



A MODEL FOR PHYSICS PRACTICAL WORK USING MOBILE LEARNING AND LEARNING MANAGEMENT SYSTEM (LMS) IN HIGHER EDUCATION: DESIGN, VALIDATION, AND EVALUATION

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Abstract. *Despite the importance of physics practical work in higher education, its implementation is often hampered by various constraints and problems. Technology, such as learning management systems (LMS) and mobile learning, can offer solutions to some of these problems and enrich students' learning experiences. Therefore, this research proposes a model called Practical Works in Physics via Mobile Learning and LMS (PWP-MLMS) that exploits features of LMSs and mobile devices to overcome specific challenges encountered in physics practical works and improve students' performance in these works. The model was designed, validated, and evaluated within the teaching context of a Moroccan university. To assess the model's effectiveness, 128 students in the Bachelor of Education, Physics-Chemistry specialization were randomly divided into two groups of 64 students each: an experimental group using the model for practical work on the topic of rectification and filtering in the electronics module, and a control group following the conventional method for the same practical work. The results of the evaluation showed that the proposed model can significantly reduce the time required to complete the practical work, have a positive influence on the students' technical skills, and improve the quality of their laboratory reports.*

Keywords: *mobile learning, LMS, practical work, physics education, higher education*

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Introduction

In the teaching of physics in higher education, practical work plays an essential role in fostering a comprehensive understanding of scientific principles. As a process-based approach, practical work engages students in practical activities that lead to a deeper understanding of theoretical concepts through direct observation and experimentation (Etkina et al., 2002). Moreover, such practical work is crucial in enabling learners to generate knowledge and meaning by relating their personal experiences, ideas, and the physical world, which is fundamental to the study of physics (Asamoah & Aboagye, 2019). Practical work can also motivate students by stimulating their interest in physics and develop their laboratory skills (Asamoah & Aboagye, 2019).

Although practical work is an integral part of the physics curriculum in higher education, its implementation is often hampered by constraints such as insufficient time for practical sessions, limited resources, pressure from assessment requirements, and a lack of technical skills in using equipment (Malathi & Rohini, 2017; Thair & Treagust, 1999). However, technology can provide solutions to some of these problems and enrich students' learning experiences. Digital simulations, virtual labs, and online platforms can alleviate resource limitations and provide opportunities for engaging and interactive practical experiences (Omilani et al., 2016; Puntambekar et al., 2021; Sypsas et al., 2020; Zacharia & Jong, 2014).

Online platforms, including Learning Management Systems (LMS), have the potential to support practical work in physics laboratories. However, despite the growing adoption of LMSs in higher education, their integration into physics practical work poses several challenges. Resistance to change among some teachers and students, as well as concerns about the usability of LMSs, are crucial factors to overcome for successful integration (Bousbahi & Alrazgan, 2015; McLain, 2017; Musa et al., 2022). It is also imperative to adjust pedagogical methods to maximize the benefits of LMSs in practical work (Alaidi et al., 2020). Compatibility issues with various devices can also



limit the effective use of LMSs (Musa et al., 2022). Furthermore, infrastructure challenges and the availability of suitable devices are notable barriers to the optimal use of LMSs in practical work in physics (Washington, 2019).

Nevertheless, the adoption of mobile learning represents a promising solution to the challenge posed by the need for traditional computing devices, such as desktop computers or laptops, for the use of LMSs in physics practical work. With the widespread use of mobile devices, students and teachers now have access to powerful tools with increased computing capacity and enhanced functionality, providing a flexible alternative for accessing and using LMSs (Daineko et al., 2022; Darmendrail et al., 2023). This approach opens up new possibilities for enriching the educational experience of students in physics practical work by jointly exploiting the advantages of mobile technologies and LMSs.

A review of the literature revealed no studies that have examined the impact of using an LMS via mobile devices on the performance of higher education students during physics practical work conducted in a laboratory. Most existing research focuses on the use of LMSs and mobile technologies in a more general educational context, without exclusively focusing on physics laboratory work. Nevertheless, a few studies have explored the use of mobile learning in practical work through mobile apps or websites without specifically integrating LMSs (Daineko et al., 2019; Darmaji et al., 2019; Kaps et al., 2021; Luchsheva et al., 2021; Malndonado et al., 2022). Other studies have examined the application of LMSs in practical work, but using devices other than mobile devices (Alykova et al., 2020; El Kharki et al., 2020; Yade et al., 2023). This research gap highlights the importance of conducting more focused studies on the specific use of LMSs via mobile devices in physics practical work to better understand and exploit their potential in this specific learning environment.

Theoretical Framework

Physics Practical Work in Higher Education

There is no universal consensus on the definition of practical work. This definition varies considerably according to educational systems and different study cycles, resulting in a variety of definitions depending on specific academic and disciplinary contexts. Generally, in science education, practical work refers to practical activities that involve direct, practical interaction with equipment or materials. These activities are carried out either individually or in small groups and focus on observation and/or manipulation (Oliveira & Bonito, 2023).

In higher education, and especially in physics, practical work plays a fundamental role in the education of students. Usually carried out in the laboratory, it involves the use of equipment and measuring instruments to perform experiments and collect data. Practical work provides students with a unique opportunity to apply theoretical concepts studied in the classroom to concrete experiments. This promotes a better understanding of physical phenomena, a refinement of scientific reasoning, and the development of skills in equipment handling, data collection and analysis, and problem solving (Asamoah & Aboagye, 2019; Hanif et al., 2008; Hofstein & Mamlok-Naaman, 2007; Kirschner & Huisman, 1998; Parreira & Yao, 2018). In addition, physics practical work helps to motivate students to pursue a career in science by providing them with concrete, practical experience in scientific research (Oliveira & Bonito, 2023).

However, despite their importance in higher education, practical work in physics faces many obstacles that can compromise both its effective implementation and the achievement of the pedagogical objectives set for these activities. Their implementation can be hampered by the unavailability of adequate resources and equipment, insufficient technical support and laboratory assistants, overcrowded classrooms, lack of professional training and motivation of lecturers, problems related to student safety and proper handling of materials, as well as pedagogical inexperience of lecturers and lack of organization and planning of activities (Abrahams, 2017; Ali et al., 2018; Ayi & Hon, 2018; Malathi & Rohini, 2017, 2022; Oliveira & Bonito, 2023).

