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ENHANCING ONLINE PRACTICAL COURSES IN MECHANICAL ENGINEERING: DEVELOPMENT AND ANALYSIS OF INNOVATIVE METHODS

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ABTRACT/ABSTRAK

This research paper introduces three innovative approaches for delivering online practical courses in the field of mechanical engineering. With the increasing popularity of eLearning platforms, educators have been encouraged to adapt their teaching methods accordingly. However, teaching practical mechanical engineering courses online has posed significant challenges due to the reliance on machinery and hands-on equipment. This study represents a pioneering effort in proposing new methods to address these difficulties. The primary goals of this research are to establish the feasibility of conducting practical courses online and to provide solutions for enhancing the quality of such courses. To achieve these objectives, the study focuses on the development, application, and analysis of pedagogical approaches, virtual tools, and simulation software. The research was carried out with three student groups enrolled in two Tunisian Higher Institutes of Technological Studies. Based on the evaluations of these experiences, the implementation of new methodologies has led to a significant improvement in students' practical skills.

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1. INTRODUCTION

Practical courses play a vital role in mechanical engineering, it is the second major component of education. Experiential learning contributes to developing the innovation competences (Charosky et al., 2021). For a variety of reasons, teaching those practical courses is a difficult endeavor. First, it necessitates the use of machines (Faria et al., 2020), didactic benches, and laboratory equipment (Leva et al., 2020). Second, educators must impart theoretical and practical information to students (Aydin et al., 2011). They must ensure that students and equipment are safe. They must also meet the educational objectives and aims.

There has been a surge in interest in online education in recent years (Lee et al., 2019), and eLearning is now widely used in most educational institutions(Sarker et al., 2019), networked learning can be a useful approach in engineering education (Huijben et al., 2021). Online practical instruction has become increasingly viable in most specialties, and more specifically in mechanical engineering, because of the development of computer technologies (Moreno-Moreno & Yáñez-Márquez, 2008).

Online laboratories are designed for studies that require fewer operations (Horton et al., 2017). Electronics, optics, and robotics are among the domains where online practical trainings are now being applied. The employment of information and communication technologies in education, on the other hand, generally results in formatted activities Hutchison & Reinking, 2011). Independently of conditions, universities must supply a high-quality education and maintain their academic standards (Gamage et al., 2020).

However, as highlighted by (Gudyanga & Jita, 2019) and (Alam et al., 2007), the emphasis on laboratory practices has changed over the years, with more focus on curriculum and teaching techniques and less on laboratory practices. Mechanical engineering practical online courses are limited (Kovačević, 2020) to design and production management software (Schimanski, 2021). Due to the necessity of experiments or machine manipulation, various types of mechanical practical training can only be taught in a laboratory or workshop. To meet academic goals, most engineering programs, particularly mechanical and civil engineering, require hands-on workshop facilities for conducting educational laboratory activities (Hernández-de-Menéndez 2019).

Previous eLearning research has mainly focused on theoretical courses (Ariesta et al., 2021; Etxebarria et al., 2012; Biswas et al., 2021; Low et al., 2021; Martin et al., 2020). In this paper, new online teaching techniques for mechanical practical courses was developed and tested. It will be useful in both regular and unusual circumstances, such as a corona pandemic. Mechanical engineering students at the Tunisian Higher Institutes of Technological Studies will test these methods. Due to several constraints, such as the need for machines and instruments to ensure students' training, teaching practical courses presents the greatest challenge. This pandemic will affect the education for the foreseeable future (Chick et al., 2020). To overcome the challenge, it is attempted to develop new educational approaches to assist mechanical engineering teachers. It is not justified that the technology forces blended or virtual training (Eri et al., 2017). There are opportunities and challenges for teachers to effect change in education methods (Watkins et al., 2021). These approaches must be used to achieve well-being conditions. Students studying mechanical engineering must learn to design (Yu et al., 2020), conduct experiments (Lyons & Brader, 2004), and manipulate machines and devices (Yin et al., 2021). Tunisian institutes, particularly mechanical engineering departments, must invest in and develop workshops, labs, and facilities (electrical, pneumatic, and hydraulic) in order to provide students with theoretical and practical knowledge based on job skills and academic objectives.

As a result of Tunisia's financial challenges, higher institutes of technological studies have been compelled to cut back on new equipment and renovations (Ghobtane & Amor, 2021). These issues have little impact on the mechanical engineering specialization, making it more difficult to meet the instructional objectives. It will be impossible to transfer teaching information into knowledge and skills if these conditions are not considered in online practical courses. Professors and students benefit from both temporal (unlimited access) and spatial (access to any position) options while using distance learning (Attardi et al., 2018).

