for improving the software. A total of 248 people responded, most of the criticisms and suggestions related to topics we discussed earlier, such as more effective face calibration and the request to have visual feedback on events that occur during the exam (such as self-saving) and the request to have the possibility to speak even only verbally with the teacher. These were all valuable suggestions that motivated us to refine and release changes that had already been planned and developed in the test environment, such as the chat environment, real-time calibration to adapt the control system to the natural movements of the person, refining the online documentation, enhancing support via social networks and email.

VIII. DATA PROTECTION ISSUES

The European Union adopted in 2016 the General Data Protection Regulation (GDPR) 3. A processing operation is likely to pose a high risk to the rights and freedoms of data subjects because of the systematic monitoring of their behaviour, the large number of data subjects whose sensitive data are perhaps processed, or even because of a combination of these and other factors. In such cases, GDPR obliges data controllers to conduct an impact assessment before commencing the processing, consulting the supervisory authority if the technical and organizational measures they have identified to mitigate the impact of the processing are not deemed sufficient, i.e., when the residual risk to the rights and freedoms of data subjects remains high.

We have drafted the Data Protection Impact Analysis (DPIA) for LibreEOL using the program made available by the French Data Protection Authority, CNIL 4, a multilingual open-source distribution made available for all Linux distros and Windows 10 under the Windows Subsystem for Linux (WSL) as appimage. 5

Following the document’s structure proposed by the CNIL, the operations involving the management of personal data (images of the student, of the room in which the examination is conducted and environmental audio) have been detailed, specifying the technical solutions adopted and the associated risk. This phase of analysis allowed us to adopt appropriate changes to the code of the proposed application, aimed at minimizing the amount of data collected, the length of the

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3The General Data Protection Regulation is a European Union regulation on the processing of personal data and privacy, adopted on April 27, 2016, published in the Official Journal of the European Union on May 4, 2016, and entered into force on May 24 of the same year and operational as of May 25, 2018. It is known as Regulation 2016/679.
4Please visit the URL: https://www.cnil.fr/fr/analyse-dimpact-la-cnil-publie-la-version-3-0-de-son-logiciel-pia
5Please visit the URL: https://appimage.org/
data retention period before deletion and the methods of secure and encrypted storage of data that must be retained for more extended periods.

In some situations, unfortunate choices had to be made, in the sense that it was necessary to give up handling data that would have allowed better support to users but could give rise to ambiguous interpretations on the appropriateness of such processing.

The outcome of the impact assessment was that the risk was negligible.

IX. CONCLUSION AND FUTURE WORK

We have created a platform for secure remote online exams that respects personal data and the users’ primary needs. Security by design and privacy by design were the foundations of our work. During the COVID-19 pandemic, the platform proved helpful, with the University of Perugia adopting it as the official tool for conducting exams remotely. The high level of participation in the questionnaire we administered, together with the high level of acceptance and the impressive number of examinations taken in one year (over 50,000), are, in our opinion, the best proof of the validity of our work.

Thanks to the difficult period that we have experienced at world level, we believe that, at least in our university, an extraordinary cultural revolution has taken place, driven by students and led to a profound transformation among the teaching staff. They have experimented mainly with an efficient and effective way of evaluation, made possible thanks to a re-thinking of how evaluation is carried out. We are confident that this acquired patrimony will remain over time and facilitate the teachers’ evaluation work and allow the students to expand their competencies and knowledge more completely.

Our future work on the platform will be inspired by a desire to increase support for teachers and students by identifying new forms of questions and answers that make the assessment process as natural, intuitive, and immediate as possible. We also wish to increase support for those who experience difficulties in their daily lives, for example, by implementing screen-reading assistants or voice assistants for entering answers to questions via voice feedback provided by the student.

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AUTHOR CONTRIBUTIONS

Conceptualization, Osvaldo Gervasi, Damiano Perri and Marco Simonetti; Data curation, Osvaldo Gervasi, Damiano Perri and Marco Simonetti; Investigation, Osvaldo Gervasi, Damiano Perri and Marco Simonetti; Methodology, Osvaldo Gervasi, Damiano Perri and Marco Simonetti; Software, Damiano Perri; Supervision, Osvaldo Gervasi; Validation, Osvaldo Gervasi, Damiano Perri and Marco Simonetti; Writing – original draft, Osvaldo Gervasi, Damiano Perri and Marco Simonetti; Writing – review & editing, Osvaldo Gervasi, Damiano Perri and Marco Simonetti.

