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Perception of the use of an e-lab platform for university students during the COVID-19 pandemic

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ABSTRACT

Developing electronic platforms during education disruptions, particularly during the COVID-19 pandemic, had become crucial to addressing educational gaps. Research has shown technology's significant contribution to improving teaching and learning methods in labs, whether theoretical or experimental. This study creates an e-laboratory platform for managing university-level physics-chemistry practical work. The aim is to measure the platform's impact on students' experimental learning and identify integration and usage constraints. Our methodology was both quantitative and qualitative, conducted in a public institution. Two hundred forty students from two departments completed the questionnaire, and 25 teachers participated in semi-structured interviews. Findings revealed that e-laboratory simulations facilitated comparing theoretical solutions with actual lab practices and achieved goals in terms of communication pace, pre-lab content exchange (video conferences), post-lab experiment records, and evaluation sessions providing feedback for student progress tracking. However, insufficient computer equipment, technical problems during experiment setup, and momentary video conference issues hindered effective communication. This study guides researchers in enhancing adult education program efficiency. Considering online learning's adaptability and cost-effectiveness, improving learning effectiveness can justify continued use of online teaching beyond the pandemic by universities. Hence, electronic laboratories and the exploration of their integration transcend the realm of university scholars; they stand as a reservoir of potentiality for the perpetual advancement of professionals across diverse domains, affording a continuum of erudition throughout one's lifetime.

Contribution/Originality: This research unveils effective physics-chemistry platforms in universities during COVID-19. Aligned with Moroccan ICT policies, this innovative initiative merits study, fills the research gap and beckons fellow scholars' attention towards technology's significant contribution to improving teaching and learning methods in labs, whether theoretical or experimental.

1. INTRODUCTION

Technological advancements have profoundly changed teaching and learning strategies in recent years due to their adaptability, variety, and ease of use, making them excellent techno-pedagogical tools in adult education, a major educational trend (Albiladi & Alshareef, 2019). Indeed, e-learning combines educational concepts, traditional teaching methods, and digital or even computer-based solutions to meet new educational needs (Zhou, Wu, Zhou, & Li, 2020). These needs may arise in emergency and educational disruption situations, such as the COVID-19 pandemic, where many universities had to turn to distance learning through technology.

In this context, Mundial and UNICEF (2016) have emphasized the need to provide alternative modes and establish value equivalence programs in emergencies, which has compelled teachers to deliver their courses digitally. Additionally, numerous studies have examined the role of digital instructions in the educational process and their effect on developing and enhancing an interactive learning environment (Danielson, 2011; Irving, 2015). Certain investigations have yielded proof of the substantial role of digital technology in enhancing evaluation methods, thereby influencing learners' intellectual understanding and proficiencies. Notably, Beatty and Gerace (2009) underscored teachers' constrained timeframe for gauging students' performance and furnishing feedback; although, contemporary technological progressions offer potential resolutions to this challenge. To exemplify, serious gaming has exhibited its efficacy in tackling ecological predicaments via simulation techniques. These earnest gaming platforms aspire to convey educational content through interactive and playful modalities while concurrently attaining pedagogical goals (De-Marcos, Garcia-Lopez, & Garcia-Cabot, 2016).

In Morocco, the foundations of education have undergone profound pedagogical and organizational transformations since the "Digital Morocco 2013" strategy, following the royal speech delivered on July 30, 2008, during the Throne Day celebration. This initiative requires the mobilization of all stakeholders in the education community to make information and communication technologies (ICT) a source of productivity for other economic sectors, particularly regarding the development of new pedagogical approaches in various scientific and technical subjects.

Other research has resulted in comparative analyses of social and political trends in the development of information technologies on an international scale, with a focus on observing and analyzing diverse experiences (Yuldasheva & Karimova, 2019). Additionally, online learning systems are defined as fully virtualized open and distance learning modalities through electronic means (Lara, Lizcano, Martínez, Pazos, & Riera, 2014). These systems aim to optimize resource utilization and reduce costs while enhancing interaction between students and teachers (Alajmi, Sadiq, Kamaludin, & Al-Sharafi, 2017). Furthermore, experiential learning represents a pedagogical model advocating active participation in activities closely related to the knowledge to be acquired, skills to be developed, and attitudes to be formed or modified (Legendre, 2005). In the field of physical and chemical sciences, which are inherently experimental, it is essential to teach them in line with their experimental nature (Kouela, 2012).

By combining various active methods, experiential learning aims to engage the learner as an actor in their learning process. It is particularly beneficial for struggling students who thrive in manipulation and experimentation situations. In this context, the learner experiences a hands-on situation, observes the results, reflects on what has occurred, and develops reasoning that can be applied. This transformation can be achieved using learning platforms, simulation software, applications, and electronic portals dedicated to delivering educational content and virtual laboratories. The latter enables the provision of recorded experiences through video imaging techniques, displaying all the experiment details by the didactic standards of the subject, especially in situations of study interruption or disruption.

Previous research has explored the development of information systems and simulation software that have been effectively used in implementing the online platform. For instance, work has been done on the three-dimensional modeling of practical work in crystallography (Daaif, Zerraf, Tridane, Benmokhtar, & Belaaouad, 2019a, 2019b) and the simulation of chemical kinetics experiments using the Monte Carlo method (Daaif, Zerraf, et al., 2019a). The main objective was to facilitate hands-on manipulations through different modules, accompanied by comprehensive documentation for strategic and flexible use (Daaif, et al., 2019). Moreover, the crucial importance of experiential learning in science education at the university level should be emphasized (Azar et al., 2022).

Based on these findings, it is interesting to study the impact of an e-laboratory platform developed in this context during the interruption of education in Morocco due to the pandemic. This platform was available to various Moroccan institutions and was a complementary tool for conducting practical work. It was used for conducting experiments in a real laboratory.

Hence, the study addressed the following questions:

1. To what extent did the e-laboratory platform positively impact the experiential learning of undergraduate students?
2. What pedagogical constraints hindered the use of the e-laboratory platform?

In this context, this study aimed to improve and support academics by addressing a hypothesis that evaluated and measured the effect of digital tools, particularly for the capitalization and management of experimental work in science under constraints like the pandemic. The aim was to measure the impact of the virtual laboratory platform dedicated to managing and capitalizing on physics and chemistry practical work developed and integrated into the digital workspace (DW). This study was conducted at the Faculty of Sciences Ben M'Sick (FSBM), affiliated with Hassan II University of Casablanca (UH2C).

