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Integrating Industry 4.0 and Lean Manufacturing Principles into Technology Education: A Roadmap for Future-Ready Technical Skills Development

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Abstract **Original Research Article**

This study investigates the integration of Industry 4.0 and Lean Manufacturing principles into technology education to enhance technical skills and industry readiness among students. Using a sample of 200 respondents, data were collected through a survey questionnaire titled "Assessment of Industry 4.0 and Lean Manufacturing Integration in Technology Education" (AILMITED). The study analyzed the impact of these principles on technical skills improvement, technology importance ratings, implementation challenges, and proposed solutions. Chi-square (χ^2) analysis revealed significant findings with a total χ^2 value of 1,888.387 ($df = 5$, $p < 0.05$) for the importance of Industry 4.0 technologies, 60.00 ($df = 3$, $p < 0.05$) for challenges in implementation, and 83.00 ($df = 3$,$p < 0.05$) for proposed solutions, indicating significant differences between observed and expected frequencies. Key results showed a mean improvement of 75% in technical skills post-integration, with Industry 4.0 technologies like IoT and AI rated as highly important. Challenges include lack of resources and resistance to change, with solutions focusing on increased funding and professional development. This study underscores the critical role of integrating advanced manufacturing principles into education to better prepare students for industry demands and suggests a structured approach to overcoming implementation challenges. The findings provide valuable insights for educators and policymakers to enhance technology education frameworks and ensure graduates are equipped with relevant skills for the evolving industrial landscape.

Keywords: Industry 4.0, Lean Manufacturing, Technology Education, Technical Skills, Workplace Readiness

INTRODUCTION

In the rapidly evolving landscape of technology education, the integration of advanced manufacturing principles and emerging technologies has become crucial for preparing students for the demands of the modern industry. The advent of Industry 4.0 and Lean Manufacturing principles represents a transformative shift in how technological processes are designed, executed, and optimized. Industry 4.0, characterized by the interconnection of cyber-physical systems, the Internet of Things (IoT), artificial intelligence, and big data analytics, offers unprecedented opportunities for innovation and efficiency. Lean Manufacturing, on the other hand, emphasizes waste reduction, process improvement, and value maximization, aiming to streamline production and enhance operational efficiency.

This study investigates the impact of integrating Industry 4.0 and Lean Manufacturing principles into technology education. Specifically, it examines how these principles affect students' technical skills, problem-solving abilities, and overall industry readiness. The integration of these principles promises to not only enhance technical competencies but also align educational outcomes with the needs of contemporary industries.

Problem Statement

The rapid advancement of Industry 4.0 technologies and Lean Manufacturing principles presents both opportunities and challenges for technology education. While these innovations have the potential to significantly enhance technical skills, improve problem-solving abilities, and increase industry readiness among students, their integration into educational curricula remains limited and inconsistent. This gap leads to a disconnect between the skills taught in educational

institutions and the demands of the modern industry, ultimately affecting the employability and effectiveness of graduates. The problem is further exacerbated by challenges such as resource constraints, resistance to change, insufficient training, and rigid curricula. There is an urgent need for a comprehensive strategy to effectively integrate these principles into technology education to ensure that students are equipped with the future-ready skills required by the industry. This research seeks to address these issues by evaluating the current state of integration and proposing actionable solutions to bridge the gap between education and industry needs.

RESEARCH OBJECTIVES

The objectives of this study are to:

- Evaluate the effectiveness of integrating Industry 4.0 and Lean Manufacturing principles into technology education for enhancing technical skills.
- Identify the key Industry 4.0 technologies that are most critical for future-ready technical skills development.
- Assess the challenges faced in implementing Industry 4.0 and Lean Manufacturing principles in educational settings.
- Propose solutions to overcome the identified challenges in the integration process.
- Analyze the impact of this integration on student outcomes, including technical skills, problem-solving abilities, and industry readiness.

Research Questions

The research questions for this study are:

Research Question 1: How effective is the integration of Industry 4.0 and Lean Manufacturing principles in enhancing technical skills in technology education?

Research Question 2: Which Industry 4.0 technologies are considered most critical by students, educators, and industry professionals for future-ready technical skills development?

Research Question 3: What are the primary challenges faced in implementing Industry 4.0 and Lean Manufacturing principles in educational settings?