This study will improve online practical course teaching methods and encourage professors of technological courses to use new IT tools. Distance learning should be taken advantage of and integrated into the domain of practical mechanical online courses. Students must have a margin of initiative in distance courses, practices in engineering classes must include a decision making (Koretsky et al., 2021). According to their scientific and technical levels, they must have some flexibility in acquiring knowledge or experiences. As (Fishman et al., 2017) prove, students must manipulate experimental procedures as in practical face-to-face courses and it should not be limited to a predetermined, prepared situation. Teachers prepare students and they must be sure that the students know the targets of learning activities (Mäkiö et al., 2021). Arguing that it should not aim to cover all the ethical issues an engineer may have to consider, but rather aim to equip students with relevant skills (Lawlor, 2021). Innovation and design teaching is a major responsibility for teachers (Turcsányi-Szabó , 2012).

Previous studies do not explore the teaching of practical mechanical courses. To overcome these challenges and improve learning quality, this article suggests new online pedagogical approaches for ensuring practical mechanical engineering courses. Based on the approaches presented in previous research, two professors from the Higher Institutes of Technological Studies of Nabeul and Kelibia in Tunisia have employed three different practical mechanical courses to test the new eLearning methodologies: coordinate measuring machine CMM, computer numerical control CNC and mechanics of materials. The solutions to earlier problems are represented by these approaches. It's also essential that the proposed solutions include collaborative workspaces (Pertiwi & Kusumaningrum, 2019) for students and instructors alike.

2. METHODS

This research conducts some materials and methods assessed students as treatment that affect particular aspects. Professors encounter various challenges in practical face-to-face classes, including:

- Equipment availability: some practical courses necessitate expensive machinery, making it impossible to have more than one machine per institute (for example, computer numerical control or coordinate measurement machines). Students are divided into groups or subgroups considering the limited number of materials/machines in laboratories.
- Laboratory and workshop availability: time slots are limited in schedules and owing to laboratory availability, it is difficult to plan practical course sessions for a significant number of groups. As a result, it is probable that some students will be unable to complete some practical courses.
- Security: Because students do not master controlling machines, professors are responsible for the safety of students and equipment in practical mechanical courses.

There are three types of practical courses at the mechanical engineering license level:

a) Experiments: Professors conduct experiments to assist students to comprehend mechanical rules and phenomena. Students do a laboratory experiment to discover some facts that mechanical specialists should already be aware of.

b) Machine manipulation: The major goal of manipulating machines is to teach students practical skills. As a result, students will be able to run a machine in a systematic manner (for example Lathe, Mill, folding machines, etc.)

c) Software Applications: Students get a fundamental knowledge of mechanical domains in software practical courses. They also use software for design, analysis, and simulation.

Industrial managers seek students with both practical and theoretical knowledge and who are ready to make an immediate impact in their organizations without undergoing any formal training. Provide opportunities for students engaging in industry is a big challenge due to the constraint to set up an environment similar industry counterpart (Yang, 2021). By the end of mechanical practical courses, students must be able to diagnose and maintain equipment, be well-versed in mechanical principles and theorems, take measurements and analyze the results and create prototypes for parts, machines, and installations.

To test the validity of the three methods various experiments were conducted. The study was conducted with three groups of students (a total of 62 mechanical engineering students) from two different academic institutions, students are more creative, when they showed more attention to peers' ideas (Pi et al., 2019). Participation in these hands-on workshops was entirely voluntary. Summarizes the number of students in each group and practical courses is presented in table 1. This study has offered to students the chance to experience online learning (Brown et al., 2012). This work consists of three phases:

- A resource design phase, which had taken place since March 16 through April 4.
- An operational phase, which was ensured between April 5th and May 20th.
- A phase of review, which took place between May 23 and May 30.

Table 1. Summarizes the number of students in each group and practical courses

Institutes	Disciplines	Levels	Courses	Number of students
Higher Institutes of Technological Studies of Nabeul	License in Mechanical Engineering Course Design and Mechanical Manufacturing	2nd year	Coordinate measuring machine CMM	26
	License in Mechanical Engineering Path Industrial Maintenance	2nd year	Computer numerical control CNC	22
Higher Institutes of Technological Studies of Kelibia	License in Maritime Engine Engineering Naval	1st Year	Mechanics of Materials	14
	License in Maritime Engine Engineering Naval	2nd year	CMMS Computerized Maintenance Management System	14