In addition, several other barriers can directly affect student performance and, consequently, the achievement of pedagogical objectives. These barriers include insufficient time for practical work, difficulties related to teamwork, complexity of experimental protocols, limited access to mentoring and coaching, and difficulties in using laboratory materials and equipment (Bitzenbauer & Meyn, 2021; Hirvonen & Viiri, 2002; Kirschner & Huisman, 1998; Oliveira & Bonito, 2023; Tesfamariam et al., 2017; Verstege et al., 2022). Furthermore, a lack of theoretical knowledge can complicate the achievement of practical work objectives by impairing students' ability to understand the mathematical model of the physical phenomenon under study, to establish agreement between theoretical and measured results, and to analyze and interpret experimental data (Laouina et al., 2021; Viegas et al., 2018).

On the other hand, the pressure on students to produce concrete, measurable results in a limited amount of



time during physics practical work can lead to several risks, including a deformation of authentic scientific practice and an emphasis on results rather than process. With too much emphasis on results, students may feel compelled to copy their peers or manipulate data to ensure that it meets expectations and theoretical predictions, rather than following a rigorous and objective scientific process (Abrahams & Millar, 2008; Fairbrother & Hackling, 1997). This pressure can undermine the pedagogical objectives of practical work, which are to improve understanding of scientific concepts, develop critical thinking, and enable students to learn from mistakes and challenges (Abrahams & Millar, 2008; Fairbrother & Hackling, 1997).

Use of Mobile Learning and LMSs in Practical Work

Mobile learning, also known as m-learning, refers to the process of acquiring knowledge and skills using mobile devices such as smartphones and tablets (Krull & Duarte, 2017; Sung et al., 2016). It is flexible learning that can take place anytime and anywhere, allowing learners to take advantage of the opportunities offered by these devices in a variety of contexts (Grant, 2019; Krull & Duarte, 2017; Sung et al., 2016). Thanks to the properties and functionalities of mobile devices, mobile learning has the potential to expand pedagogical and didactic boundaries and connect different learning locations and contexts that were previously separated (Grant, 2019; Krull & Duarte, 2017; Sung et al., 2016).

In the context of practical physics work, mobile learning is proving to be a promising pedagogical tool that offers innovative and interactive learning experiences. As versatile tools, mobile devices facilitate the measurement and recording of data thanks to their sensors and dedicated physics applications (González Delgado et al., 2018; Kinser, 2015; Monteiro et al., 2021; Salnyk, 2019). These applications help students analyze data, create graphs, and perform calculations (Hochberg et al., 2018; Kinser, 2015). In addition, these devices can capture and record videos of experiments, offering the possibility to review and analyze experiments at a later time (Hochberg et al., 2020; Monteiro et al., 2021). They also promote collaboration during group-based practical work through the use of messaging applications and collaboration platforms to share data and communicate ideas. Mobile devices also allow access to online resources such as manuals, videos, and simulations, providing students with additional rich learning material during their practical work (Hochberg et al., 2018). In addition, these devices offer students the opportunity to use these online resources to prepare for physics experiments before conducting them, which could improve their performance during practical work.

Online platforms, such as LMSs, can greatly facilitate access to resources relevant to practical physics work via mobile devices. These LMSs centralize and distribute diverse pedagogical content, including demonstration videos, assignments, assessments, laboratory protocols, course materials, simulations, and virtual experiments, thus enriching students' practical experiences (Shah, 2023; van de Heyde & Siebrits, 2019). They provide effective tools for communication and collaboration, which are essential for collaborative practical experiences, through discussion forums, group projects, and online learning communities (Shah, 2023; van de Heyde & Siebrits, 2019). In addition, LMSs offer significant potential for personalizing content and assessments according to students' specific needs (Shah, 2023; van de Heyde & Siebrits, 2019). They also allow for detailed monitoring of students' engagement and progress, as well as the provision of targeted feedback that can improve their performance in practical work (Shah, 2023).

In order to guarantee the use of LMSs via mobile devices in practical work, several conditions need to be met. Considering that the use of mobile devices may take place as part of a Bring Your Own Device (BYOD) policy, where students use their own devices to access the LMS (Siani, 2017), it is imperative that the LMS is easily accessible on a variety of mobile devices and compatible with a wide range of operating systems and web browsers (Alrasheedi et al., 2015; Ivanc et al., 2012). In addition, the LMS must provide an ergonomic user interface and include functionality tailored for mobile use to facilitate smooth navigation and interaction for users on their personal devices (Alrasheedi et al., 2015; Mtebe & Kondoro, 2016).

Research Aim and Research Question

This study aimed to develop and evaluate a mobile learning model that integrates with an LMS to enhance the educational experience and improve the performance of higher education students in physics practical work. The proposed model, called Practical Works in Physics via Mobile Learning and LMS (PWP-MLMS), leverages the functionalities of LMSs and mobile devices to address specific challenges faced by students in this context. The objective of PWP-MLMS is to facilitate students' autonomous work in physics practical tasks, thereby reducing



the need for direct lecturer intervention. It accounts for students' pre-existing theoretical knowledge of physics, which is crucial for understanding, analyzing, and interpreting experimental results, as well as the technical skills required to handle laboratory equipment and materials properly. Additionally, this model aims to guide students in executing experimental protocols, promote a collaborative learning environment for solving practical work-related problems, and optimize the submission and evaluation of laboratory reports.

To evaluate the effectiveness of the PWP-MLMS model, this study attempted to answer the following research question: Is there a significant difference in student performance in physics practical work between those using the PWP-MLMS model and those using the conventional method? The research compared the outcomes of both groups to determine the impact of the proposed model on students' performance. This comparison aimed to provide insights into the potential benefits of integrating mobile learning with LMS in higher education physics practical work.