Research Question 4: What solutions can be proposed to address the challenges associated with the integration of these principles?

Research Question 5: How does the integration of Industry 4.0 and Lean Manufacturing principles impact student outcomes, including technical skills, problem-solving abilities, and industry readiness?

Research Hypothesis

The research hypotheses for this study are:

H_0: The integration of Industry 4.0 and Lean Manufacturing principles does not significantly enhance technical skills in technology education.

H_1: The integration of Industry 4.0 and Lean Manufacturing principles significantly enhances technical skills in technology education.

H_0: Industry 4.0 technologies are not rated differently in terms of importance by students, educators, and industry professionals.

H_2: Industry 4.0 technologies are rated differently in terms of importance by students, educators, and industry professionals.

H_0: The challenges faced in implementing Industry 4.0 and Lean Manufacturing principles are uniformly experienced across different educational settings.

H_3: The challenges faced in implementing Industry 4.0 and Lean Manufacturing principles vary across different educational settings.

H_0: Proposed solutions to address the challenges associated with Industry 4.0 and Lean Manufacturing integration do not vary in effectiveness.

H_4: Proposed solutions to address the challenges associated with Industry 4.0 and Lean Manufacturing integration vary in effectiveness.

H_0: The integration of Industry 4.0 and Lean Manufacturing principles does not significantly impact student outcomes, including technical skills, problem-solving abilities, and industry readiness.

H_5: The integration of Industry 4.0 and Lean Manufacturing principles significantly impacts student outcomes, including technical skills, problem-solving abilities, and industry readiness.

OBJECTIVES OF THE STUDY

The objectives of the research work are as follows:

- Assess the improvement in technical skills by evaluating the influence of Industry 4.0 and Lean Manufacturing principles on students in technology education.
- Identify key Industry 4.0 technologies perceived as most critical by students and educators to prioritize in curriculum development.
- Examine implementation challenges, including issues related to resources, resistance to change, training, and curriculum constraints during the integration of these principles.
- Propose solutions to overcome identified challenges and provide actionable recommendations for enhancing the integration process.

- Evaluate the improvement in student outcomes, including technical skills, problem-solving abilities, and industry readiness, to determine the overall effectiveness of the integration efforts.

SIGNIFICANCE OF THE STUDY

The significance of the study is to:

- Enhance understanding of how integrating Industry 4.0 and Lean Manufacturing principles can improve technical skills development in technology education.
- Inform educational practices by providing recommendations for incorporating these principles into curricula.
- Guide policy making by offering insights into the benefits and challenges of implementation.
- Advance research by contributing to the academic literature on these principles' impact.
- Address implementation challenges by identifying common issues and proposing practical solutions for successful integration.

LITERATURE REVIEW

For several years, Lean Manufacturing has been widely adopted by industries to enhance operational performance. However, it is often criticized for its fixed production sequences and slow responsiveness, which limit its ability to adapt to constantly changing customer demands, product variability, and customization needs, thereby restricting its applicability in the digital era (Saad et al., 2021). On the other hand, Industry 4.0 technologies offer modularity and flexibility, enabling the mass production of highly customizable products. Despite this, Industry 4.0 is frequently viewed as a solution provider with limited capacity for organizational process improvement. Therefore, integrating Lean Manufacturing with Industry 4.0 technologies could offer a competitive advantage in the digital era.

In another study, Alfutaih et.al. (2020) investigate the impact of Industry 4.0 technologies on companies that have adopted lean manufacturing systems, focusing on the Bursa manufacturing industry in Turkey. The study highlights several dimensions of lean production, including the Pull System, Production Equipment, Statistical Methods, Equipment Maintenance, Product Similarities, Communication with Suppliers, and Cause of Problems. Data was collected through a survey sent to 250 companies, resulting in 169 usable responses. Analysis using frequency, reliability, correlation, and factor (ANOVA) methods revealed that while there is a significant positive relationship between Industry 4.0 technology and most lean production dimensions, no significant relationship was found between Industry 4.0 and the Cause of Problems factor (Alfutaih & Demirkol, 2020). The findings suggest that companies using lean manufacturing should proactively integrate Industry 4.0 technologies to adapt to technological advancements and meet evolving customer demands. The authors also propose that future research should employ quantitative approaches to explore how Industry 4.0 adoption affects specific competencies and departments within organizations.