2.1. Virtual Machine

Students manipulate real machines for training purposes in face-to-face practical courses till they improve their practical skills. In distant learning, a virtual machine can be used in some practical courses to ensure that the learning objectives are met. These machines are usually integrated into mechanical software and can be used in the classroom or online (Craifaleanu & Craifaleanu, 2022). A three-step teaching methodology for students of design and mechanical manufacturing at Nabeul's Higher Institutes of Technological Studies has been developed to enable them to carry out practical courses on coordinating measuring machines. Firstly, prepare videos to describe the real machine. They help students to improve their theoretical and experimental knowledge about the real machine. Second, create a video demonstrating how to manipulate the virtual machine and control software. Videos instruction are widely used as a supplementary instruction (Miner & Stefaniak, 2018). These videos must be precise and have a good quality (Alam et al., 2007). Finally, to organize training sessions, communicate with students, and evaluate them, the Virtual University of Tunis's distant eLearning platform was used. This study was conducted with a group of 28 voluntary students over the course of four one-hour sessions.

2.2. Simulation Software

Simulation software can be used to replace didactic machines (Chao et al., 2016) in some practical mechanical teaching. These programs include component libraries for various types of training, as well as flexible manipulation, unlimited design, and real-time simulation; these characteristics assist professors in meeting training objectives. Virtual components have the same features as real ones. There are software programs that allow you to manage students and administer online tutoring. They're employed in hydraulic, pneumatic, electro-mechanical, refrigeration, and thermal equipment, among other things. According to (Turhan et al., 2019) in learning the satisfaction, efficiency, certainty, complexity and learning are significant indicators for the choice of the collaborative tool.

Our case study was developed for computer numerical control machine tool programming practical training. By the completion of these practical courses, students should be able to describe the operating principle of numerically controlled machines, set up machines for operation, and execute a CNC program. This course was taught using a new pedagogical method that was broken into three steps:

- First, a software that simulates the real machine that is available at Nabeul's Higher Institutes of Technological Studies was developed. Students can use this software to learn the right procedures for starting a CNC machine. They can assemble and measure tools. They specify the origin of the program. They have the ability to program and simulate the software.

- In the second step, training documents and presentations were uploaded to the Virtual University of Tunis's distant platform.
- Finally, we've prepared an online evaluation system to check if students completed the software simulation assignments correctly.

This study was conducted with a group of 24 voluntary students over the course of fi ve weeks, with each session lasting one hour. Figure 1 depicts the developed simulation software for enhancing online practical courses in mechanical engineering.

Figure 1. Simulation software Source: Adapted from [SPINNER] Machine

2.3. Experimental exploration

In this method, the teacher conducts a practical experience in the laboratory and then sends the students the experimental results as well as a video of the experience. Other parameters will be calculated, analyzed, interpreted, and/or compared by students. This method is only applicable in practical courses where the educational objectives are limited to comprehending a mechanical phenomenon or law, such as fluid mechanics, general mechanics, materials mechanics, and so on.

This method was tested with a group of 14 voluntarily participating students in practical materials mechanics courses. This experience took place over the course of five weeks, with each session lasting one hour. By the completion of these practical courses, students must be able to select a material, describe its mechanical behavior in response to various solicitations, and compute the structure's dimension. This pedagogical method was created in a five-step process. First, the professor has recognized all the practical experiences. Then, he sent the videos of these experiences as well as the results to students (every four students work together in a subgroup). Figure 2 is the traction test video that the teacher prepared and sent to the students.

Figure 2. Video of Traction Test

The students then complete the experimental study and submit reports to the teacher using Moodle Platform. Fourth steps, the teacher may evaluate the reports. Finally, he organized a distance synchronous session to rectify and repair the errors of the student studying.

3. RESULTS

Students received an anonymous set of survey questions to answer at the end of the session to evaluate their experiences. The purpose of the survey was to learn more about students' opinions on organization sessions, online course tools, educational resources, and their level of satisfaction with newly developed approaches. In this experiment, students were also asked to specify the problems they encountered.

The results of the tests and activities were used to create a second evaluation. The knowledge development of students who finished online practical courses were compared to those who took the equivalent classroom practical courses. 48 students answered the survey, the results will be presented below.

❖ **Gender of the students surveyed**

As illustrated in figure 3, male students represent 63,63 percent of those who responded to the evaluation questionnaire, while female students represent 36,37 percent. The mechanical engineering industry's specificity explains this result.