The pedagogical advantage of integrating a remote virtual laboratory platform is to offer the possibility of using flexible and adaptive methods to conduct and manage practical work collaboratively. From the teachers' perspective, this platform should enable them to manage learning moments by ensuring traceability of the steps of preparation, manipulation, correction, remediation, and synthesis. This setup thus provides students with opportunities to deepen their knowledge using intelligent means, particularly for designing intelligent classroom services based on computer systems.

2. REVIEW OF LITERATURE

2.1. Online Learning

2.1.1. Specification

Online learning is a form of open and distance education that is fully virtualized through electronic means, providing a significant amount of information, primarily in the form of data and updates. This information often overwhelms teachers who struggle to process hundreds of documents generated by their students' actions (Lara et al., 2014).

Digital and electronic technologies (such as the Internet, Web 4.0, intranets, and extranets) enable access to educational programs outside the traditional classroom (Gaikwad & Vrishalli, 2016) and allow remote instructor interaction. However, the barriers to implementing and delivering online learning can be traced to technology (T), the individual (I), pedagogy (P), and enabling conditions (EC) (Ali, Uppal, & Gulliver, 2018).

Furthermore, distance learning facilitates interactions with content, pedagogical activities, hands-on experiences, peers, and learning tools, enabling students to achieve high educational satisfaction and cognitive understanding of course material (Tirziu & Vrabie, 2015).

Indeed, Web 4.0 is now being witnessed, also known as integration, (Aghaei, Nematbakhsh, & Farsani, 2012) in which machines and the human brain can directly interact. Participating in open web-based learning enables secure, collaborative, constructivist, and sustainable data sharing, such as virtual environments that establish platforms for managing practical work and experiments through multimedia and audiovisual tools. This involves experimental learning based on the simulation of real experiences or recording experiments conducted in a laboratory setting.

2.1.2. Categorization

Essential aspects of the concept of online learning, especially for experimental sciences that rely on experimentation, are reflected in its distributed, engaging, and flexible nature (Dominici & Palumbo, 2013). Indeed, an online learning system can conform to the definition of a socio-technical system as it involves actors (teachers and learners), structure (organization and environment), tasks (knowledge and skills), and technology (e-learning) (Upadhyaya & Mallik, 2013) considering the interactivity of the learning process and rhythmic communication in different modes: synchronous and asynchronous.

In correlation, the adoption of an online learning system relies on various advantages related to:

- Learners' motivation to actively participate in theoretical courses or practical work conducted in a distance mode.
- The development of learner autonomy and initiative in controlling their cognitive development.
- The stimulation of learner-teacher and learner-learner interactions by encouraging communication, collaboration, supervision, and self-supervision.
- The differentiation of learning rhythms allows learners to progress at their own pace, using multimedia elements in real learning situations.

2.2. E-Learning Modalities

E-learning has been widely adopted in higher education through various initiatives developed in university curricula. In 2014, 99% of institutions worldwide had learning management systems (LMS) in their electronic platforms, and 85% were effectively utilized (Dahlstrom & Bichsel, 2014). In the same vein, in Morocco, several projects have been developed as part of a "Digital University" dedicated to creating online teaching and learning methods through Massive Open Online Courses (MOOCs).

2.2.1. Virtual Classroom

It is a device used to facilitate a community by bringing together a group of individuals consisting of trainers and learners through a synchronous virtual environment (Raes et al., 2020). The virtual classroom includes videoconferencing techniques to transmit documents, exchange oral or written information, and conduct experiments. In our study, an e-laboratory platform represents a set of virtual classrooms, each containing recorded laboratory experiments. Furthermore, virtual classrooms are characterized by their flexibility and the ability to interact directly with peers. The advantages of virtual classrooms can be classified into two categories:

i. Organizational advantages related to access to education and teaching effectiveness (Raes et al., 2020).
ii. Pedagogical advantages are related to the quality of learning (Raes et al., 2020).

2.2.2. Social Learning or e-Tutoring

The mode of learning with human support is based on the theory of social learning developed by Canadian psychologist Albert Bandura (Bandura, 1989; Bandura & Walters, 1963) in developmental psychology research (Grusec, 1992). The cone of learning hierarchically ranks different learning methods further confirming the "social learning" approach developed by American educators Dale and Nyland (1960). Social learning (or vicarious learning) is based on reflective and active observation. This approach confirms that by observing others, learners understand how new behaviors are produced. In contrast, social learning differs from traditional "top-down" instructor-to-learner communication-based classical learning.

2.2.3. Mobile Learning (M-Learning)

Crompton (2013) defines mobile learning as: "learning across multiple contexts, through social and content interactions, using personal electronic devices."(Crompton, 2013). Furthermore, information is fragmented, decentralized, and becoming increasingly mobile. Therefore, it is relevant to adopt a new style of learning that can be strategic, based on short and gamified content that is interconnected. Mobile learning, or m-learning, is more intuitive. It refers to connectivity and the ability to learn faster and interact (consume, edit, and produce) with content in a specific pedagogical context.

2.2.4. Micro-Learning

Micro-learning is a distance learning method that involves learning through small units of training and targeted short-term activities. The goal of micro-learning is to deliver knowledge on a specific theme based on precise objectives, while the effects on productivity can be quickly measured.

Sequences of 3 to 10 minutes have a positive impact on knowledge acquisition and assimilation (Coakley, Garvey, & O'Neill, 2017). This approach provides adaptation to the dependencies and constraints of the human brain regarding the duration of reflection, attention, concentration, and high flexibility (Leach & Hadi, 2017) from a psychological point of view. In our study, some experiments lasted no more than 10 minutes in their execution and recording, and it was the role of video editing technicians to ensure that the video clips respected the minimum duration of the experiments for flexibility in their understanding.

2.2.5. Serious Games and Gamification

Serious games utilize simulation technologies of objects and environments, aiming to deliver educational content through gamified means to achieve pedagogical objectives, incorporating reward systems and social networks within an educational context (De-Marcos et al., 2016).

In relation to gamification, it embodies a pedagogical methodology that exudes playfulness and amusement, standing as a potent tool for captivating learner interest. This methodology encompasses repetitive elements and instigates a pleasurable and stimulating sense of rivalry among peers (Ding, 2019). Gamification can be characterized as the deliberate integration of game components to induce a game-like encounter within the realm of tasks and environments that are not inherently games (Seaborn & Fels, 2015).

2.3. Flexible Learning: A Pedagogical Solution in Cases of Education Disruption

Lee and McLoughlin (2010) defined flexible learning as: "a set of educational approaches and systems concerned with providing learners with increased choice, convenience, and personalization to suit their needs. In particular, flexible learning provides learners with choices about where, when, and how learning occurs, by using a range of technologies to support the teaching and learning process." It is a pedagogical approach that emphasizes the principles of constructivism by offering choices in educational environments. These educational choices include scheduling of classes, pedagogical content, learning styles, resources, location, requirements for ongoing progress, and communication channels (Collis, Moonen, & Vingerhoets, 1997; Goode, Willis, Wolf, & Harris, 2007).