Sah et al. (2024) conduct a systematic literature review to explore the integration of Industry 4.0 and Lean technologies in manufacturing. Their analysis of 156 peer-reviewed sources reveals that integrating Industry 4.0 technologies, such as IoT, big data analytics, AI, and machine learning, with Lean manufacturing principles can significantly enhance operational efficiency, quality control, and responsiveness. This review identifies key benefits, such as improved real-time data collection and process automation, while also noting challenges like high initial costs and the complexity of technology integration. The findings underscore the potential for these combined approaches to drive operational excellence but also highlight gaps in the current literature and practical applications. This review is relevant to our research as it provides a comprehensive understanding of how integrating Industry 4.0 with Lean manufacturing can enhance technology education.

Integrating Industry 4.0 technologies with lean manufacturing principles can address specific challenges faced by high-variety, low-volume sectors like aerospace manufacturing. James et.al (2019) explore this integration and its potential to enhance manufacturing processes through a cyber-physical environment. Their study, utilizing discrete event simulation, shows that combining Industry 4.0 tools with lean practices—termed Lean Industry 4.0—can effectively address difficulties in changing factory layouts and benchmarking practices in aerospace. This approach provides valuable insights into how Industry 4.0 technologies can complement traditional lean principles, offering practical applications for other high-technology sectors such as life sciences and defense. This research is pertinent to our study as it highlights the benefits of merging these approaches, supporting our goal of integrating Industry 4.0 and lean principles into technology education to better equip students for industry demands.

Integrating Industry 4.0 technologies with lean manufacturing systems can be effectively achieved through targeted action plans. Vlachos et al. (2021) demonstrate this by developing a plan for integrating autonomous guided vehicles (AGVs) and

the Internet of Things (IoT) into lean manufacturing operations. Their case study of a large manufacturing company revealed a structured approach involving design, integration, and continuous improvement phases for successfully implementing these technologies. The study highlights that the integration plan addresses key lean automation objectives, such as cost reduction, reliability, and simplicity, while managing the interplay between social, technical, and operational factors (Vlachos et al., 2021). This research is relevant to our study as it provides a practical framework for merging lean principles with Industry 4.0 technologies, underscoring the potential for improved efficiency and operational excellence in manufacturing settings. This insight supports the aim of our research to develop effective integration strategies for technology education.

The potential of Industry 4.0 technologies to transform education is explored by Malyzhenkov (2023), who investigates their integration into educational settings to support Sustainable Development Goals. The study highlights the distinct opportunities and challenges associated with applying digital technologies in education, particularly as part of the emerging "Education 4.0" concept. Malyzhenkov (2023) identifies that while some technologies can significantly enhance educational practices, their effectiveness varies and is influenced by how well they align with the specific needs of educational environments. This research is pertinent to our study as it provides a foundational understanding of how Industry 4.0 technologies can be utilized in education, thereby informing strategies for integrating these technologies into technology education curricula.

Moraes et al. (2022) examine the integration of Industry 4.0 technologies within the framework of Education 4.0, focusing on their benefits for enhancing learning processes. Through a systematic review of literature from major databases, including Scopus, Web of Science, and ScienceDirect, the study analyzes 51 articles and 23 in-depth readings to assess how technologies like augmented reality, simulation, Internet of Things (IoT), and virtual reality contribute to education. The findings reveal that these technologies are predominantly utilized in higher education, offering advantages such as increased content immersion, enhanced student engagement, and the development of soft skills. Despite their potential, the application of these technologies remains limited, primarily to manufacturing-related courses and universities. Moraes et al. (2022) argue that Industry 4.0 technologies, while supportive of the learning process, are underused across educational stages, suggesting that broader implementation could further advance the goals of Education 4.0. This study is relevant as it underscores the gap in the application of Industry 4.0 technologies within education and highlights opportunities for expanding their use to improve learning outcomes.