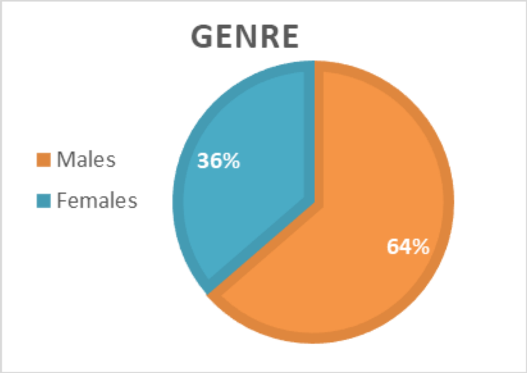

Figure 3. Student's gender

❖ **Q1: Did you follow a distance course before?**

As demonstrated in Figure 4, the majority of students had taken an online course in the past. As a result, they have prerequisites for using distant learning systems.

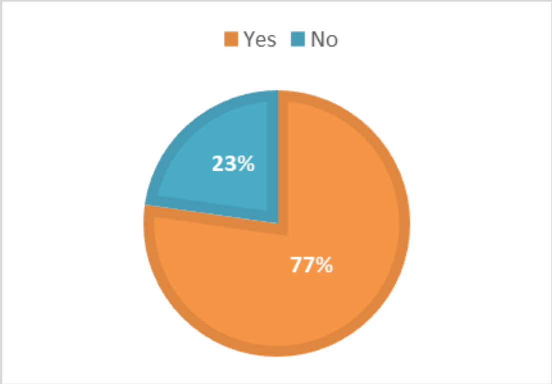

Figure 4. Following a distance course before

❖ **Q2: Did you follow an online practical course before?**

According to the data in table 2, 100 percent of students have never taken an online practical course. Therefore, it is a totally new experience for them.

Table 2. Participation in practical online courses before

Answers	**Percentage**
Participate	0 %
Never participate	100 %

❖ **Q3: What IT equipment do you used to participate in this course**

To manipulate a virtual machine, all students must use a computer. They can also use other devices, such as smartphones and tablets, to access the platform's resources (documents, videos, animations, activities, and so on) and to participate in online conferences.

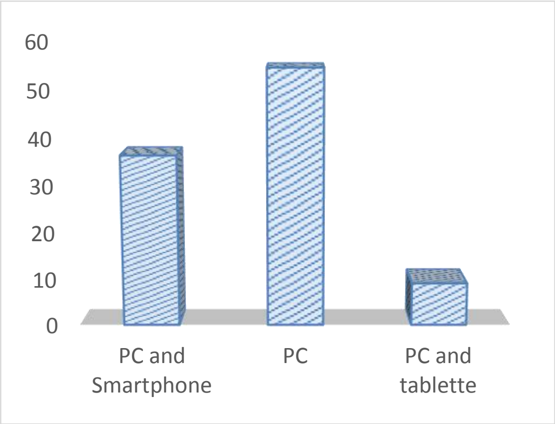

Figure 5. IT equipment used

All students have used computers at least once to engage in practical courses, according to the results of the questionnaire, as shown in figure 5. More than 54% of students have only just used computers. Only 9% of students have used tablets with computers, while 36% have used their smartphones with PCs.

❖ **Q4: Do you find the manipulation of Moodle platform is simple?**

As illustrated in figure 6, almost 64% of those who took part in this experience said the platform was simple to use. Moodle does, in fact, provide an easy-to-use learning environment for students.

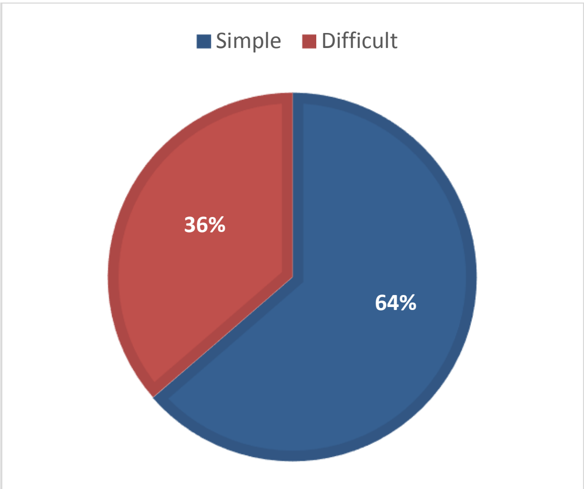

Figure 6. Simplicity of Moodle platform

❖ **Q5: What is your satisfaction level for courses organization?**

As shown in figure 7, only 36% of students are dissatisfied with the practical course organizations, with 62 percent satisfied or very satisfied. The conditions of the online course execution explain this conclusion.

