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Design and development of a mechatronic instructional laboratory for technical education students

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Abstract
The rapid advancement of automation and intelligent systems has increased the demand for technically skilled manpower with competencies in mechatronics. However, many technical education institutions lack adequately equipped laboratories to support effective hands-on training. This study focuses on the design and development of a mechatronic instructional laboratory for technical education students. The laboratory will provide students with hands-on experience with cutting-edge mechatronics equipment, enhancing their practical skills performance, critical thinking, problem-solving, and collaboration. By integrating theoretical knowledge with practical applications, students will gain a deeper understanding of complex mechatronic systems, preparing them for the demands of the industry. The project's primary objective is to bridge the gap between academia and industry by providing students with the skills and knowledge required to excel in the field of mechatronics. The laboratory will serve as a platform for students to explore, innovate, and develop solutions to real-world problems, fostering creativity, entrepreneurship, and innovation. By incorporating the Mechatronics Instructional Laboratory in electrical technology education, the college can enhance students' employability, practical skills performance, and understanding of complex systems. This project will provide valuable insights for educational institutions, policymakers, and industry stakeholders on the importance of mechatronics laboratory in technical education, ultimately contributing to the development of a skilled workforce that meets the needs of the industry. The successful implementation of this project will position Federal College of Education Technical Ekiadolor as a hub for mechatronics education, providing students with the skills and knowledge necessary to succeed in the rapidly evolving field of mechatronics

Keywords: Mechatronics instructional laboratory, technical education, industry-oriented skills development

Introduction

The integration of mechatronics laboratories in educational institutions has become increasingly important for developing practical skills in students. Mechatronics, a multidisciplinary field that combines electronics, mechanics, and software engineering, provides students with hands-on experience in designing, building, and testing complex systems. Through projects and experiments in mechatronics labs, students can develop essential skills such as programming, circuit design, and system integration (Kumar 2020) [8]. Mechatronics labs offer a unique learning environment that combines theoretical knowledge with practical application. Students can apply theoretical concepts to real-world problems, developing a deeper understanding of the subject matter. The hands-on nature of mechatronics labs promotes critical thinking, problem-solving, and creativity.

According to Bolton (2015) [3], mechatronics education is most effective when students are exposed to practical activities that require them to design, build, test, and troubleshoot real systems. Such laboratories enable learners to develop competencies in areas such as motor control, sensor interfacing, programmable logic controllers (PLCs), microcontrollers, and robotics, which are essential for modern manufacturing and production systems. The use of mechatronics labs in education prepares students for the demands of the modern workforce. Industry requires engineers and technicians who can design, develop, and implement complex systems, and mechatronics labs provide students with the skills and knowledge necessary to succeed in these roles (Kumar 2020) [8]. Students also develop important skills such as teamwork, communication, and project management (Johnson, 2017) [4]. Mechatronics labs can increase student engagement and motivation, making learning more enjoyable and interactive (Alvarez *et al*., 2019) [2]. This can be particularly beneficial for students who struggle with traditional teaching methods, providing an alternative learning pathway that caters to different learning styles (Hmelo-Silver, 2004) [5]. To maximize the benefits of mechatronics labs, educational institutions should ensure that they are well-equipped and maintained. This includes providing adequate funding for equipment, software, and personnel, as well as ensuring that laboratory facilities are safe and accessible (Kumar *et al*., 2020) [8]. Additionally, institutions should consider incorporating project-based learning and other hands-on approaches to maximize the effectiveness of mechatronics labs (Johnson *et al*., 2017) [4]. The benefits of mechatronics labs extend beyond the classroom, as students can apply the skills and knowledge they gain to real-world problems. Mechatronics labs can also facilitate collaboration between students, industry partners, and faculty members, promoting innovation and entrepreneurship (Alvarez., 2019) [2]. Furthermore, mechatronics labs can help students develop important soft skills, such as communication, teamwork, and problem-solving, which are essential for success in industry (Johnson., 2017) [4]. Mechatronics labs are an essential component of modern engineering and technology education. They provide students with hands-on experience, promote critical thinking and problem-solving, and prepare students for the demands of the modern workforce. By incorporating mechatronics labs into educational programs, institutions can provide students with a comprehensive learning experience that prepares them for success in industry.