Furthermore, another strategy that relies on flexible learning, particularly in an online context, frees participants from the spatial and temporal limitations of the traditional learning environment. It focuses on the learning process rather than the final outcomes and emphasizes authentic and dynamic tasks that value errors as opportunities for learning.

Moreover, the scope of flexible learning has expanded beyond the dimension of course offerings to encompass new pedagogies based on the concept of flexibility (Ryan & Tilbury, 2013). Additionally, Gordon (2014) and Ryan and Tilbury (2013) argue that flexibility in education is not only a characteristic of learners but also a pedagogical feature of educational strategies at institutional levels.

2.4. Experiential Learning: Principles of Quality

When the concept of experiential learning emerged in the early 1970s, it already had a strong foundation with several thinkers in education, particularly in adult education. According to Kolb (1984) learning is "the process whereby knowledge is created through the transformation of experience" (Kolb, 1984). The model developed by Kolb (1984) defines the characteristics that describe experiential learning as follows:

- Learning is the process of knowledge creation.
- Learning should be viewed as a continuous process based on experience, rather than a result to be achieved.
- The goal of teaching is to stimulate inquiry and enhance the process of knowledge acquisition, rather than memorizing large amounts of information.
- The learning process should resolve conflicts between two opposing modes of adapting to the world: concrete/abstract and internal/external experience.
- Learning is not solely the responsibility of cognitive and perceptual functions. Learning requires the participation of the whole body: reflection, feeling, perception, and behavior.
- Learning involves interaction between individuals and the environment.

According to Kolb, there are four modes of processing new information based on the following cognitive functions: perception, thinking, action, and feeling. Although several authors have revised Kolb (1984) the following characteristics are generally attributed to experiential learning:

- It is learner-centered.
- It arises from an inductive process based on experience.
- It focuses on both the learning process and the learned outcomes.

The choice of this model is due to its simplicity and adaptability. Experiential learning represents an ongoing process of adaptation to the world and is considered the most significant process of human adaptation.

Two basic principles guide experiential learning:

- The principle of continuity: This principle states that current experience builds upon past experience and shapes future experience. There is a continuum of experiences.
- The principle of interaction: Experience is always relevant and relational. All experiences result from the interaction between the subjectivity of the learner who undergoes the experience and the objective conditions of the environment in which the experience occurs.

Table 1. Components of the e-laboratory platform for the management and capitalization of practical work in physics-chemistry.

Components of the e-laboratory platform				
Items to use before the Practical work (PW)		**Items to use after the practical work (PW)**		
Digital manuals	**Videoconferences Pre-PW**	**Recorded practical work**	**Student-student communication forums**	**Student-teacher videoconferences Post-PW**
Prepared by the tutor for the practical work of the taught module, making it possible to describe the statements of the hypotheses, the manipulations, and the instructions to be pursued.	Organized by the teacher, making it possible to present the protocols to be used during the manipulations, to detail the statements, to prepare before the practical session and to describe the elements to be implemented in the reports.	He glossy for make it possible to retrace the stages of the experiments carried out in the laboratory, to reanalyze and understand them, to remedy the errors made and to note all the details which could not be corrected.	Created to discuss the progress and progress of students by forming collaborative groups under the supervision of the tutor of Practical work (PW).	Used to schedule virtual meetings to conduct formative assessment sessions.

3. DESCRIPTION OF THE E-LABORATORY PLATFORM FOR THE MANAGEMENT AND CAPITALIZATION OF PRACTICAL WORK

3.1. Digital Components of the E-Laboratory Platform

The e-laboratory platform developed in this work represents an educational solution that helps learners to engage in the experiential learning situation effectively thanks to the components available online, according to two types of use: Pre-PW and Post-PW (PW i.e.: Practical Work). The five main innovative components are shown in Table 1.

3.2. Educational Advantages and Constraints

According to the general context of integrating and using such an e-laboratory platform, the advantages can be ascertained by:

- Motivation and encouragement: Learners are intrinsically motivated to achieve the course's objectives, actively participate in practical work, put their knowledge into practice, and develop their skills.
- The development of autonomy and intervention: Learners are the masters of their learning and the controllers of their cognitive development in an experimental situation. They can get feedback by giving feedback on what they know or what they need to improve.
- Stimulation of interaction and collaboration: Learners are encouraged by communication, collaboration, and exchange of scientific concepts, notions, demonstrations, virtual presentations, and reports of projects or mini-projects. Confrontations with others generally represent necessary moments when collaborators look for justifications to consolidate in the way of interaction (Muftisada, Bassiri, Tridane, & Belaaouad, 2019).
- The diversification of learning rhythms: Learners can progress at their own pace, using fictitious pedagogical elements in real experiential learning situations, which helps the teacher to differentiate between correspondence and learning regularity.
- Learning by trial and error: Learners can move forward and improve based on their mistakes that show gaps preventing them from progressing. This approach makes improving the pedagogical strategy in a safe context possible, thanks to several trials where the learners gain a concrete experience without risks.

The platform proposed in this work thus has limits, which show that in certain learning situations, they can be counter-productive. These limits may be related to the following factors:

- Relevance of integration: The platform must be subjected to different cognitive theories of the learning process (behaviorist, constructivist, etc.). For the e-laboratory platform to be relevant, the development and use must be done according to the developer's intention, the educational objectives, and the targeted students.
- Material and logistical constraints: This is related to the availability of machines, consoles, relevant networks, or resources that allow the platform to run, technological tools for development and installation, and administrative permissions.

We can cite four factors that act directly on the decision to act towards such an education system: (a) self-confidence, (b) the need to refer to others, (c) the need to use their experience, and finally, (d) inculcate the training model (Habybellah, Bassiri, Said, Mohamed, & Benmokhtar, 2019).

3.3. Practical Work Management Process on the E-Laboratory Platform by the Teacher

The approach to be followed by the teacher using the e-laboratory platform respects the essential steps and methods guidelines. Figure 1 represents the generic model established for the process of management of practical work by the teacher.