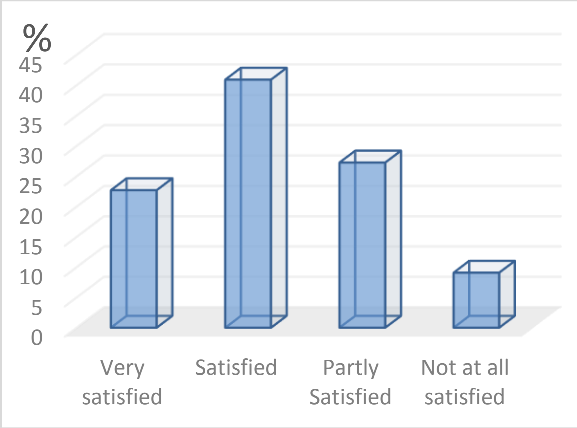

Figure 7. Satisfaction of organization

❖ **Q6: What is your satisfaction level for the rhythms of learning?**

According to figure 8, most students are satisfied with their learning rhythms; roughly 23% are only slightly satisfied.

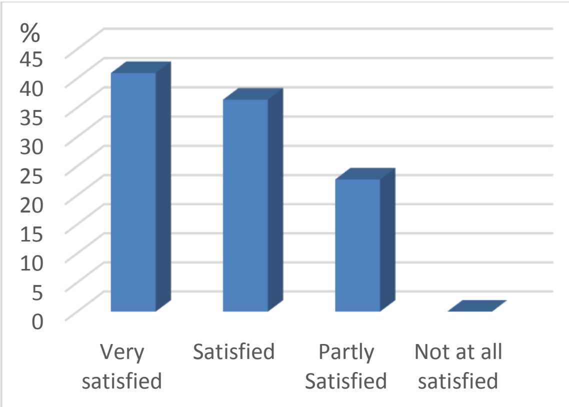

Figure 8. Rhythms satisfaction

❖ **Q7: Type of preferred pedagogical support?**

It is important to highlight that, according to the survey results, illustrated in figure 9, students prefer to use videos and animations rather than PowerPoint presentations or PDF documents.

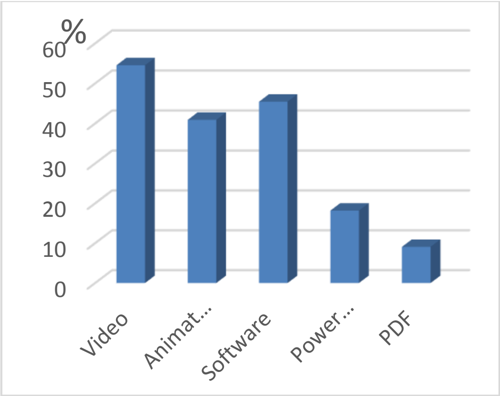

Figure 9. Preferred pedagogical support

❖ **Q8: Degree of satisfaction level for courses vis-à-vis the quality of the videos?**

As shown in the figure 10, approximately 77 percent of the students who participated in this study were pleased with the quality of created videos. While 23% believe that the explanation provided by videos is partially satisfying. This will motivate us to enhance the video quality in future sessions.

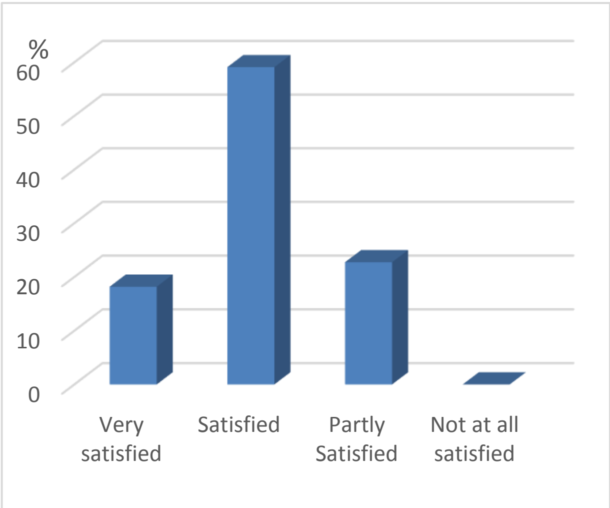

Figure 10. Satisfaction with the quality of videos

❖ **Q9: What is your degree of satisfaction to learn practical courses with a virtual machine?**

The use of the virtual CMM machine has been rated as exceptional or satisfying by all students, as illustrated in figure 11. As a result, It can be concluded that the first pedagogical method is appropriate for practical training.