REFERENCES

[1] Sultan Refa Alothai. A novel framework of success using e-assessment during corona pandemic. International Journal of Emerging Technologies in Learning, 16(12), 2021.
[2] Nuha Alruwais, Gary Willis, and Mike Wald. Advantages and challenges of using e-assessment. International Journal of Information and Education Technology, 8(1):34–37, 2018.
[3] Abed Alkarim Ayyoub and Oqab Jabali. University students’ evaluation of e-assessment in light of the coronavirus pandemic. Cypriot Journal of Educational Sciences, 16(4):1434–1449, 2021.
[4] Fatima Azni and Heba Bakr Khoshaim. The covid-19 pandemic and the challenges of e-assessment of calculus courses in higher education: A case study in saudi arabia. International Journal of Learning, Teaching and Educational Research, 20(3), 2021.
[5] Randy Elliot Bennett. Inexorable and inevitable: The continuing story of technology and assessment. Computer-based testing and the internet: Issues and advances, 1(1):201–217, 2006.
[6] Nicole A Buzzetto-More and Ayodele Julius Alade. Best practices in e-assessment. Journal of Information Technology Education: Research, 5(1):251–269, 2006.
[7] Daria Bylieva, Victoria Lobatyuk, Sergey Tolopygin, and Anna Rutsova. Academic dishonesty prevention in e-learning university system. In World Conference on Information Systems and Technologies, pages 225–234. Springer, 2020.
[8] Velusami Deepika, Krishnamurthy Soundaraya, Kaliaperumal Karthikeyan, and Ganapathy Kalaiselvan. ‘learning from home’: role of e-learning methodologies and tools during novel coronavirus pandemic outbreak. Postgraduate Medical Journal, 97(1151):590–597, 2021.
[9] Judy Donovan, Cynthia Mader, and John Shinsky. Online vs. traditional course evaluation formats: Student perceptions. Journal of Interactive Online Learning, 6(3):158–180, 2007.
[10] Alden Jack Edson. Learner-controlled scaffolding linked to open-ended problems in a digital learning environment. ZDM, 49(5):735–753, 2017.
[11] Mohammad Ali H Eljinni, Salwa Alsamarai, Suha Hameed, and Amaal Amawi. The impact of e-assessments system on the success of the implementation process. International Journal of Modern Education and Computer Science, 4(11):76, 2012.
[12] Osvaldo Gervasi, Riccardo Catanzani, Antonio Riganelli, and Antonio Laganà. Integrating learning and assessment using the semantic web. In Osvaldo Gervasi, Marina L. Gavrilova, Vinip Kumar, Antonio Laganà, Heow Pueh Lee, Youngsong Mun, David Taniar, and Chih Jeng Kenneth Tan, editors, Computational Science and Its Applications – ICCSA 2005, pages 921–927, Berlin, Heidelberg, 2005. Springer Berlin Heidelberg.
[13] Osvaldo Gervasi and Antonio Laganà. Eol: A web-based distance assessment system. In Antonio Laganà, Marina L. Gavrilova, Vinip Kumar, Youngsong Mun, C. F. Kennedy Tan, and Osvaldo Gervasi, editors, Computational Science and Its Applications – ICCSA 2004, pages 854–862, Berlin, Heidelberg, 2004. Springer Berlin Heidelberg.
[14] Osvaldo Gervasi, Damiano Perri, Marco Simonetti, and Sergio Tasso. High performance computing and computational intelligence applications with multi-chaos perspective. In Yeliz Karaca, Dumitru Baleanu, Yu-Dong Zhang, Osvaldo Gervasi, and Majaz Moonis, editors, Multi-Chaos, Fractal and Multi-Fractional Artificial Intelligence of Different Complex Systems, pages 40+. Elsevier, in Press, April 2022.
[15] Lester Gilbert, Denise Whitelock, and Veronica Gale. Synthesis report on assessment and feedback with technology enhancement. Project report, University of Southampton Institutional Repository, July 2011.
[16] N Gordon. Colour blindness. Public Health, 112(2):81–84, 1998.
[17] Isabel Guitart Hormigo, M Elena Rodríguez, and Xavier Baró. Design and implementation of dashboards to support teachers decision-making process in e-assessment systems. In Engineering Data-Driven Adaptive Trust-based e-Assessment Systems, pages 109–132. Springer, 2020.
[18] Hatim Ibrahim and Abdullah Saad H Alqahtani. The impact of adopting web 2.0-based e-book on student learning skills. EURASIA Journal of Mathematics, Science and Technology Education, 14(6):2509–2522, 2018.

[19] Luke Jefford and Richard Harvey. An interface to support color blind computer users. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI ’07, page 1535–1538, New York, NY, USA, 2007. Association for Computing Machinery.