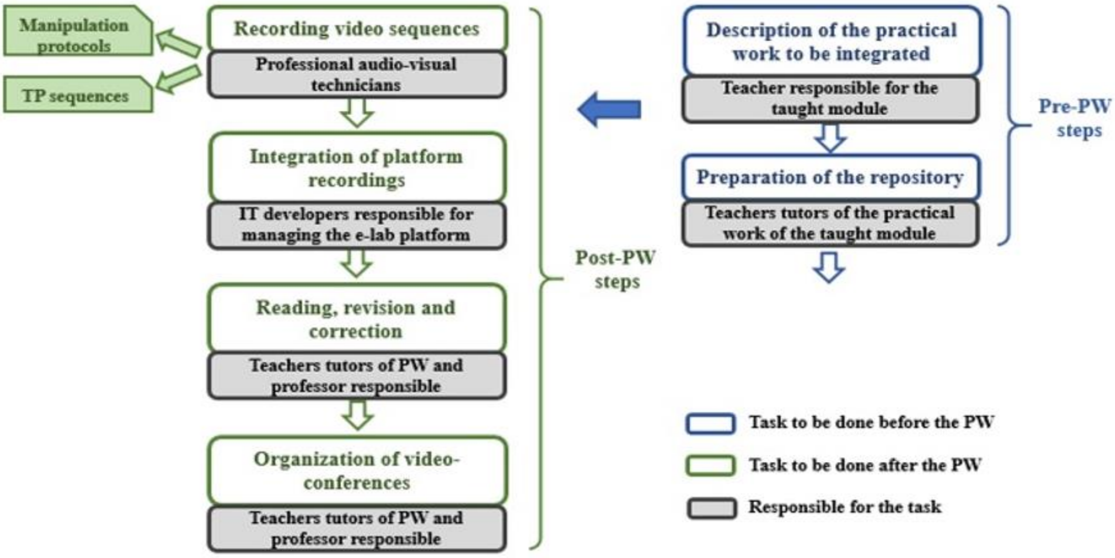

Figure 1. Practical work management process on the e-laboratory platform.

3.4. Hardware and Software Equipment

The Hassan II University of Casablanca provided students with a digital workspace (ENT) considered as an available and free tool allowing access to various digital resources through an institutional address. A "workshop" type option was used to collect and review student work by teachers, and to have it peer-reviewed, participants could submit all types of work as digital files (text files, presentations, sheet calculations, etc.).

The "Blackboard Collaborate" tool for creating virtual classrooms, offices, and meeting spaces was used to engage students in a more real-time collaborative and interactive learning experience. The Google Meet tool developed by Google was proposed as well, which is the constitution of the new Google Hangouts and Google Chat versions.

Figure 2 represents the list of activities and resources included in the e-laboratory platform provided in the digital workspace of teachers, the latter was allowed to add any necessary resource (documentation files for practical work or video capsules for example) and organize any activity (videoconferences, workshops, or forums) for the management of practical work before or after its realization in the laboratory.

Figure 2. List of activities available on the platform, and list of resources available on the platform.

Users accessed the platform via their mobile phones, knowing that these represented a motivating and engaging environment from a pedagogical point of view (Muftisada, Daaif, Tridane, & Belaaouad, 2020) thus reinforcing the approach of mobile learning, social learning, and distance education, which represented a powerful vector for promoting socio-professional skills (Bassiri, Boulahouajeb, Aichi, Belaaouad, & Radid, 2018).

The material equipment used consisted of audiovisual devices (filming, editing, and recording of the sequences of the practical), a list of which is presented in Table 2. The objective was to work with autonomy with a suitable level of professionalism in terms of products and services, making it possible to ensure quality training.

4. METHODOLOGY

4.1. Study Environment

The current investigation transpired during the academic year 2019-2020, situated at the Ben M'Sick Faculty of Sciences at Hassan II University in Casablanca. The selection of this locus was intrinsically tied to the rationale of streamlining the research procedure, notably within the newly imposed COVID-19 sanitary restrictions in Morocco. These circumstances had imposed distinct limitations and protocols on interpersonal interaction and mobility. The Ben M'Sick Faculty of Sciences, denoted as FSBM accommodates an approximate populace of 11,500 scholars within the 2015-2016 timeframe. FSBM amalgamates six fundamental undergraduate programs and eighteen postgraduate degrees, encompassing twenty-three research units, two research centers, one observatory (dedicated to research in didactics and higher education pedagogy), and nineteen laboratories spanning diverse domains including sciences, engineering techniques, materials, biotechnology, and geosciences. Table 2 exhibits the audiovisual equipment used for recording video sequences of practical work during this investigation.

Table 2. Audiovisual equipment is used for recording video sequences of practical work.

Equipment	Number
Professional camera with pro tripod	2
Mini dome varifocal (VF) 5M pixel camera	3
4 Channel 5Megapixels digital video recorder (DVR) with 1 4 Terabyte disk (TB Disk) + 16A centralized power supply	1
Camera selector	1
High-definition multimedia interface (HDMI) 2 Terabytes (TB) Video / Audio recorder C285	1
WIRELESS AW315 (A model or identifier for the specific wireless lavalier microphone) lavalier microphone	2
Mixing console	1
LED spotlight	2
Light projector mounting bar	2
Cabinet for arrangement A 9U (Rack units (a standard measurement for the height of equipment in a rack or cabinet, where 1U is 1.75 inches or 44.45mm) P450	1
Service provision: Wiring, connections, installation and commissioning	1
Interactive light emitting diode (LED) display	1
Streaming encoder	1
Computer / Core i7-9700 / 8GB / 1TB / Ultra high definition (UHD) 3 Screen or equivalent	1
SMT 1000 VA (Refers to a specific Uninterruptible power supply (UPS) model) Tower - 8 Outputs	1

The development and digitization service belonging to the common services of the faculty has missions in collaboration with the pole of scientific research, cooperation, and partnership in all that concerns networks and security, database systems, Information technology (IT) development, applications, and software, Information technology (IT) maintenance, peaks and statistics, digital transformation, publishing of diplomas.

The Ben M'Sick Faculty of Sciences is affiliated with Hassan II University of Casablanca (UH2C) which adopts various projects around digitization and training from the point of view of management, administration, teaching, and filing documents, such as administrative and educational management of schooling, dedicated to the submission of theses, for the management of scientific research, for the submission of scientific journals, etc.

4.2. Target Population and Sample

The target population comprised all students enrolled in the physics and chemistry departments of the Ben M'Sick Faculty of Sciences in Casablanca. The observation was carried out on a representative sample of 240 students enrolled in physics and chemistry (120 students from each department): department of physics (A, n^1 = 120) and department of chemistry (B, n^2 = 120). They represented 33.47% of the population. The students selected in the sample were supervised by 15 tutors of practical work in the physics department and 12 teachers in the chemistry department.

Table 3 and Table 4 represent the students' distribution by semester within the two departments. Simple random sampling technique was used and applied independently for each department and semester.

Table 3. Distribution of sample members according to the level of study variable.