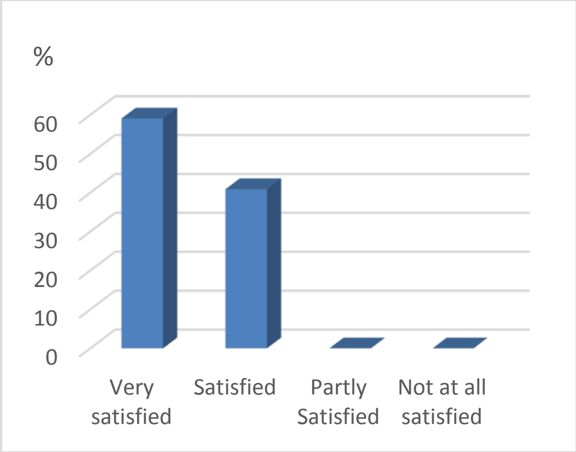

Figure 11. Satisfaction to virtual machine online learning

- **Q10: What is your degree of satisfaction to learn practical courses with simulation software?**

As shown in figure 12, about 93% of students are very satisfied or satisfied with the developed simulation software. While 7% are a little satisfied.

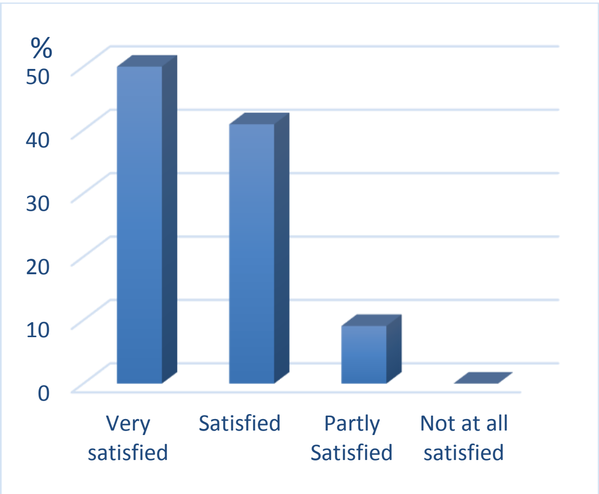

Figure 12. Satisfaction level with software simulation

- **Q11: What is your degree of satisfaction about pedagogical method used in the practical courses "mechanics of materials"?**

According to the survey results illustrated in figure 13, about 64.28 percent of students are satisfied or very satisfied with the experimental explorations technique. However, 35.72 percent of participants are partially or not satisfied with this method. Because this approach does not allow students to practice or simulate experiences, the most likely explanation for the unfavorable result is understandable.

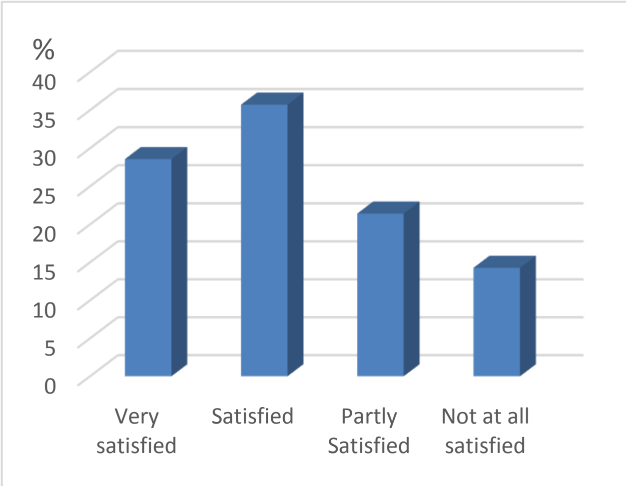

Figure 13. Satisfaction about pedagogical method used in "mechanics of materials"

- **Q12: What is your degree of satisfaction with synchronous online meetings?**

As reflected in figure 14, most of the students are satisfied with the scope of synchronous meetings. However, 23% of participants are dissatisfied. The dissatisfaction is due to problems with connection quality and sound with some students.

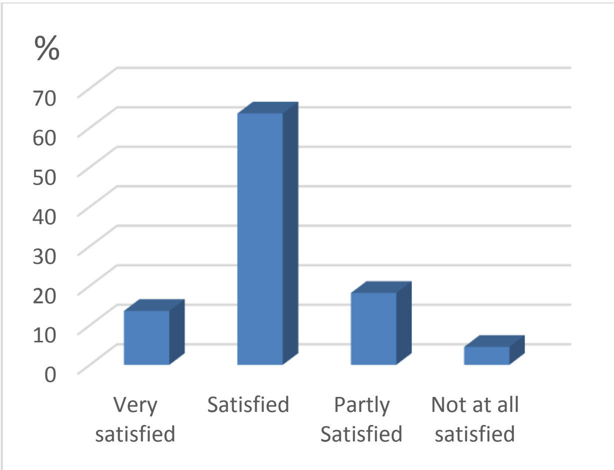

Figure 14. Satisfaction level with synchronous online meetings

- **Q13: Before and after this experience do you prefer classroom or online methods to learn practical courses?**

Prior to this experience, and as can be seen from figure 15, most students preferred classroom practical courses. However, as a result of our experience, more than half of the students have selected online study.