The integration of Industry 4.0 technologies into professional education significantly impacts the training of specialized labor for the job market. Lopes et al. (2024) examined how two Brazilian educational institutions prepared their manufacturing students for digital technologies through a case study of 35 student projects. The study revealed the use of simulation systems, 3D modeling, Internet of Things (IoT), and augmented and virtual reality in students' projects. It highlighted the necessity of investing in digital laboratories and equipment to provide practical, hands-on experience with these technologies. The research underscores that realistic project-based learning is crucial for effectively preparing students for the industrial workforce. Despite the emerging nature of Industry 4.0 technologies in education, Lopes et al. (2024) demonstrated that their application enhances the alignment between educational outcomes and industry needs, thereby improving students' readiness for the job market.

The integration of Industry 4.0 technologies into technical and vocational education and training (TVET) is crucial for preparing the Nigerian workforce for the digital economy. George et al. (2024) explored strategies and approaches to embedding digital competencies in Nigeria's TVET programs, emphasizing the need to align curricula with Industry 4.0 demands. Their study addresses challenges such as inadequate infrastructure, limited funding, and policy gaps, while highlighting successful models and best practices for digital skills integration. The chapter underscores the role of various stakeholders, including government bodies, educational institutions, and industry partners, in facilitating this transition. George et al. (2024) offer actionable recommendations for enhancing Nigeria's TVET landscape to ensure a workforce capable of leveraging digital technologies effectively.

The role of Education 4.0 technologies is integral to preparing future engineers and researchers for the Industry 4.0 era. Gowripeddi et al. (2020) investigated how advanced and collaborative learning practices, collectively termed Education 4.0, can build competencies in data-driven technologies essential for the next generation. Their study focuses on three case studies: Remote Engineering in manufacturing, Remote Labs in academic settings, and the transition of students from Remote Lab builders to Remote Engineering Framework builders. The key outcomes include mapping essential skills, assessing the impact of industrial work exposure, and analyzing the correlation between educational and industrial technologies. Gowripeddi et al. (2020) provide valuable insights into how

modern educational technologies can enhance the effectiveness of Industry 4.0 processes and prepare students for evolving industrial demands.

The gamification approach has gained popularity in education for its effectiveness in enhancing engagement and learning outcomes. Salleh et al. (2024) developed a game designed to facilitate interactive learning of lean manufacturing activities. This project integrates gamification with interactive learning methods to offer an alternative, engaging educational tool. The game incorporates various interactive elements, including animations, sound effects, and videos, to provide a comprehensive understanding of lean manufacturing practices. Developed using ActivePresenter and incorporating simulation videos from FlexSim, the platform aims to visualize real production environments and improve users' grasp of production systems. By including a basic assessment component, the game allows users to test their knowledge and receive immediate feedback. Salleh et al. (2024) anticipate that this approach will effectively support lean manufacturing education and enhance users' learning experiences through interactive, game-based methods.

Kuzmina et al. (2023) propose a new master's degree program focused on lean manufacturing technologies, aimed at enhancing productivity and operational effectiveness through professional management. The article highlights the importance of aligning educational content with industry needs, recommending active collaboration between universities and industrial partners. This collaboration ensures that the curriculum remains relevant and enriched with real-world cases, thereby improving career prospects for students. The program emphasizes the DMAIC methodology and the application of Quality Management methods for continuous organizational improvement. By integrating these elements, the program seeks to support the professional growth of employees and ensure the sustainability of their improvement projects.

Jovanoski et al. (2024) discuss the development of the Smart Learning Factory – Skopje (SLFS), the first Macedonian learning factory designed to advance the Lean 4.0 journey in South-East Europe. The SLFS aims to address challenges faced by manufacturing enterprises, particularly in less developed regions, by serving as a showroom for Lean and Industry 4.0 technologies, a training center for workforce upskilling, a laboratory for technological experimentation, and a development hub for integrated solutions. The focus on Digital Lean emphasizes the use of software tools to support Lean implementation and enhance the performance of Lean tools in both initial and advanced stages of adoption.

The application of lean manufacturing theory to higher professional education can significantly improve service quality in universities. Glushchenko et al. (2021) investigate how lean principles can be utilized to enhance service delivery in higher education. Their study develops a method for integrating lean manufacturing concepts into university operations, proposes a model for quality assessment, and employs a range of scientific methods such as synthesis, analysis, and expert assessments. This research underscores the potential of lean manufacturing to improve educational services and introduces a four-level model aimed at enhancing service quality in higher education institutions.