Semesters of the license cycle	Department of physics (A, n^1 = 120)		Department of chemistry (B, n^2 = 120)		Total	
	N	P	N	¨P	N	P
Semester 2	51	42.5%	56	46.67%	107	44.58%
Semester 4	40	33.33%	39	32.5%	79	32.92
Semester 6	29	24.17%	25	20.83%	54	22.5%
Total	120	100%	120	100%	240	100%

Note: N: Number.
P: Percentage.

Table 4. Distribution of sample members according to the gender variable.

Gender	Department of physics (A, n^1 = 120)		Department of chemistry (B, n2 = 120)		Total	
	N	P	N	¨P	N	P
Male	47	39.17%	69	57.5%	116	48.33%
Female	73	60.83%	51	42.5%	124	51.67%
Total	120	100%	120	100%	240	100%

Note: N: Number
P: Percentage

Simple random sampling technique was used because it enables to establish the underlying theory. Besides, the advantage of this technique lies in the fact that it does not require any additional data in the sampling frame other than the complete list of members of the observed population and their contact information. Furthermore, the absence of linkage between the selection of different elements is an advantage for implementing adaptive sampling. In the current study, the sampling was interrupted and resumed without causing any bias (examining the elements in the order of drawing).

4.3. Data Collection Instruments

A mixed-method research design was used in this study, encompassing both quantitative and qualitative methods. The quantitative facet involved the gathering of data via a questionnaire disseminated to the student cohort. To assess the e-learning tools, an appraisal matrix titled the "Rubric for eLearning Tool Evaluation," was employed, devised by Anstey and Watson (2018) at the Center for Teaching and Learning at Western University. This matrix furnishes educators with a systematic framework, featuring delineated criteria and levels of attainment, to appraise the appropriateness of an e-learning tool concerning learners' requisites and educational objectives. It encompasses eight distinct categories, each housing a collection of specific attributes or criteria. The survey offered detailed portrayals of the e-laboratory tool's attributes, aligning with the predetermined standards encapsulated within the eight categories.

The questionnaire was presented in its final version with four main sections, following the previous standards, to facilitate reading, response, analysis, and processing of the questions it contained:

- Use of diverse resources available on the e-laboratory platform.
- Communication and support between the student and the teacher.
- Evaluation and development of certification sessions.
- Access and technical constraints.

The first part contained identification questions, and the second part included questions based on Likert-scale evaluation from 1 to 3 (low, high, very high).

For the qualitative data, we chose to conduct semi-structured interviews with teachers using open-ended questions to identify and describe the constraints that hinder the adoption of the e-laboratory platform. The questions were prepared in advance and categorized thematically according to an interview guide based on the previously described grid. The semi-structured interview format appeared to be the most suitable for providing answers to the research questions. It also facilitated collection of the most usable information for analysis in various forms (proposals, recommendations, etc.).

The questions asked during the interviews with the teachers were divided into four categories:

1. Available hardware resources for the laboratories.
2. Software resources available on the e-laboratory platform.
3. Support and evaluation of students.
4. Access conditions and technical constraints.

The questionnaire was distributed electronically, and 100% of the sample members responded and sent the questionnaire electronically to their supervisors. Interview sessions were subsequently scheduled with the teachers to collect their responses.

4.4. Validation of the Questionnaire

SPSS software (IBM SPSS Statistics 22) was employed to directly assess the consistency of items within the questionnaire. This evaluation was grounded in the correlation model, which gauged the interrelatedness among questionnaire items. The technique employed to gauge the internal coherence of a scale in the questionnaire involved the computation of the "Cronbach's Alpha" coefficient. This index is a recognized method to ascertain the reliability and consistency of a measurement scale. To perform this, the elements of the questionnaire were grouped and separated according to the measured construct and alpha index was calculated for each set of elements. The reliability of the scale was assumed from its value 0.8 (Peterson, 1995).

The questions were divided into four sections, with four to six questions assigned to each subsection. The final number of questions in each section, as well as the values of "Alpha Cronbach", are shown in Table 5.

Table 5. Validation of items by the "Cronbach's Alpha" index.

Items	Number of questions	Alpha Cronbach
1. Use of the diversified resources available on the e-laboratory platform	6	0.951
2. Student-teacher communication and support	6	0.863
3. Evaluation and development of certification sessions.	4	0.947
4. Access and technical constraints	6	0.812
Entire questionnaire	22	0.928

Every computed value surpasses the advised threshold of 0.8, thereby affirming substantial interconnectedness among all items. As a result, all the items were retained, leading us to deduce that the internal validity of the questionnaire stands as acceptable. The questions prepared for the teachers for the interviews were also checked and validated by four experts in the field of probability and statistics. A total of 94% of the questions were taken and considered, but other questions were regenerated and reformulated according to the context, to guarantee accepted reliability.

5. RESULTS AND DISCUSSION

5.1. Quantitative Study

Microsoft Excel software was used to present and analyze the results. Table 6 presents the proportions of respondents according to the satisfaction rate, and Table 7 presents the averages and standard deviations of the satisfaction proportions for the different sections. Regarding the "Use of the diversified resources available on the e-laboratory platform", Figure 3 illustrates that 142 students (59.17%) agreed (very high) with the manipulations recorded in the video clips, as they allowed them to confront the theoretical solutions with the reality, compared to the practices in the classroom laboratory. It was also observed that 114 students (47.5%) found that the practical works presented in the e-laboratory platform were able to achieve the objectives recommended by the course in a very high way, and they were able to prepare the students well for the exam. Likewise, the educational resources provided in the digital workspace were interactive and understandable in a very high manner, according to 101 students (42.08%) who are quite satisfied.

Furthermore, Table 7 shows that 119 students on average (with a standard deviation of 17.11) were very highly satisfied with the use of the diversified resources available on the e-laboratory platform. Concerning "Student-teacher communication and support", Figure 4 illustrates that 132 students (55%) found that the teacher communication was high and made sure that the explanations and information were well understood, against 72 students (30%) who found that the communication and explanation of the teacher were very high. Thus, 118 students (49.17%) stated that the pace of the practical work presented in the e-lab platform was encouraging and motivating is high. However, 95 students (39.58%) were not satisfied with the video conferences allocated by the teachers, in fact, they claimed that they were weakly appropriate to communicate and discuss problems and answer questions, against 68 (28.33%) students who were very highly satisfied. In addition, we observed that 86 students (with a standard deviation of 226.69) rated the student-teacher communication as high.

Table 6. Number of students responding to the questionnaire according to the rate of agreement or satisfaction.