The design and development of a mechatronic instructional laboratory require careful consideration of instructional objectives, curriculum requirements, student population, safety standards, and cost constraints. Kalpakjian and Schmid (2014) [6] emphasize that laboratory facilities should be aligned with course outcomes to ensure that students gain relevant and transferable skills. In addition, the use of modular and flexible laboratory setups allows for scalability and future upgrades as technology evolves. Incorporating locally fabricated training modules and materials can also reduce costs and promote indigenous technological development (Akinola & Owolabi, 2018) [1]. The acquisition of practical skills in mechatronics is crucial for electrical technology students to excel in their chosen profession. However, despite the recognized importance of practical skills in electrical technology education, students in Federal College of Education Technical Ekiadolor continue to face challenges in acquiring adequate practical skills in mechatronics. This is evident in the poor performance of students in practical assessments and their inability to apply theoretical knowledge to real-world problems (Kumar, 2020) [8]. The lack of adequate mechatronics laboratory facilities and equipment has been identified as a significant contributor to this problem (Alvarez, 2019) [2]. Currently, there is a dearth of research on the impact of mechatronics laboratory on electrical technology students' practical skills performance in Federal College of Education Technical Ekiadolor. While there are studies on the effectiveness of mechatronics laboratory in other contexts (Hmelo-Silver, 2004; Johnson, 2017) [4, 5], there is a need for a specific investigation into the situation in Federal College of Education Technical Ekiadolor.

Statement of the Problem

With the increasing adoption of automation, robotics, and intelligent control systems in manufacturing, construction, and service industries, the demand for technicians and technologists with mechatronic skills has continued to grow. Despite this growing demand, many technical education institutions struggle to adequately prepare students for these emerging industrial realities. One of the major problems facing technical education institutions is the inadequacy of instructional laboratories that support the teaching and learning of mechatronics. In many institutions, existing laboratories are poorly equipped, outdated, or designed to teach single disciplines such as mechanical or electrical technology in isolation. This fragmented approach limits students' understanding of system integration, which is the core concept of mechatronics. As a result, students often graduate with strong theoretical knowledge but insufficient practical experience in integrating mechanical components, electronic circuits, sensors, actuators, and control systems into functional systems.

Additionally, the lack of modern training equipment such as programmable logic controllers (PLCs), microcontroller kits, industrial sensors, and automated systems restricts students' exposure to current industrial technologies. Where such equipment exists, it is often inadequate in quantity, poorly maintained, or inaccessible due to overcrowded laboratory spaces. This situation reduces opportunities for hands-on practice, experimentation, and independent learning, thereby affecting students' skill acquisition and confidence in handling real-world mechatronic systems.

Another significant problem is the high cost of imported laboratory equipment, which poses a serious challenge for many technical institutions, particularly in developing economies. Limited funding often prevents institutions from establishing fully functional mechatronic laboratories or upgrading existing ones. Consequently, instructors are forced to rely heavily on theoretical instruction, demonstrations, or improvised teaching methods that do not adequately simulate real industrial environments. This funding challenge also affects the training of instructors, many of whom lack sufficient exposure to modern mechatronic technologies and laboratory-based teaching methods.

Aim and Objectives

The main aim of this study is to design and develop a functional, safe, and cost-effective mechatronic instructional laboratory that will enhance the teaching and learning of mechatronics for technical education students and improve their practical skills in line with modern industrial requirements. Specifically the study seeks to achieve the following objectives:

1. Examine the effect of mechatronics laboratory on electrical technology students' practical skills performance.
2. Identify the challenges faced by students and instructors in using mechatronics laboratory for practical skills development.
3. Determine the strategies for improving the practical skills development of electrical technology students through mechatronics laboratory.