In summary, the review by Khan et al. (2023) provides a thorough examination of Lean methodologies applied in higher educational institutes. Their literature review, spanning from 2019 to 2023, identifies key areas where Lean practices have been adopted to improve operational efficiency, enhance student outcomes, and manage resources effectively. The study addresses several critical research questions, including the adoption of Lean methods, the most suitable tools for educational settings, and the challenges faced during implementation. It highlights the successful adaptation of Lean principles from the manufacturing sector to education, leading to streamlined processes, waste reduction, and improved satisfaction among staff and students. However, the review also underscores persistent barriers such as cultural resistance, limited knowledge, and insufficient leadership commitment. These insights emphasize the need for continued research and development in applying Lean methodologies within higher education to overcome these challenges and maximize benefits.

MATERIALS AND METHODS

This study employed a mixed-methods approach to evaluate the integration of Industry 4.0 and Lean Manufacturing principles into technology education. Data collection was conducted using a structured survey titled "Assessment of Industry 4.0 and Lean Manufacturing Integration in Technology Education" (AILMITED). A total of 200 respondents, including students, educators, and industry professionals, participated in the survey. The AILMITED survey was designed with a combination of closed-ended and open-ended questions. It included Likert-scale questions to capture quantitative data on technical skills improvement, the importance of Industry 4.0 technologies, challenges in implementation, proposed solutions, and improvements in student outcomes. The open-ended questions allowed respondents to provide more detailed insights and suggestions. The survey was administered both online and in-person to accommodate the preferences and availability of the

respondents. Online administration was conducted via email and educational platforms, while in-person administration took place at educational institutions and industry events. In addition to the survey, qualitative data were collected through semi-structured interviews and focus groups with educators and industry professionals to gain deeper insights into the challenges and opportunities of integrating these principles into the curriculum. Relevant educational and industry documents were reviewed to provide additional context and support for the findings. Quantitative data were analyzed using descriptive statistics and chi-square analysis to evaluate the distribution of challenges and solutions, as well as to compare observed versus expected frequencies. Thematic analysis was applied to the qualitative data to identify key themes and insights. Ethical considerations included obtaining informed consent, maintaining confidentiality, and ensuring respondent anonymity throughout the study.

RESULTS AND DISCUSSION

Technical Skills Improvement

Table 1. Technical Skills Improvement.

Measure	Number of Responses	Percentage of Respondents
Mean Improvement	150	75%
Median Improvement	140	70%
Mode Improvement	160	80%
Standard Deviation	17	8.5%
Range	120 - 170	60% - 85%

Source: *Created by the Author*

This table summarizes the improvement in technical skills observed among students after integrating Industry 4.0 and Lean principles.

Importance of Industry 4.0 Technologies

Table 2. Importance Ratings of Industry 4.0 Technologies.

Technology	Number of Responses	% Highly Important	Mean Rating
Internet of Things (IoT)	170	85%	4.5
Artificial Intelligence (AI)	156	78%	4.4
Robotics	140	70%	4.2
Big Data	100	50%	3.5
Additive Manufacturing	110	55%	3.8
Cyber-Physical Systems	120	60%	4.0

Source: *Created by the Author*

This table provides the number of responses, percentage of respondents who rated each technology as highly important, and the mean rating for each Industry 4.0 technology.

Challenges in Implementation

Table 3. Distribution of Challenges.

Challenge	Number of Responses	% of Responses
Lack of Resources	90	45%
Resistance to Change	60	30%
Insufficient Training	30	15%
Curriculum Constraints	20	10%

Source: *Created by the Author*

This table shows the distribution of reported challenges in implementing Industry 4.0 and Lean principles.

Proposed Solutions

Table 4. Frequency of Proposed Solutions.

Solution	Number of Responses	Percentage of Respondents
Increased Funding	75	37.5%
Professional Development	100	50%
Curriculum Flexibility	70	35%
Industry Partnerships	25	12.5%

Source: *Created by the Author*

This table shows the frequency of responses and the corresponding percentage of respondents for each proposed solution to address implementation challenges in integrating Industry 4.0 and Lean Manufacturing principles into technology education.

Improvement in Student Outcomes

Table 5. Student Outcomes Improvement.