Questionnaire sections	Queries	Satisfaction proportions					
		Low		High		Very high	
		N	P	N	P	N	P
Use of diversified resources available on the e-laboratory platform	The manipulations recorded in video capsules were able to compare the theoretical solutions to reality, compared to the practical carried out in the face-to-face laboratory	23	9.58%	75	31.25%	142	59.17
	The course of practical work on the e-laboratory platform achieved the objectives recommended by the course I took and prepared me correctly for the exam	35	14.58%	91	37.92%	114	47.5%
	The educational resources provided in my digital space were interactive and understandable	32	13.33%	107	44.58%	101	42.08%
Student-teacher communication and support	The teacher communicated and made sure that the explanations and information were well understood	36	15%	132	55%	72	30%

Questionnaire sections	Queries	Satisfaction proportions					
		Low		High		Very high	
		N	P	N	P	N	P
	The pace of the practical presented virtually to the e-lab platform by the teachers was encouraging and motivating	42	17.5%	80	33.33%	118	49.17%
	The videoconferences allocated by the teachers were appropriate for communicating and discussing issues and answering questions	95	39.58%	77	32.08%	68	28.33%
Evaluation and development of certification sessions	The digital workspace allowed us to schedule virtual meetings with teachers to conduct assessment sessions	21	8.75%	147	61.25%	72	30%
	Elaboration of online student groups to follow practical work and prepare reports	21	8.75%	144	60%	75	31.25%
Access and technical constraints	Detection of technical problems of access to the digital space depending on the difficulties of operating the platform, accessing, and participating in videoconferences and response times	16	6.67%	54	22.5%	170	70.83%
	Speed of execution of the e-lab platform	30	12.5%	46	19.17%	164	68.33%
	Ergonomics and ease of use	48	20%	55	22.92%	137	57.08%

Note: N: Number
P: Percentage

Table 7. Average and standard deviations of the satisfaction proportions.

Questionnaire sections	Number of items	Number of questions	Satisfaction proportions					
			Low		High		Very high	
			AV	SD	AV	SD	AV	SD
Use of the diversified resources available on the e-laboratory platform	3	6	30	5.09	91	13.064	119	17.11
Student-teacher communication and support	3	6	26.51	26.51	25.25	96.33	86	22.69
Evaluation and development of certification sessions	2	4	21	0	145.5	1.5	73.5	1.5
Access and technical constraints	3	6	31.33	13.09	51.67	4.03	157	14.35

Note: AV: Average
SD: Standard deviation.

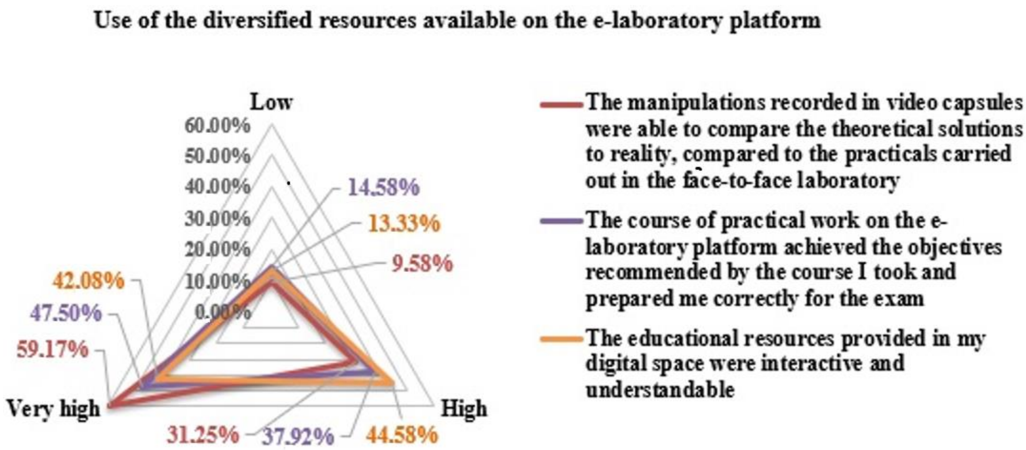

Figure 3. Use of the diversified resources available on the e-laboratory platform.

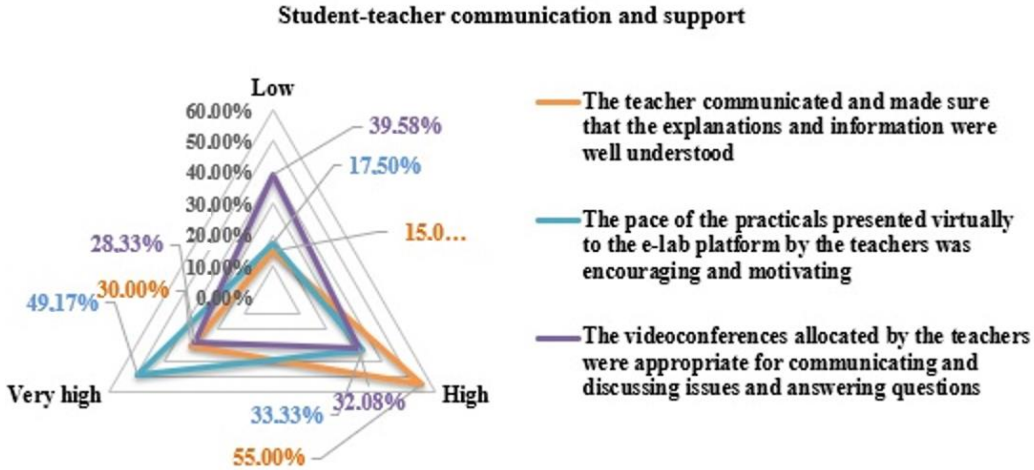

Figure 4. Student-teacher communication and support.

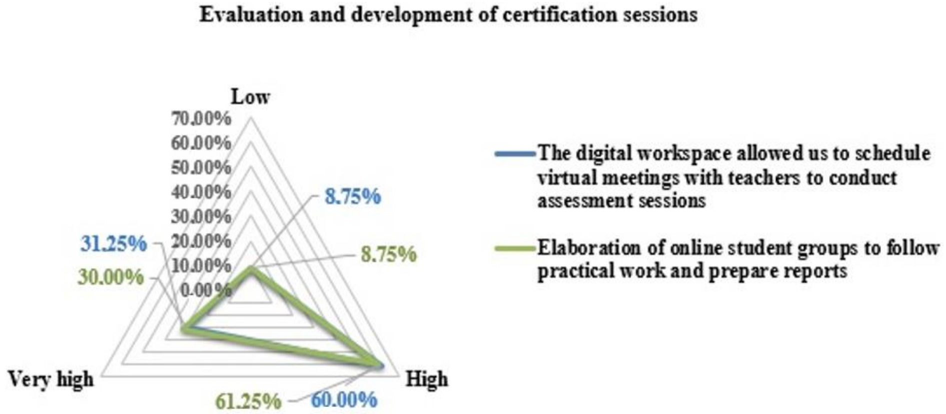

Figure 5. Evaluation and development of certification sessions.