Proposed Model

Pedagogical Principles Considered in Model Design

The PWP-MLMS model aims to overcome the difficulties commonly encountered in physics practical work sessions while exploiting the specific functionalities of mobile devices and LMSs to enrich students' educational experiences. This model provides flexible resources and activities that allow students to prepare for practical work sessions at home and perform them in the laboratory. This overcomes the challenges posed by limited access to monitoring and insufficient time for practical work (Kirschner & Huisman, 1998; Oliveira & Bonito, 2023). In addition, the model aims to fill gaps in the theoretical knowledge needed to understand physical phenomena and interpret experimental data (Kirschner & Huisman, 1998; Oliveira & Bonito, 2023) by assessing students' prior knowledge and proposing appropriate remedial activities.

The PWP-MLMS model introduces a detailed equipment guide, which includes explanatory resources on the operating principles of the different apparatus and equipment used, as well as the safety standards to be followed when handling them. Through this guide, the proposed model aims to overcome the difficulties that students encounter when using laboratory equipment (Bitzenbauer & Meyn, 2021; Tesfamariam et al., 2017; Verstege et al., 2022) by providing them with the knowledge they need to improve their technical skills and increase their confidence in handling equipment. In addition, this guide aims to remedy safety problems related to students and equipment during practical work (Ali et al., 2018; Ayi & Hon, 2018) by providing students with resources dedicated to important safety measures to ensure they are well prepared to handle equipment safely and perform procedures without risk.

The PWP-MLMS model also proposes a solution to the complexity of experimental protocols in physics (Hirvonen & Viiri, 2002) by making available specially developed resources to guide and support students who have difficulties in autonomously conducting these experiments. Faced with the challenges associated with the pressure to produce results (Abrahams & Millar, 2008; Fairbrother & Hackling, 1997), the model takes advantage of the advanced functionalities of mobile devices, such as still and video cameras. These tools allow students to document experimental procedures, obstacles encountered, and solutions adopted through video and photographs. Submitted via the LMS, these videos allow the lecturer to verify the authenticity of the results and assess the relevance of the methods employed. They also offer students the opportunity to review and analyze their experiments retrospectively, anywhere and anytime, which helps to improve their understanding of experimental procedures (Hochberg et al., 2020; Monteiro et al., 2021). Additionally, the photographs captured can enhance and illustrate laboratory reports, which students submit through the LMS at the end of practical work sessions.

To provide a more comprehensive and nuanced assessment of the skills developed and knowledge applied during practical work, the PWP-MLMS model requires students to submit portfolios of laboratory work. These portfolios include videos documenting experiments and laboratory reports enhanced with photographs. The portfolios are then assessed through a dual approach using mobile devices and the LMS, including peer assessment and lecturer assessment, which enrich the learning process in many ways. Peer assessment encourages students to actively engage with the work of their peers, fostering critical reflection and a deeper understanding of different approaches and solutions to the problems posed (Liu & Carless, 2006). This type of assessment also promotes the development of interpersonal skills, such as the ability to give and receive constructive feedback (Liu & Carless, 2006). In addition, lecturer assessment provides an expert and objective appraisal of the work submitted, ensuring that academic standards are met and that students receive clear guidance for their future development (Liu & Carless, 2006).



To encourage collaboration between students, the proposed model introduces virtual discussion spaces on the LMS, accessible via mobile devices before, during, and after physics practical work in laboratory sessions. The aim of these spaces is to facilitate student communication, both instantaneous and deferred, with peers and teachers. They also enable the sharing of resources, the publication of complex problems encountered during laboratory experiments, and collaboration in the search for solutions to these problems, as well as in the writing of laboratory reports. This approach aims to foster a constructive group dynamic in which everyone's knowledge and experience contribute to collective learning (Hrastinski, 2009).

Model Design

A Unified Modeling Language (UML) activity diagram, shown in Figure 1, has been used to give a detailed overview of how the proposed model works when used in a practical work session. First, the student is given a prerequisite test to assess the theoretical knowledge needed to understand the physical phenomena covered in the practical work and to correctly interpret experimental results. In the event of failure, as shown in the activity diagram (Figure 1), the student accesses a remediation activity. This involves remedial instruction using multimedia resources, followed by a reassessment test to confirm that the required knowledge has been acquired. This reassessment test covers the same prerequisites as the initial test, but with different questions to minimize test-retest bias (Haladyna et al., 2002). The student is then invited to consult the practical work manual, which specifies the objectives of the sessions, lists the experiments to be carried out and the equipment needed to perform them, presents questions or problems related to these experiments, and sets out the essential safety instructions to be followed in order to avoid any accidents. The manual also provides guidelines for writing the experiment report and precise instructions on the content of the experiment videos to be produced.

In case of difficulties in performing the experiments described in the practical manual, the proposed model allows the student to access an experiment guide that provides additional resources, such as videos and image-enriched text. The videos provide visual demonstrations of experimental setups and techniques, while the enriched documents provide detailed, step-by-step instructions on how to set up and conduct the experiments. These resources are designed to guide and support students as they apply the experimental protocol.

In the proposed model, the student must record videos of the experiments and write a laboratory report. These videos and the report are then submitted. The laboratory report can be enriched with photos taken with a mobile device to illustrate experimental setups, procedures, and results obtained. The report can be written as a traditional digital document using mobile devices and uploaded to the LMS or entered directly into the LMS interface. In parallel, submitting videos of experiments adds an extra dimension by capturing key moments in the experiments and highlighting procedures, manipulations, and results in a dynamic way. Before submission to the LMS, these videos can be edited on the student's mobile device to enhance their quality and relevance.

Once submitted through the LMS, laboratory reports are subject to a double evaluation. First, the lecturer evaluates the reports according to predetermined criteria, which are communicated to the students in advance and are aligned with the pedagogical objectives of the practical work. At the same time, a peer evaluation system is set up so that each student can evaluate several reports and, conversely, each report can be evaluated by several students. To ensure the effectiveness and constructiveness of this peer assessment, several measures are recommended: the lecturer should provide explicit assessment criteria and ensure that students understand them before the assessment begins; encourage constructive feedback; guarantee the anonymity of reports to promote impartial and fair assessment; and finally, supervise the assessment process to ensure that feedback is relevant (Liu & Carless, 2006; Topping, 2009).