Outcome	Number of Responses	% of Respondents
Technical Skills	160	80%
Problem-Solving Skills	150	75%
Industry Readiness	140	70%

Source: *Created by the Author*

Chi-Square Analysis for Importance Ratings of Industry 4.0 Technologies

Table 6. Chi-Square Analysis for Importance Ratings of Industry 4.0 Technologies.

Technology	Observed Frequency	Expected Frequency	Degree of Freedom (df)	Alpha (α)	Chi-Square Value Calculated (χ^2)	Critical Value	Inference
Internet of Things (IoT)	170	33.33	5	0.05	1,888.387	11.07	Reject
Artificial Intelligence (AI)	156	33.33					
Robotics	140	33.33					
Big Data	100	33.33					
Additive Manufacturing	110	33.33					
Cyber-Physical Systems	120	33.33					

Source: *Created by the Author*

Chi-Square Analysis for Challenges in Implementation

Table 7. Chi-Square Analysis for Challenges in Implementation.

Challenges	Observed Frequency	Expected Frequency	Degree of Freedom (df)	Alpha (α)	Chi-Square Value Calculated (χ^2)	Critical Value	Inference
Lack of Resources	90	50	3	0.05	60.00	7.82	Reject
Resistance to Change	60	50					

Insufficient Training	30	50					
Curriculum Constraints	20	50					

Source: *Created by the Author*

Chi-Square Analysis for Proposed Solutions

Table 8. Chi-Square Analysis for Proposed Solutions.

Solutions	Observed Frequency	Expected Frequency	Degree of Freedom (df)	Alpha (α)	Chi-Square Value Calculated (χ^2)	Critical Value	Inference
Increased Funding	75	50	3	0.05	83.00	7.82	Reject
Professional Development	100	50					
Curriculum Flexibility	70	50					
Industry Partnerships	25	50					

Source: *Created by the Author*

DISCUSSION OF RESULTS

The analysis of data presented in the tables offers valuable insights into the impact of integrating Industry 4.0 and Lean Manufacturing principles into technology education. Each table sheds light on different aspects of this integration, from technical skills improvement to challenges in implementation, and the importance of Industry 4.0 technologies.

- **Technical Skills Improvement:** The results show significant improvement in students' technical skills following the integration of Industry 4.0 and Lean Manufacturing principles. Table 1 reveals that the majority of respondents (75%) observed a mean improvement in technical skills, with a mode improvement of 80%. The consistency in improvement, as reflected by the relatively low standard deviation (8.5%), suggests that the integration of these principles has positively impacted students across various technical disciplines. The range of improvement (60% - 85%) further indicates that while most students benefitted, the extent of improvement varied, likely due to individual differences and the specific Industry 4.0 technologies employed.
- **Importance of Industry 4.0 Technologies:** Table 2 highlights the perceived importance of various Industry 4.0 technologies in enhancing technology education. The Internet of Things (IoT) and Artificial Intelligence (AI) were rated highly important by 85% and 78% of respondents, respectively, with mean ratings of 4.5 and 4.4. Robotics also received a strong endorsement (70% of respondents), while Big Data, Additive Manufacturing, and Cyber-Physical Systems were deemed less critical, though still significant. These findings underscore the essential role of IoT and AI in modernizing technical education, preparing students for future technological advancements.
- **Challenges in Implementation:** The challenges in implementing Industry 4.0 and Lean Manufacturing principles, as depicted in Table 3, highlight the difficulties faced by educational institutions. Lack of resources was the most frequently reported challenge (45% of respondents), followed by resistance to change (30%) and insufficient training (15%). Curriculum constraints were also noted (10%), indicating a need for more adaptable and flexible educational frameworks. These challenges must be addressed to maximize the benefits of integrating Industry 4.0 technologies.
- **Proposed Solutions:** Table 4 presents the proposed solutions to the challenges identified. Professional development emerged as the most commonly suggested solution, with 100 respondents (50%) emphasizing its importance. Increased funding, with 75 responses (37.5%), and curriculum flexibility, with 70 responses (35%), were also frequently recommended, reflecting the need for investment and adaptability in education. Industry partnerships,

though less commonly suggested with 25 responses (12.5%), highlight the potential for collaboration between academia and industry to overcome implementation barriers.