The results were very similar for "Evaluation and development of certification sessions" for both statements. Indeed, Figure 5 illustrates that 147 students (61.25%) stated that the digital workspace allowed them to plan virtual meetings with teachers very high to conduct evaluation sessions, and 144 students (60%) were able to develop (very high) online groups to follow up on assignments and prepare reports.

In addition, an overall average of 145 students (with a standard deviation of 1.5) strongly agreed (very high) with the assessment systems and certification sessions.

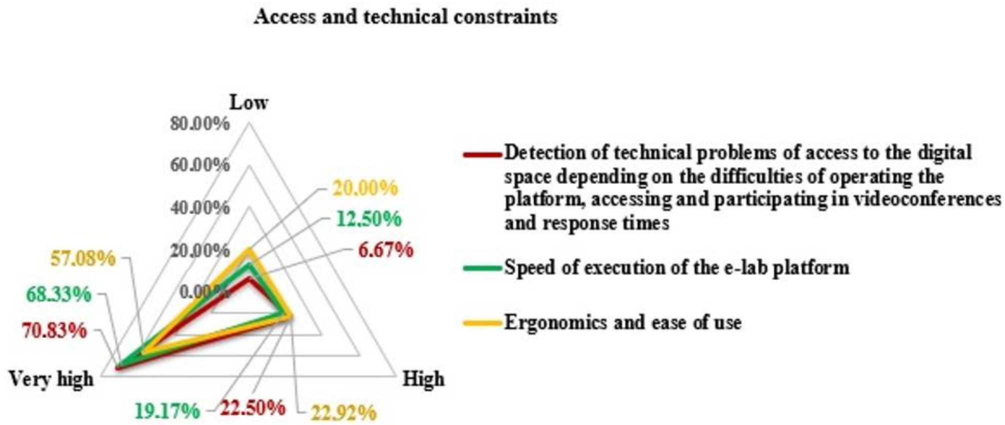

Figure 6. Access and technical constraints.

Regarding "Access and technical constraints," Figure 6 illustrates that 170 students (70.83%) stated very highly that they did not encounter any technical problems with the access and operation of the platform. They were satisfied with the participation in the videoconferences and the response time. Also, 164 students (68.33%) found the platform very fast, ergonomic, and easy to use, according to 137 (57.08%). All in all, 157 students (with a standard deviation of 14.35) on average stated that the access to the platform and the technical constraints were effective and relevant to a very high degree.

The results obtained from the quantitative study showed that the e-laboratory platform could provide diverse digital resources to the students. The students were satisfied with the recorded manipulations in the video capsules. These resources allowed students to confront theories with reality, met the pedagogical objectives, prepared students well for the examination, and were interactive and comprehensible.

Numerous antecedent investigations have embraced a congruous concept akin to our study, yielding outcomes commensurate with our findings. Indeed, our results harmonize with the findings of Bilyalova, Salimova, and Zelenina (2019) in their scholarly endeavor delineating the distinctive attributes of digital pedagogy, its extant deployment landscape, envisaged consequences, and the dialectics encompassing its merits and demerits. They assert that digitization emerges as an efficacious avenue for elevating the caliber of education, underscoring that digital erudition appears markedly advantageous for students. Comparing our results with those of Bilyalova et al. (2019) we can say that these authors observe that digitalization in the academic world is not just a tool but an environment of existence that opens up new possibilities for (a) learning anytime, (b) lifelong learning, (c) designing individual educational pathways, and (d) becoming creators.

Likewise, this observation finds congruence in their investigation, affirming students' adeptness in upholding digital etiquettes encompassing aspects like divulging personal data, participating in discourse, managing inappropriate communications, trading disagreeable content, and evincing regard for diverse viewpoints. Indeed, it is imperative to inculcate within university scholars the principles of reasonable digital tool employment for pedagogical ends while cultivating affirmative stances towards technological innovations that incubate perennial erudition, collaborative endeavors, individual impetus, and productive output. On the other hand, communication between teachers and students was significant. The results showed that the practical work supervisors ensured students' understanding and that any explanations were paced and creative through video conferences.

In the same vein, Aksyukhin, Vyzen, and Maksheneva (2009) stated that the learner needs a sense of creativity and willingness to cooperate with peers and colleagues to find new solutions to encountered problems, as well as the ability to critically evaluate the proposed information in terms of reliability and integration. This outcome signifies an elevated echelon of digital correspondence and interaction among students via electronic mediums (Jones & Mitchell, 2016). Indeed, Kara (2018) contends that a high degree of digital communication and interaction underscores the amplitude of social participation within the milieu of cultural interchange.

Additionally, digitization can be likened to a paradigm shift in communication and interaction with others and society. On the other hand, the platform facilitated effective formative assessment sessions, individually and in groups, to prepare practical work reports. These findings corroborate with those of Pla-Campas, Arumí-Prat, Senye-Mir, and Ramírez (2016) who indicated in their research that participation in digital assessments positively impacted students' summative grades.

Furthermore, the platform provided detailed feedback for monitoring the students' status and documenting the results of their online tests. This is consistent with what Caballero-Hernández, Palomo-Duarte, and Dodero (2017) confirmed in their research, proposing that state monitoring allows evaluation by associating different states with a probability of achieving a learning objective regarding self-efficacy. Moreover, our platform can be considered an "applied game" (Schmidt, Emmerich, & Schmidt, 2015) implementing a user-centered transfer of concepts and design qualities from the virtual gaming world to evaluate knowledge and even experimental skills.

In contrast, these findings are similar to those of Shute, Leighton, Jang, and Chu (2016). The authors focused on using technologically rich learning environments that promote progress in student assessment. Our results align with those of Alsamadi (2017). Additionally, attitudes toward internet use and self-efficacy influence students' digital citizenship practices at the university level. Furthermore, the platform was characterized by fast execution and efficient and relevant ergonomics through a conducive virtual environment. As asserted by Bilyalova et al. (2019) digitization enables accessibility to information in its various forms: textual but also audio and visual. This corroborates the research of Shute and Rahimi (2017) which focuses on using technologically rich learning environments that stimulate progress in student assessment.

5.2. Qualitative Study

The qualitative results were analyzed using the teachers' responses (opinions and comments) expressed in short answers. The objective of the qualitative study was to identify and describe the constraints hindering the adoption of the e-laboratory platform for the management and capitalization of practical work in physics and chemistry. The answers were intertwined in terms of free expressions and affirmations to convey ideas, especially since the questions were related to each other, as they complemented each other in terms of meaning. According to the theoretical model adopted, we represent in Table 8 the constraints that have contributed to the adoption of this platform.