The PWP-MLMS model also includes an equipment guide that uses multimedia content to describe the role of each piece of equipment used in the experiments and provides detailed instructions on its use and the safety standards to be followed when handling it. This guide can be consulted by students before or during the practical work to familiarize them with the equipment and facilitate its preparation and safe and efficient use. The descriptions in this guide will also help students identify equipment in the laboratory. Additionally, students can refer to this guide when writing their laboratory reports to ensure the correct use of technical terms.

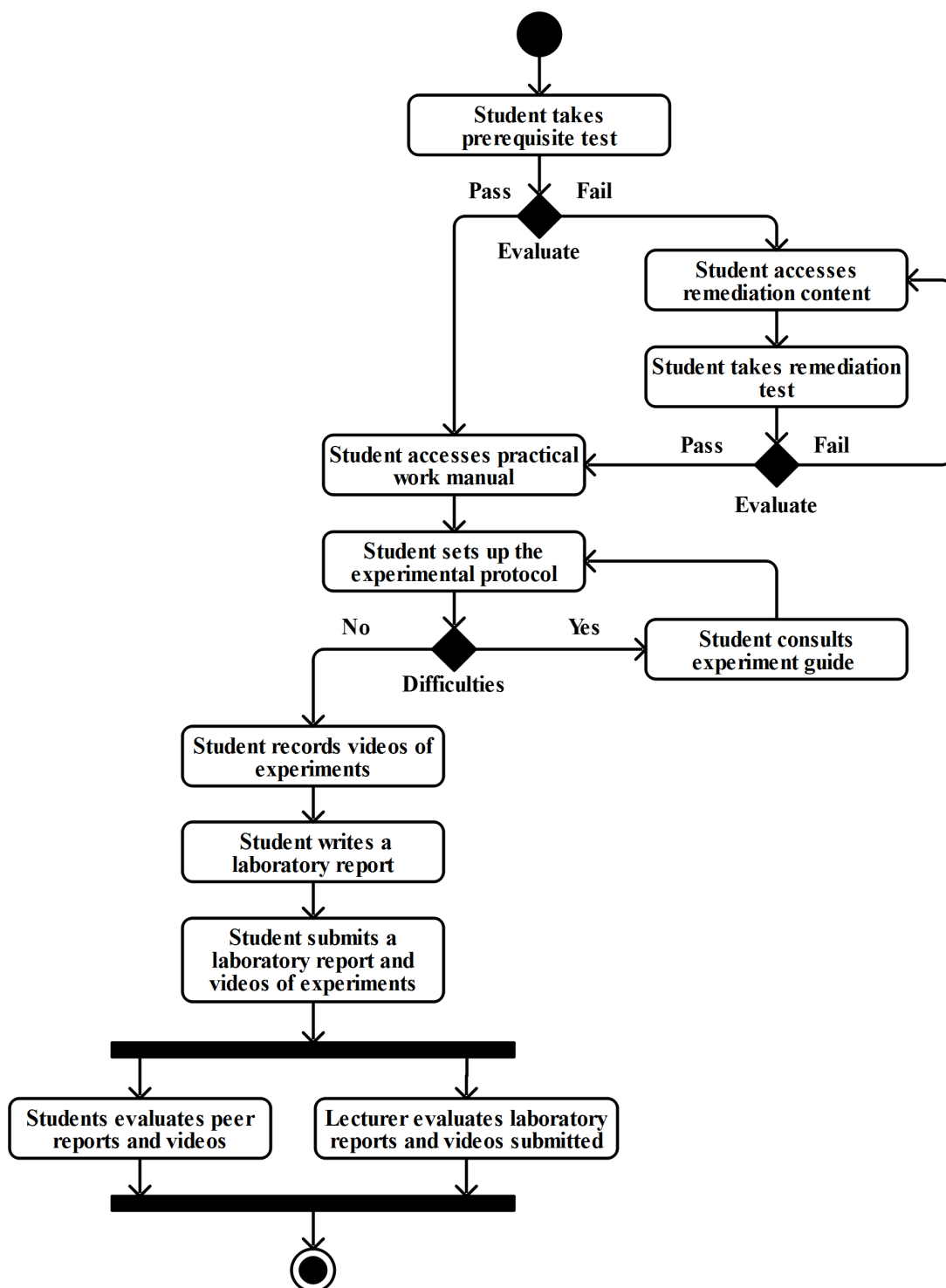
In addition, the PWP-MLMS model includes a discussion area where students can ask questions about practical work instructions and difficulties encountered, as well as answer questions from their peers. This space also allows students to share resources, ideas, tips, and comments about their practical work. It also provides the opportunity to form study groups and facilitates collaboration on laboratory reports. The lecturer takes an active role in supervising discussions, ensuring that they remain productive and relevant. He or she guides students in their



reflections, encourages constructive debate, shares additional resources as needed, provides targeted support to students who are struggling, and offers constructive feedback and clarification to deepen understanding of the issues being discussed.

Figure 1

Activity Diagram of PWP-MLMS



Model Validation

As part of the validation of the proposed model, the Moodle LMS platform (version 3.11) was selected for implementation of the practical work sessions. Moodle was chosen due to its open-source nature, which makes it a cost-effective solution for universities (Deliwe, 2020). Furthermore, its versatility and customizability align with specific needs, facilitating the deployment of a wide range of educational activities and resources. These features are particularly relevant in the context of implementing the proposed model, as they enable the integration and management of the various educational components envisaged. Moodle also offers an optimal learning experience on mobile devices, thanks to its dedicated application. In addition, the platform offers responsive themes specifically designed to adapt to various screen sizes and resolutions, enabling users to access content comfortably via a web browser.