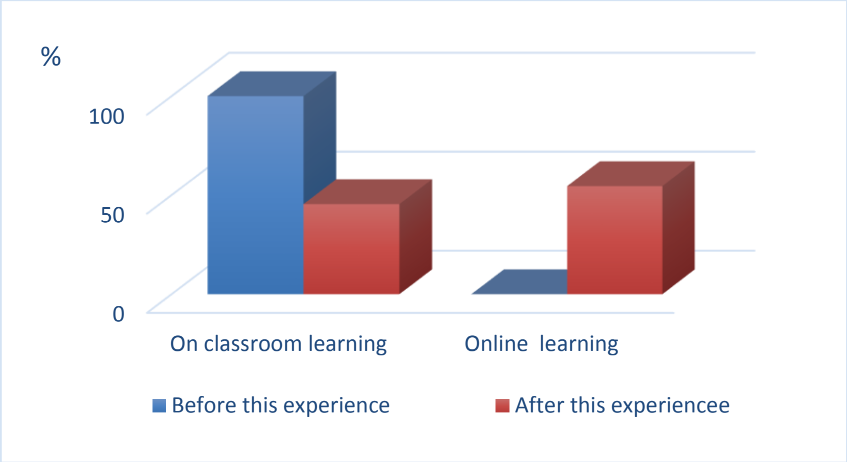

Figure 15. Preference method to learn practical courses

❖ **Q14: Do you think that the methods used in these courses facilitate the understanding of practical mechanical engineering concepts?**

It's important to note that 72.72 percent of students who choose to take part in this experience are pleased with the results and believe that the new methods have met their pedagogical expectations, as illustrated in figure 16.

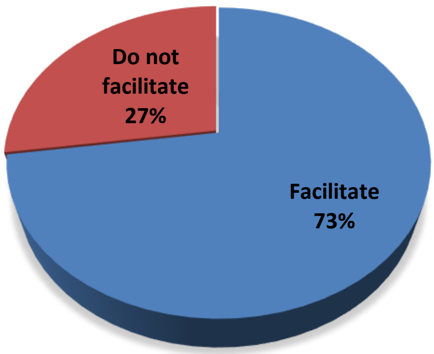

Figure 16. Students think that new method facilitate mechanical practical training

❖ **Remarks and suggestions from students**

It can be noticed that the majority of the students ‘comments and suggestions concern connection and sound concerns. The new pedagogical methods of learning practical courses online were well received by students.

❖ **Summative assessment**

Table 3 compares the class averages in final evaluations between online training and the previous three years with the same courses but using a face-to-face technique to assess the achievement of educational objectives.

Table 3. Averages of Summative Assessment

Academic years		Averages		
		CMM	**CNC**	**Mechanics of Materials**
Face-to-face	First year	12.08 / 20	11.12	12.96
	Second year	12.76 / 20	12.59	13.82
	Third year	11.47 / 20	12.96	13.46
Online training		14.78 / 20	15.04	13.22

The analysis of the data presented in Table 3 demonstrates that the implementation of new methodologies has resulted in a significant improvement in students' average outcomes, specifically in the CMM and CNC practical courses. Virtual machines and software simulations have proven to be valuable teaching tools in this context. However, it is noteworthy that the average assessment scores in the mechanics of materials practical course remain similar to previous years.

Considering these findings, it is recommended to consider employing the experimental exploration approach in future iterations. Based on the results of the summative assessment comparison, it can be concluded that student skills in mechanical engineering have witnessed substantial improvements, and the educational objectives have been successfully achieved through the utilization of these three innovative teaching approaches.

4. DISCUSSION

This paper contributes to the ongoing discourse surrounding eLearning by presenting the outcomes of a pilot project conducted with three groups of Tunisian mechanical engineering students. The primary objective of this study was to test the effectiveness of three innovative approaches for delivering practical mechanical engineering courses online. To evaluate the efficiency of these strategies, a Google Forms-based questionnaire was administered to the participants, and their final examination results were compared. The questionnaire aimed to assess the satisfaction levels of students regarding the computer tools, teaching techniques, and organization of the training.