- **Improvement in Student Outcomes:** Table 5 highlights the improvement in student outcomes following the integration of Industry 4.0 and Lean Manufacturing principles into technology education. The most significant improvement was observed in technical skills, with 160 respondents (80%) acknowledging enhancement in this area. Problem-solving skills were also positively impacted, with 150 respondents (75%) reporting improvement. Additionally, 140 respondents (70%) noted an increase in industry readiness, indicating that the integration of these principles not only enhances specific technical abilities but also better prepares students for the demands of the industry. This data underscores the effectiveness of Industry 4.0 and Lean Manufacturing integration in fostering well-rounded, industry-ready graduates.
- **Chi-Square Analysis for Importance Ratings of Industry 4.0 Technologies:** The chi-square analysis in Table 6 reveals statistically significant differences in the importance ratings of Industry 4.0 technologies. The total chi-square value (1,888.387) far exceeds the critical value (11.07) at $\alpha = 0.05$, leading to the rejection of the null hypothesis. This indicates that the observed frequencies of importance ratings significantly differ from the expected frequencies, particularly for IoT and AI. These technologies were rated far more important than expected, suggesting a strong consensus on their critical role in modern education.
- **Chi-Square Analysis for Challenges in Implementation:** Similarly, the chi-square analysis in Table 7 shows significant differences between observed and expected frequencies of reported challenges. The total chi-square value (60.00) exceeds the critical value (7.81) at $\alpha = 0.05$, leading to the rejection of the null hypothesis. The most notable discrepancies were in the categories of lack of resources and curriculum constraints, where observed frequencies were significantly higher than expected. This further emphasizes the need to address these key challenges.
- **Chi-Square Analysis for Proposed Solutions:** The Chi-Square Analysis in Table 8 indicates that increased funding and professional development are highly significant solutions for overcoming challenges, with their observed frequencies notably exceeding the expected frequencies. The Chi-Square value for increased funding (83.00) far surpasses the critical value (7.82), leading to the rejection of the null hypothesis. In contrast, industry partnerships showed a lower observed frequency (25) compared to the expected (50), suggesting it is less critical as a solution. This analysis emphasizes the need for increased funding and professional development while highlighting a reduced emphasis on industry partnerships.

In summary, the data analysis highlights the positive impact of integrating Industry 4.0 and Lean Manufacturing principles into technology education while also identifying significant challenges and potential solutions. The chi-square analyses provide statistical validation for these findings, underscoring the importance of targeted interventions to enhance the effectiveness of these integrations.

Framework for Integration

To effectively integrate Industry 4.0 and Lean Manufacturing principles into technology education, the following framework outlines the essential steps:

- Integrate Industry 4.0 technologies and Lean Manufacturing principles into course modules.
- Employ project-based learning and industry collaboration to apply real-world scenarios.
- Provide training and continuous professional development for educators in relevant technologies.
- Assess learning outcomes and evaluate the effectiveness of the integrated curriculum.
- Invest in technological resources and build infrastructure to support practical learning.
- Develop a strategic plan and engage stakeholders for phased implementation.

CONCLUSION

The study highlights the critical importance of integrating Industry 4.0 and Lean Manufacturing principles into technology education to enhance technical skills and industry readiness. By incorporating these principles, educational institutions can address current challenges, such as outdated curricula and insufficient practical experience. The findings demonstrate significant improvements in technical skills and problem-solving abilities among students. Successful implementation requires a comprehensive approach, including updated curricula, educator training, and industry partnerships. The framework developed provides actionable steps to facilitate this integration, ensuring that future technologists and engineers are well-prepared for the evolving demands of the

industry.

RECOMMENDATIONS

Based on the findings, the following recommendations are made:

- Update the curriculum to include Industry 4.0 and Lean Manufacturing principles, ensuring that educational content aligns with current industry standards and technological advancements.
- Invest in ongoing professional development for educators to enhance their knowledge and skills related to Industry 4.0 technologies and Lean Manufacturing practices.
- Strengthen partnerships between educational institutions and industry professionals to provide students with practical, real-world experience and insight into Industry 4.0 applications.
- Increase resource allocation for technology upgrades and training materials to support the effective implementation of Industry 4.0 and Lean Manufacturing in educational settings.

Establish feedback mechanisms to regularly assess and refine the integration of Industry 4.0 principles based on input from students, educators, and industry stakeholders.

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