To validate the PWP-MLMS model, Moodle was installed on a web server, and a responsive theme was employed to ensure a consistent learning experience that was accessible on a variety of screen sizes, including smartphones, tablets, and desktops. Resources and activities in line with the proposed model were implemented. A usability test was then conducted with a group of 12 student volunteers, using their own mobile devices to navigate the LMS, access the various resources, and perform various tasks. This evaluation yielded feedback on the user experience, identified technical issues and access difficulties, and highlighted areas for improvement in the design of the LMS interface.

Following the completion of the usability test, a pilot test was initiated involving a larger sample of 30 student volunteers. The objective of this test was to assess the efficacy of the entire pedagogical model in real-world conditions, including access to resources, the execution of practical work, and interaction with learning activities. Participants utilized the PWP-MLMS model in two physics practical work sessions, exploring various potential learning pathway scenarios. At the conclusion of the pilot test, the data collected, including student feedback and LMS usage data, was subjected to analysis. Based on the results of this analysis, the necessary technical and pedagogical modifications were made to refine the implementation of the model.

Research Methodology*Context and Participants*

To assess the effectiveness of the PWP-MLMS model in higher education, an experiment was conducted as part of physics practical work at the Higher Normal School of Abdelmalek Essaadi University in Morocco. The study involved 128 students enrolled in a bachelor's degree in education, specializing in physics and chemistry. Students were randomly divided into two groups of 64 each: a control group (CG) and an experimental group (GE). The students were assigned to groups using the random sampling selection function in SPSS 27, ensuring a fair distribution and minimizing potential bias.

The practical work was conducted as part of the electronics module, with the subjects chosen for the practical work being rectification and filtering. The CG students carried out the practical work in a conventional manner, utilizing printed manuals and benefiting from the teacher's explanations. In contrast, the GE students employed the proposed model. The principal aim of the experiment was to ascertain the impact of the PWP-MLMS model on student performance in these electronics practical works. The objective was to determine whether students who utilized this model demonstrated superior performance compared to those who completed the practical work in a conventional manner.

To prevent any potential bias resulting from the utilization of technology in the analysis of the experiment's outcomes, all participating students received prior training on the use of the model via the LMS and their mobile devices. Participants were informed of the nature of the research and its objectives and were invited to participate on a voluntary basis. All data collected during the study was anonymized and treated as confidential and secure.

Instrument

In this study, the resources and activities for the rectification and filtering practical work were set up on the Moodle platform according to the PWP-MLMS model, as illustrated in Figures 2A and 2B. The objectives of this practical work were to enable students to understand the basic principles of rectification and filtering, as well as their role in the conversion of electrical energy. Additionally, the objective was to familiarize students with the use



of diodes for full-wave and half-wave rectification, as well as capacitors for post-rectification filtering. Finally, the practical work was designed to provide students with experience in analyzing input and output signals using an oscilloscope, with the aim of assessing the effectiveness of the rectification and filtering techniques implemented.

The test of the theoretical prerequisites recommended in the proposed model was carried out using 10 multiple-choice questions. These questions were examined by three expert lecturers in the field to assess their relevance and representativeness of the body of theoretical knowledge required for the rectification and filtering practical work. The test was deemed to have been passed if the student obtained a mark equal to or higher than 70%, a threshold established by the expert lecturers. In the event of a score below the threshold, the student is directed to a remediation activity. To implement this activity, Moodle's "Lesson" activity module was utilized. This module was employed to structure the content into several pages, each dedicated to a specific theme covered by the prerequisite test. Content-related questions were integrated throughout the lesson to enable students to assess their understanding of the revised themes and follow a learning path adapted to their needs. Furthermore, personalized feedback was employed to provide immediate feedback on the students' answers, with the intention of reinforcing their learning or assisting them in identifying and understanding their mistakes. The remediation activity was considered complete when the student reached the activity's end page. After successfully completing the prerequisite test or remediation activity, the student was able to access the practical work manual.

Moodle's "Page" resource was used to create the practical work manual. The manual defined the objectives of this practical work, listed the equipment required, provided a detailed list of experiments to be carried out, as well as questions for students to answer and guidelines for report writing. Students were asked to perform several experiments, including single rectification using a single diode, double rectification using a diode bridge, filtering after single rectification, and filtering after double rectification. One of the tasks assigned for each experiment was to draw on paper the characteristics of the input and output signals. In order to include these characteristics in the laboratory report, the students had to photograph them using their mobile devices and include these photos in their reports. In addition, students were required to record videos illustrating various experiments and submit these videos with their laboratory reports.

A section dedicated to the creation of an experiment guide was created, comprising four concise videos that explain how to set up the experimental protocols to be carried out by the students. These videos were accessible either directly or via links embedded beneath the electronic schematics of the experiments in the practical work manual, thanks to the automatic linking option available in Moodle. Students were encouraged to view these videos if they encountered any difficulties in implementing the experimental protocols.