Research questions

The following research questions will guide the study

1. What are the specific mechatronics equipment and tools required for Technical Education students' hands-on experience?
2. What extent does hands-on experience with mechatronics equipment improve Technical Education students' practical skills performance?
3. How effective is the Mechatronics Instructional Laboratory in bridging the gap between academia and industry in the field of mechatronics?

Literature Review

Concept of Mechatronics

Mechatronics is an interdisciplinary field that integrates mechanical engineering, electronics, control systems, and computer programming to design and operate intelligent systems and products. According to Bolton (2015) [3], mechatronics emphasizes system integration rather than isolated disciplinary knowledge, making it highly relevant to modern industrial applications such as automation, robotics, and smart manufacturing. Mechatronic systems typically consist of sensors, actuators, controllers, and mechanical components working together to perform specific tasks efficiently. In the context of education, mechatronics provides students with a holistic understanding of how different engineering domains interact. This integrated approach enhances learners' ability to analyze, design, and troubleshoot complex systems, which is a key requirement in contemporary industries.

Effect of Mechatronics Laboratory on Students' Practical Skills Performance

Several studies have examined the impact of laboratory-based instruction on students' performance. Research findings generally indicate that students who learn in well-equipped laboratories perform better in practical tasks than those who rely mainly on classroom instruction. Bolton (2015) [3] emphasized that exposure to real equipment and industrial simulations enhance students' technical proficiency and adaptability.

In Electrical Technology programmes, the use of mechatronics laboratories has been associated with improved practical skills in areas such as wiring, control circuits, automation, and fault diagnosis. Students gain firsthand experience in integrating electrical systems with mechanical and electronic components, which improves their overall performance and preparedness for industry-related tasks.

Challenges in the Use of Mechatronics Laboratories

Despite their importance, the effective use of mechatronics laboratories is often hindered by several challenges. These include inadequate funding, high cost of equipment, and lack of trained instructors, poor maintenance culture, and unreliable power supply. Akinola and Owolabi (2018) [1] observed that many institutions depend heavily on imported equipment, which is expensive to acquire and maintain.

Additionally, overcrowded laboratories and insufficient equipment limit students' access to hands-on activities. Instructors may also lack sufficient training in modern mechatronic systems, reducing the effectiveness of laboratory instruction. These challenges underscore the need for well-planned laboratory design and the use of locally fabricated instructional modules.

Strategies for Improving Practical Skills through Mechatronics Laboratories

Improving practical skills development through mechatronics laboratories requires deliberate strategies. These include adopting project-based learning, competency-based instruction, and collaborative learning approaches. Project-based learning encourages students to work on real-life problems, fostering creativity, critical thinking, and teamwork (Prince & Felder, 2006) [10].

The use of modular laboratory setups and locally sourced materials can also enhance sustainability and accessibility. Instructor training and continuous professional development are equally important to ensure effective laboratory utilization. When these strategies are implemented, mechatronics laboratories can significantly enhance the quality of technical education.

Methodology

The study adopted a descriptive survey research design. The descriptive survey design was used to collect information on the availability of mechatronics equipment, challenges faced by students and instructors, and strategies for improving practical skills development through the mechatronics instructional laboratory. The quasi-experimental design, involving an experimental and a control group, was used to examine the effect of the mechatronics instructional laboratory on students' practical skills performance. This combination of research designs was considered appropriate because it allows for both in-depth description of existing conditions and objective assessment of the impact of laboratory use on students' performance.

The study was conducted at the Federal College of Education (Technical), Ekiadolor, Edo State, Nigeria. The institution is a specialized teacher education college that trains technical education students in various vocational and technical disciplines, including Electrical Technology.

The population of the study comprised all Technical Education students and instructors in the Department of Electrical Technology at the Federal College of Education (Technical), Ekiadolor. A sample was drawn from the population using a purposive and random sampling technique. Purposive sampling was used to select Electrical Technology students who were directly involved in mechatronics-related practical courses. Random sampling was then applied to assign students into experimental and control groups to ensure fairness and reduce selection bias.