5.2.1. Material Resources Available to Laboratories

Several teachers have highlighted the main material constraints that do not encourage the use of the platform offered by the university in a relevant way, such as the insufficiency of computers, servers, and cameras available to the laboratories within the two departments (physics and chemistry). This caused a significant difference between the material available and requests for use by teachers, as some were forced until computers or cameras were open, and no one took advantage of them on demand. This was due to administrative mismanagement, which was supposed to set strict hours of use or provide departments with sufficient equipment for requests.

Table 8. Constraints hindering the use of the e-laboratory platform.

Interview topics	Constraints hindering the use of the e-laboratory platform	Proportions of declarations (%)
Material resources available to laboratories	• Insufficient computers, cameras and servers; • The number of practical works to be recorded does not correspond to the material available; • Poor administrative management of material equipment; • Lack of management of hours of use.	42.09%
Software resources available on the e-laboratory platform	• Availability of practical work management resources (Videos, manuals, etc.); • Availability of synchronous and asynchronous communication tools; • User-friendly graphical interfaces.	17.37%
Student support and evaluation	• Communication is not fully effective; • Lack of indicators to measure student involvement in the platform; • Relevant interaction only during momentary interventions via videoconferences; • Lack of integrity and equality in evaluations.	53.23%
Access conditions and technical constraints	• Easy access via the digital workspace (ENT); • Lighting and sound problems during some recordings; • Interruption of the Internet during videoconference sessions.	20.54%

5.2.2. Software Resources Available on the E-Laboratory Platform

If most teachers had a negative opinion about the insufficient material and digital resources, several others agreed on their quality and availability continuously throughout the distance learning period. Some teachers reported that the e-lab platform provided various resources to manage the recorded labs online, as well as to communicate with the students who demonstrated their remarkable interaction with the presented videos in a synchronous and/or asynchronous manner. As for the teachers, the problem was less digital than material. Once the video was recorded, some of the administrative staff specialized in editing took care of everything technical to the stage.

5.2.3. Student Support and Evaluation

The teachers' responses about communication with students and their support throughout the online practical work differed. They stated, to a large extent, that the communication was ineffective, especially since there was no indication that the students followed the manipulations recorded on the platform on time and in the prescribed manner, respecting the educational standards. They also mentioned that communication was only valuable in momentary interventions via video conferencing, in which conversations were immediately before or after the labs. This is because students enjoy freedom in using devices (computers or smartphones) and the e-laboratory platform. In addition, some teachers claimed that both exams were difficult to pass under conditions that guaranteed students the right to integrity and equality since the only means were oral examinations based on the other writing.

5.2.4. Access Conditions and Technical Constraints

The teachers' responses to access conditions and technical constraints to the platform were aligned with the Digital Workspace (ENT) available through institutional email provided by the university, which ensured adequate access and engagement. There were some technical issues related to the shooting of videos depicting the manipulations, such as poor lighting or poor sound in certain capsules. This was due to the communication between the teachers and the editing and mixing supervisors, but this was a small percentage. However, internet in the laboratories was interrupted frequently, which caused a real technical problem for teachers, especially when videoconferences required high speed.

6. CONCLUSION

The current study aimed to explore the success rate of the e-laboratory platform for managing and capitalizing on physics and chemistry practical work from the student's perspective. The results are favorable and benevolent, showing that our e-laboratory platform for experimental work management offers a rich and diverse digital surface. It provides a set of scientific resources to ensure enhanced continuity of research work at any time, serving the joint development of scientific and pedagogical training and research. It also supports the exchange and sharing of scientific experiences between students and teachers within the framework of scientific research. These experiences encompass all aspects related to end-of-studies projects.

It is worth noting that this work can be replicated at other laboratories within the institution and in other Moroccan universities, as this platform also enables the cloning of this experience with minimal investment in terms of material, financial, and human resources. Indeed, the platform also allows foreign researchers to benefit from all available references, communicate, and collaborate with Moroccan researchers.

Furthermore, the e-laboratory platform would enhance theoretical learning by consolidating the theory-practice bridge and putting real. Another important aspect at the educational level is that this platform could promote the socio-constructivist approach (Mariyani-Squire, 1999) conditioned by the learning process in a social context. This would foster teaching autonomy for teachers and learning autonomy for students in a flexible learning environment. On the other hand, flexibility is represented as an approach that offers the personalization of taught education to meet the diverse needs of learners, thereby providing choices in educational environments. These pedagogical choices encompass the schedule of practical work, pedagogical content, learning styles, digital resources, learning location, and communication support (Goode et al., 2007).

The study's hypothesis has been confirmed as the manipulation of experiments through the virtual laboratory has a positive practical implication on students' outcomes, given the pedagogical advantages the platform has offered. Hence, the following practical implication can be deduced in terms of:

- Validity: The platform offers an immersive and interactive environment that can enhance the validity of manipulations compared to typical ones.
- Support and monitoring: The platform aims to improve the practical work process in experimental learning by accompanying the student and monitoring their progress.
- Feedback and traceability management: The platform informs both the teacher and the student about their achievements or areas for improvement by providing comprehensive feedback and ensuring the traceability of any task the student performs.
- Self-regulation: The platform promotes experimental skills throughout the learning process, helping the learner progress at their own pace.

7. LIMITATIONS AND FUTURE STUDY

Although this study produced significant results based on quantitative research, it faced certain limitations as well. Firstly, the research was limited to a sample from a single academic institution in Morocco. This was due to the limited equipment and resources available in the laboratory, which constrained us to work with a limited and restricted number of students. Additionally, the study was subject to constraints related to a set of ministerial decisions regarding compliance with COVID-19 emergency situations, which prevented gatherings and contact, taking into account all precautionary measures.

Moreover, this study relied solely on students from the physics and chemistry departments, when other departments could also be integrated into this work. However, given that the study was conducted only regarding physics and chemistry and that the preparation of a pedagogical reference was limited to these two subjects, this can be considered a scientific limitation of the study. Indeed, any pedagogical reference should contain a detailed description of the use of the e-laboratory platform in other contexts in terms of scientific subjects, such as experimental sciences. Furthermore, in a future study, the authors could identify the constraints and obstacles that hinder the adoption of such a conceptualization and management platform for physics and chemistry practical work in a university context (lack of training, software, appropriate equipment, administrative support, etc.). Last, but not the least, an interesting avenue for future research would be to seek to confirm these results using a larger sample size by conducting similar experiments in other departments and higher education institutions, in order to draw a more general conclusion.

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