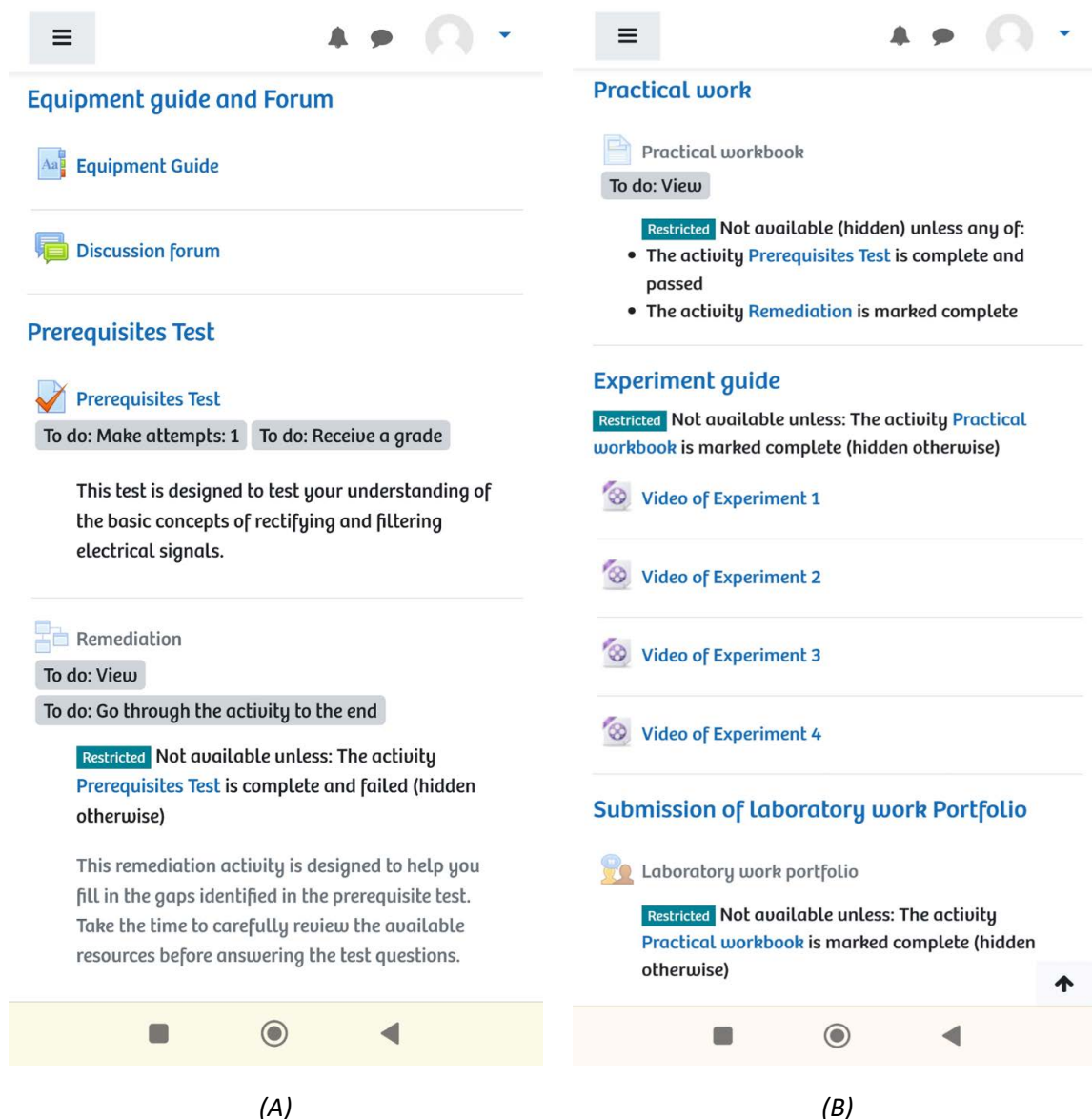
An equipment guide for practical work was established through the utilization of the "Glossary" activity within Moodle. Each piece of equipment required was given a dedicated entry in the glossary, including detailed information such as the name of the equipment, one or more illustrative photos, its function, instructions for use, and associated safety instructions. To enhance this information, videos demonstrating the correct use of certain equipment were also included. The glossary was readily accessible from the dedicated practical work page on the LMS, enabling students to swiftly search for a specific piece of equipment using its name or relevant keywords. Furthermore, the LMS and glossary were configured to automatically link the equipment name and associated terms to the corresponding glossary entry. This automatic linking feature provided students with immediate access to information about each piece of equipment when they encountered its name or associated terms in different practical work activities and resources.

A discussion area was established through the use of the "Forum" activity available on the Moodle platform. This forum was specifically dedicated to the discussion of practical work instructions as well as problems encountered in setting up the required experiments. Students were encouraged to ask and answer questions from their peers, thereby promoting an active exchange of knowledge and experience. In addition, participants were given the opportunity to share additional resources, such as videos or tutorials, that could help their peers better grasp the topics covered in practical work. Furthermore, participants were encouraged to share their own experiences and insights regarding the experiments, including any useful techniques or strategies that they had discovered. The lecturer was present throughout the discussions in the forum, offering guidance and assistance to students who required it.



Figure 2

Overview of Resources and Activities for Smartphone-based Rectification and Filtering Practical Work



To facilitate the submission of practical work portfolios, including laboratory reports and videos of experiments conducted, the “Workshop” activity on the Moodle platform was utilized. This activity was configured to permit the submission of laboratory reports in either online text format or as digital document attachments, while videos of experiments were submitted as attachments. Additionally, a form was created to assess the quality of written reports as well as the clarity and relevance of experiment videos. The workshop was configured to allow for peer assessment with a random assignment of work, thus ensuring that every student participated in the evaluation of a submitted portfolio. Furthermore, the lecturer had the ability to assess the submitted practical work portfolios, review the assessments made by the students, and provide constructive feedback on them.



Procedures

As part of this study, CG and GE students engaged in practical work focused on rectification and filtering over a total period of eight hours. The CG students approached the practical work in a conventional manner, receiving a description sheet of the activities to be carried out and supplementary oral explanations provided by the lecturer. Should any difficulties arise in setting up the experimental protocols, the students could request assistance from the lecturer. In contrast, the GE students carried out the same practical work using the PWP-MLMS model via their mobile devices, without any direct intervention from the lecturer.

To assess the performance of the students in both groups, three primary criteria were established. The first criterion was the time required to complete the experimental setups, measured in minutes. The second criterion evaluated the students’ technical skills, specifically their ability to handle instruments and equipment correctly and safely, follow experimental procedures, and make the required measurements, which was scored on a 100-point scale. The third criterion was the quality of the laboratory report prepared and submitted by each student, which was also graded by the lecturer on a 100-point scale. The quality of the report was graded on the clarity and precision of the description of the procedures and materials used, the accuracy and presentation of the data, the analysis and interpretation of the results obtained, and the correct use of scientific terminology.

To ensure the authenticity of the results and to assess the relevance of the methods used, the lecturer directly supervised the CG students’ work in the laboratory. EG students submitted videos demonstrating their results and the methods used. The subsequent analysis of these videos by the lecturer and peers during the assessment of the practical work portfolios facilitated the verification of the authenticity of the results and the evaluation of the appropriateness of the methods used.