Initially, most students held the belief that practical courses could not be effectively conducted online. However, as they experienced the advantages of online techniques throughout the courses, their perception gradually shifted, and by the end of the program, they adjusted their viewpoint accordingly. The feedback from students indicated that they found the professors' instructions clear and appropriate for completing practical online courses. They expressed satisfaction with the available resources, activities, and the Moodle platform used in the courses. Notably, students who completed all stages of these online methods achieved higher grades on the final exams. This suggests a significant improvement in the quality of their test answers as a result of the implemented strategies.

While some practical courses in mechanical engineering present challenges in online instruction due to technological limitations, the remarkable advancements in computer technologies have made it feasible to overcome these obstacles. Furthermore, the ongoing progress in computer technology holds the potential to reduce the reliance on physical laboratories, opening new possibilities for teaching and learning in the field of mechanical engineering (Potkonjak et al., 2016). As a result, it is apparent that virtual practical courses have the potential to substitute real practical courses until students can acquire the essential skills through hands-on experience. These novel teaching approaches were rigorously tested to gather student feedback and ensure the achievement of learning outcomes, particularly in a challenging mechanical engineering course involving computer numerical control, coordinate measuring machine, and mechanics of materials. Based on student feedback, it is evident that online practical courses offer additional advantages such as convenience and flexibility in training. This increased level of satisfaction with online learning further supports the effectiveness and value of these innovative approaches. The impact of distance learning on the quality of practical training can be assessed based on the final results of the courses. It is observed that the student outcomes in the mechanics of materials practical course remain almost identical, indicating that the transition to online learning has not significantly affected the results. However, notable improvements are observed in the coordinate measuring machine and computer numerical control courses. The average grades in these courses have increased by more than two points.

This improvement can be attributed to the nature of practical courses with virtual machines or simulation software. In these virtual environments, all students actively engage in manipulating the virtual machines or simulation software, allowing them to develop and refine their practical skills. In contrast, in traditional laboratory settings, only one student can manipulate the machine at a time, while others observe due to limitations in machine availability and time constraints. The utilization of virtual machines and simulation software offers a safe and secure environment for students to practice. It also facilitates self-reflection on their strengths and weaknesses through simulated feedback, enabling them to enhance their skills. Additionally, these methods provide professors with the ability to assess student skills in a reproducible and objective manner. Overall, the adoption of virtual practical courses has proven beneficial, enabling students to actively participate, practice, and receive valuable feedback in a controlled setting, leading to improved outcomes in the coordinate measuring machine and computer numerical control courses.

Based on the findings of this study, it can be inferred that the effective implementation of online practical courses hinges on three key factors: computer tools, educational content, and the quality of tutoring. These aspects play a crucial role in ensuring the successful delivery and outcomes of online practical courses. It can also be noticed that the use of online collaboration spaces, forums, and group debates helped in the pedagogical renovation, involving, and motivating our students, creative teaching engaging and motivating students (Eichhorst et al., 2018). Students who were more responsible for the course, had succeeded in higher grades (Balduf, 2009). Web resources such as platform, collaboration tools, and synchronous meetings, as well as material and technological resources such as a computer, internet connection, simulation software, and headset microphone, are important to the achievement of any online practical course.

While experimental exploration did not yield improvements in student outcomes compared to the other two methods, it still holds potential for future online courses. By designing applications or animations that go beyond linear or predefined scenarios, it will be possible to incorporate experimental exploration. These applications should empower students to configure settings, input test data, and obtain experiment results independently, without requiring instructor participation. Despite the challenges associated with integrating online practical courses, especially in the field of mechanics, the majority of students have had a positive experience. The results indicate a significant improvement in the quality of information and skills as a result of these new methods. Consequently, this experience serves as an effective means of enhancing eLearning education and can be esasily implemented in future academic years.

5. CONCLUSION

This paper serves as a compelling demonstration of the viability of teaching practical courses online. It introduces innovative teaching strategies specifically designed for online practical mechanical engineering courses. The Moodle platform was employed as a valuable tool in these initiatives, providing support for educational resources, videos, applications, and student evaluations.

The evaluations conducted on these experiences revealed that students not only embraced the new methods but also appreciated them, leading to significant enhancements in their practical abilities. Given the effectiveness of these pilot experiences in achieving educational objectives, it is strongly recommended to continue implementing them in future academic years. Furthermore, there is potential for further improvement in the proposed methods, such as incorporating hybrid learning, which will be explored in upcoming experiments.

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