Three main instruments were used for data collection:

1. Mechatronics Equipment Checklist (MEC)
2. Practical Skills Performance Test (PSPT
3. Mechatronics Laboratory Utilization Questionnaire (MLUQ

Data collection was carried out in stages. First, permission was obtained from the relevant authorities of the Federal College of Education (Technical), Ekiadolor. The mechatronics instructional laboratory was then set up and used for practical instruction over a specified period. Students in the experimental group participated in structured hands-on activities, while those in the control group followed the conventional instructional approach. The Practical Skills Performance Test was administered at the end of the instructional period. Questionnaires were distributed to students and instructors, collected, and properly organized for analysis.

Data collected were analyzed using both descriptive and inferential statistics. Descriptive statistics such as mean and standard deviation were used to answer the research questions related to equipment availability and challenges. Inferential statistics, including the t-test and Pearson correlation coefficient, were used to test the null hypotheses at 0.05 level of significance. The results were presented in tables and interpreted accordingly.

Discussion of Results

The discussion of results provides a detailed interpretation of the findings obtained from the study on the design and development of a mechatronics instructional laboratory for Technical Education students at the Federal College of Education (Technical), Ekiadolor. The results are analyzed in relation to the research objectives, research questions, and hypotheses, and are compared with findings from previous studies.

The analysis of the Practical Skills Performance Test (PSPT) revealed a significant difference in the practical skills performance of students who used the mechatronics instructional laboratory compared to those who did not. Students in the experimental group demonstrated higher levels of competence in performing tasks such as sensor interfacing, motor control, basic PLC programming, and system troubleshooting. This finding confirms that hands-on experience in a well-equipped laboratory enhances students' practical skills, providing them with a stronger understanding of theoretical concepts and their applications in real-world settings.

Data obtained from the Mechatronics Laboratory Utilization Questionnaire (MLUQ) indicated that students and instructors faced several challenges in using the laboratory and the study identified several strategies that could enhance the effectiveness of the mechatronics instructional laboratory in developing students' practical skills:

This finding aligns with the conclusions of Okafor and Bello (2021) [9], who emphasized that modern technical laboratories play a critical role in reducing the mismatch between the competencies acquired in educational institutions and the expectations of employers.

Conclusion

The study on the design and development of a mechatronics instructional laboratory for Technical Education students at the Federal College of Education (Technical), Ekiadolor, has demonstrated the critical role of practical, hands-on learning in technical education. The findings of the study indicate that a well-equipped and properly structured mechatronics laboratory significantly enhances students' practical skills performance, fosters critical thinking, encourages problem-solving, and promotes collaboration among students.

Students who engaged in laboratory-based activities, such as sensor interfacing, motor control, PLC programming, and robotic assembly, showed marked improvement in their ability to apply theoretical knowledge to real-world engineering tasks. The study also confirmed that the laboratory serves as a bridge between academic instruction and industry requirements, equipping students with the skills and competencies needed in modern automated and technology-driven workplaces.

Despite the benefits, the study identified challenges that affect the full utilization of the laboratory, including inadequate equipment for the number of students, limited instructor expertise, and maintenance constraints. Addressing these challenges through strategic measures, such as the provision of additional equipment, instructor training, project-based learning approaches, and the use of locally fabricated training modules, will further enhance the effectiveness and sustainability of the laboratory.

In conclusion, the establishment of a mechatronics instructional laboratory is an essential step toward modernizing technical education, improving the quality of practical training, and producing graduates who are competent, innovative, and industry-ready. The findings underscore the need for continuous investment in laboratory facilities, instructional resources, and instructor capacity development to ensure that technical education remains relevant and responsive to the demands of contemporary industrial and technological environments.

Recommendations

Based on the findings and conclusions of the study, the following recommendations are proposed to enhance the effectiveness of the mechatronics instructional laboratory and improve practical skills development among Technical Education students at the Federal College of Education (Technical), Ekiadolor:

1. Provision of Adequate Equipment and Tools
2. Instructor Training and Capacity Building
3. Adoption of Project-Based and Experiential Learning
4. Collaboration with Industry

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