Data analysis was performed using SPSS software, version 27. Descriptive statistics (mean and standard deviation) and inferential statistics were used to compare the performance of CG and EG students. Since the data were found to be normally distributed, t-tests were used to assess differences between the performance of the two groups. A difference was considered statistically significant at $p < .05$. When significant differences were found using the t-test, effect sizes were calculated to determine the magnitude of these differences.

Research Results

The performances of the CG and EG students were compared using three evaluation criteria: the time required to complete the experimental set-ups, the technical skill mastery, and the quality of the laboratory reports. During the practical work sessions devoted to rectification, the students built single-alternance and double-alternance rectifier circuits on test plates using four separate series of junction diodes. They then set up corresponding filter circuits using four capacitors of varying capacitance, respectively. The time taken by each student to complete each circuit was measured and recorded. The sum of each student’s completion times in both the CG and EG was calculated and used to compare performance between the two groups. Table 1 shows the descriptive statistics for students’ completion times in both groups, as well as the t-test results between the two groups.

Table 1
Comparison of Experimental Setup Times Between CG and EG

Group	N	M (min)	SD (min)	t	df	p	d
EG	64	39.02	7.208	-5.284	126	< .001	-0.934a
CG	64	46.98	9.675				

Note. ^a large effect size, ^b medium effect size, ^c small effect size

The results presented in Table 1 demonstrate a statistically significant difference in completion times between the experimental setups of the CG and EG, as evidenced by the independent samples t-test ($p < .001$). GE students completed the experimental setups at a faster rate than their CG counterparts. Moreover, the effect size indicates a significant difference between the times of the two groups ($|d| > 0.8$) (Cohen, 1988), suggesting a significant impact of the use of the PWP-MLMS model on experimental setup completion times.



Table 2 presents the descriptive statistics of the scores assessing the technical skills demonstrated by CG and EG students in carrying out the experimental setups, as well as the results of the independent samples t-test comparing the scores obtained by students in the two groups. The result of this test reveals a statistically significant difference between the technical skills of students in the CG and EG groups ($p < .001$). Indeed, EG students demonstrated superior mastery of technical skills compared to their CG peers. The large effect size observed ($d > 0.8$) (Cohen, 1988) suggests a notable effectiveness of the PWP-MLMS model used by the EG. This model enabled the students in this group to develop their ability to handle instruments and equipment correctly and safely, follow experimental procedures, and perform the required measurements.

Table 2

Comparison of Technical Skills Scores Between CG and EG During Experimental Setups

Group	N	M	SD	t	df	p	d
EG	64	85.31	8.383	6.407	126	<.001	0.912 ^a
CG	64	77.06	9.671				

Note. ^a large effect size, ^b medium effect size, ^c small effect size

Table 3 presents the descriptive statistics of the grades awarded by the lecturer to the laboratory reports submitted by CG and EG students at the conclusion of the practical work sessions, along with the results of the independent samples t-test comparing these grades. The results of the t-test indicate a statistically significant difference between the grades obtained by students in the two groups ($p < .001$), with higher grades for GE students. A large effect size ($d > 0.8$) (Cohen, 1988) indicates a significant impact of the PWP-MLMS model on the quality of laboratory reports. This demonstrates a beneficial effect on students' ability to clearly and accurately describe the procedures and materials used, collect and present accurate data, analyze and interpret the results obtained, and correctly use scientific terminology.

Table 3

Comparison of Grades for Laboratory Reports Submitted by CG and EG Students

Group	N	M	SD	t	df	p	d
EG	64	81.88	9.466	4.920	126	<.001	0.87 ^a
CG	64	73.14	10.589				

Note. ^a large effect size, ^b medium effect size, ^c small effect size

Discussion

This research presents the PWP-MLMS model developed to enrich the educational experience of university students and improve their performance in physics practical work. This model exploits the functionalities of LMSs as well as the mobile devices available to students to solve some of the difficulties inherent in practical work. PWP-MLMS allows students to perform these activities autonomously, reducing the need for direct intervention by lecturers. It takes into account students' prior theoretical knowledge of physics, as well as their ability to use laboratory equipment correctly, and provides the necessary support and guidance when needed. It also promotes collaboration among students to solve problems encountered during practical work and optimizes the process of submitting and evaluating laboratory reports.

Based on the proposed model, resources and activities dedicated to physics practical work were developed and integrated into a Moodle platform. These resources and activities were then utilized by students in an experimental group as part of their practical work. Concurrently, students in a control group carried out the same practical work using a conventional method.

The study revealed that the adoption of the PWP-MLMS model significantly reduced the time required by EG students to complete experimental setups in comparison with CG students. This significant reduction in the



time required by students using the proposed model to complete their experiments can be attributed mainly to the use of the equipment guide, the experiment guide, and the discussion forum. The equipment guide, which provides information about the equipment used and how to use it, enables students to become familiar with the equipment, increasing their confidence in its use and reducing their anxiety about using it incorrectly or damaging it (Lal et al., 2020; Nikolic et al., 2015). This anxiety can impede the learning process. Additionally, this familiarity with the equipment enables students to identify it quickly and correctly, reducing the time spent searching for it. The equipment guide also provides advice on the most efficient way to use the equipment, thereby enabling students to avoid handling errors and reduce the time wasted correcting trial and error.

The concise videos in the experiment guide, which present experimental procedures in a step-by-step format, contribute significantly to reducing the time invested by students in executing experimental protocols when using the PWP-MLMS. This observation is consistent with the findings of other research indicating the efficacy of videos in reducing the time required to complete assigned practical tasks during practical work (Box et al., 2017; Burewicz & Miranowicz, 2006; Campbell et al., 2020; Jordan et al., 2016; Nadelson et al., 2015; Stieff et al., 2018). In particular, these videos facilitate the accelerated familiarization of students with the equipment (Onyeaka et al., 2023) and enhance their capacity to comprehend and follow procedures in a more efficient manner, thereby reducing the time dedicated to trial-and-error and the necessity for repetition (Burewicz & Miranowicz, 2006). Furthermore, these videos permit students to advance at their own pace and revisit specific sections according to their needs, thereby fostering more effective time management during laboratory sessions (Jordan et al., 2016).