[20] Yassine Khifi and Hassan A. El-Sabagh. A novel authentication scheme for e-assessments based on student behavior over e-learning platform. International Journal of Emerging Technologies in Learning (iJET), 12(04):pp. 62–89, Apr. 2017.

[21] Christophe Kiennert, Nathan De Vos, Manon Knockaert, and Joaquín García-Alfaro. The influence of conception paradigms on data protection in e-learning platforms: A case study. IEEE Access, 7:64110–64119, 2019.

[22] Antonio Laganà, Osvaldo Gervasi, Sergio Tasso, Damiano Perri, and Francesco Franciosa. The ecm virtual education community prosumer model for promoting and assessing chemical knowledge. In Osvaldo Gervasi, Beniamino Murgante, Sanjay Misra, Elsa Stankova, Carmelo M. Torre, Ana Maria A.C. Rocha, David Tanier, Bernady O. Apduhan, Eufemia Tarantino, and Yeonseung Ryu, editors, Computational Science and Its Applications – ICCSA 2018, pages 533–548, Cham, 2018. Springer International Publishing.

[23] Carlo Lazzari, Sean McAlear, Abdul Nusair, and Marco Rahottini. Psychiatric training during covid-19 pandemic benefits from integrated practice in interprofessional teams and ecological momentary e-assessment. Rivista di psichiatria, 56(2):74–84, 2021.

[24] Avraham Leff and James T Rayfield. Web-application development using the model/view/controller design pattern. In Proceedings fifth ieee international enterprise distributed object computing conference, pages 118–127. IEEE, 2001.

[25] Terence Love and Trudi Cooper. Designing online information systems for portfolio-based assessment: Design criteria and heuristics. Journal of Information Technology Education: Research, 3(1):65–81, 2004.

[26] M Marmor. Vision, eye disease, and art: 2015 keeler lecture. Eye (London, England), 30:287–303, 11 2016.

[27] Harvey Mellar, Roumiana Peycheva-Forsyth, Sarpal Kocdar, Abdulkadir Karadeniz, and Blagovesna Yovkova. Addressing cheating in e-assessment using student authentication and authorship checking systems: teachers’ perspectives. International Journal for Educational Integrity, 14(1):1–21, 2018.

[28] David Nicol. E-assessment by design: using multiple-choice tests to good effect. Journal of Further and higher Education, 31(1):53–64, 2007.

[29] Alexandra Okada, Denise Whitelock, Wayne Holmes, and Chris Edwards. e-authentication for online assessment: A mixed-method study. British Journal of Educational Technology, 50(5):861–875, 2019.

[30] Federico Giorgetti Osvaldo Gervasi and Antonio Laganà. Distance assessment system for accreditation of competencies and skills acquired through in-company placements (dasp), 1999. INET ’99, The Internet Global Summit, 9th INET International Conference, 22–25 June 1999 McEnery Convention Center San José, CA, USA.

[31] Kay Penny and Jacqueline Brodie. Student and staff perceptions of the use of multiple choice testing in higher education assessments. In EDEN Conference Proceedings, pages 184–192. George Mason University Libraries, 2014.

[32] Damiano Perri, Marco Simonetti, Andrea Lombardi, Noelia Faginas-Lago, and Osvaldo Gervasi. Binary classification of proteins by a machine learning approach. In Osvaldo Gervasi, Beniamino Murgante, Sanjay Misra, Chiara Garau, Ivan Blečič, David Tanier, Bernady O. Apduhan, Ana Maria A. C. Rocha, Eufemia Tarantino, and Carmelo Maria Torre, editors, Computational Science and Its Applications – ICCSA 2020, pages 549–558, Cham, 2020. Springer International Publishing.

[33] Damiano Perri, Marco Simonetti, Andrea Lombardi, Noelia Faginas-Lago, and Osvaldo Gervasi. A new method for binary classification of proteins with machine learning. In Osvaldo Gervasi, Beniamino Murgante, Sanjay Misra, Chiara Garau, Ivan Blečič, David Tanier, Bernady O. Apduhan, Ana Maria A. C. Rocha, Eufemia Tarantino, and Carmelo Maria Torre, editors, Computational Science and Its Applications – ICCSA 2021, pages 388–397, Cham, 2021. Springer International Publishing.

[34] Damiano Perri, Marco Simonetti, Sergio Tasso, and Osvaldo Gervasi. Learning mathematics in an immersive way. In Software Usability, pages 1–15. IntechOpen, March 2021.

[35] Damiano Perri, Marco Simonetti, Sergio Tasso, Federico Ragni, and Osvaldo Gervasi. Implementing a scalable and elastic computing environment based on cloud containers. In Osvaldo Gervasi, Beniamino Mur-
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