In the proposed model, the discussion forum can help reduce the time allocated to experimental procedures by facilitating the exchange of knowledge and experience between students. When a student encounters a practical difficulty, he or she can seek assistance from peers who have already encountered and solved similar problems, thus reducing the need for time-consuming trial and error (Palincsar & Herrenkohl, 1999). Furthermore, the forum provides access to additional resources and advice from more experienced peers, enabling the student to avoid or quickly solve practical problems, thus reducing the time required to set up experimental procedures.

The results of this study also showed that the PWP-MLMS model positively influenced the technical skills of EG students, outperforming those of CG. EG students were shown to be better able to handle instruments and equipment correctly and safely, follow experimental procedures, and perform required measurements. The positive impact of the proposed model on EG students' technical skills can be attributed to the use of the equipment guide, experiment guide, and discussion forum. The equipment guide enables students to learn about the functionality and operating instructions of each piece of equipment used in experimental setups, thus developing their ability to handle equipment correctly. Furthermore, consulting the safety instructions in the equipment guide makes students aware of the importance of safety and provides them with the knowledge they need to use equipment safely and avoid incidents.

The experiment guide's provision of concise, step-by-step videos describing how to carry out experimental procedures to EG students who perceived themselves as unable to do so significantly contributed to the development of advanced technical skills among EG participants, compared with CG participants. By providing visual demonstrations, these videos guide students in the safe and precise handling of instruments and equipment, facilitating replication of procedures in the laboratory and improving understanding and retention of procedural and safety information (Box et al., 2017; Campbell et al., 2020; Höffler & Leutner, 2007; Seery et al., 2017; Stieff et al., 2018). Videos have been demonstrated to be an effective means of conveying procedural knowledge (Ayres et al., 2009; Höffler & Leutner, 2007). They can be employed in laboratory settings to illustrate instrument handling, phases of experimental procedures, and safety rules in a more effective manner than textual support, still images, or verbal explanations provided by the lecturer (Höffler & Leutner, 2007). Furthermore, videos can be paused, rewound, and viewed multiple times, allowing students to review complex procedural steps if necessary (Zhang et al., 2006). This is particularly beneficial for mastering challenging techniques and understanding the nuances of experimental setups.

The discussion forum can contribute to the enhancement of technical skills among students engaged in practical work activities through a variety of mechanisms. Primarily, it facilitates the exchange of knowledge, experience, and best practices between participants, particularly with regard to the specific use of equipment and the implementation of experimental procedures. Secondly, it offers students the opportunity to obtain feedback on their methods of handling instruments and equipment, as well as to seek assistance from more competent individuals to overcome difficulties encountered during practical work. This dynamic of exchange and support enables students to perform practical tasks that they would be unable to complete on their own, thus contributing to the improvement of their technical skills (Hrastinski, 2009; Vygotsky, 1978).



The findings of this study indicate that the utilization of the PWP-MLMS model enabled EG students to produce laboratory reports of superior quality compared to those produced by CG students. The impact of the model on the quality of the laboratory reports can be attributed to the theoretical knowledge assessment and remediation activities, in conjunction with the use of the equipment guide and experiment videos. By assessing the theoretical knowledge essential for analyzing and interpreting the results of practical work and implementing remediation activities following the identification of deficits in this knowledge, the model provides students with the conceptual understanding and vocabulary needed to carry out adequate analysis and interpretation of experimental data, as well as to articulate their observations and analyses effectively (Bransford et al., 2000). With regard to the equipment guide, it enhances the quality of laboratory reports by assisting students in accurately and clearly describing the equipment utilized, while promoting the use of appropriate scientific terminology.

Visualizing experimental procedures through the use of experiment videos improves the accuracy with which students document methods and procedures in their reports. These videos also facilitate comprehension of laboratory techniques (Box et al., 2017; Campbell et al., 2020; Höffler & Leutner, 2007; Seery et al., 2017; Stieff et al., 2018), thereby enhancing the ability to take necessary measurements and record accurate observations and results, leading to conclusions that are more reliable and valid. Furthermore, a better understanding of experiments through these videos reduces procedural errors among students, enabling them to focus more on the analysis and interpretation of results, which are essential aspects of laboratory reports.

In practical work, students are confronted with the challenge of simultaneously performing a series of procedural steps while attempting to comprehend the underlying scientific principles and make sense of their results. This dual cognitive demand can rapidly exceed the capacity of students' working memory, leading to cognitive overload (Sweller et al., 2019). By presenting experimental procedures in a step-by-step format, videos of experiments can assist in reducing the cognitive load required to comprehend and execute these procedures (Yang & Tao, 2015), thereby freeing up cognitive resources that can be allocated to the analysis and interpretation of results in laboratory reports (Sweller et al., 2019).

Conclusions and Implications

The PWP-MLMS model presented in this study exploits the LMSs established within universities and the mobile devices available to students to enable them to carry out physics practical work. This model shows significant potential for increasing students' autonomy in their practical work and lightening the workload of the academic staff involved. It provides students with the support they need to complete these activities independently, taking into account the theoretical and practical knowledge required for practical work. In this study, the model was implemented via a Moodle platform and evaluated by comparing the performance of an EG using the model with that of a CG using conventional practical work. The results revealed that the model contributes to a significant reduction in the time required to complete practical work, has a positive influence on students' technical skills, and improves the quality of their laboratory reports.

Although the results of this study indicate that the PWP-MLMS model offers significant advantages, certain limitations should be noted. Firstly, the model's implementation was tested at a single academic institution, which may limit the generalizability of the results to other institutional contexts. Secondly, this study did not explore students' attitudes towards the model, a factor that could have a notable impact on its acceptance and effective use. Consequently, future studies should consider evaluating the effectiveness of the model in other institutions and examining student reactions with a view to optimizing its adoption and use.

Declaration of Interest

The authors declare no competing interest.

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