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From Craftsmanship to Smart Manufacturing: A Proposal to Offer a Bachelor of Science in Mechatronics Engineering (BSMechE-FRA) with a Specialization in Footwear Robotics and Automation at Marikina Polytechnic College

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ABSTRACT

The rapid advancement of Industry 4.0 technologies including robotics, CAD/CAM systems, and cyber-physical manufacturing has transformed global production, yet Marikina City, known as the Shoe Capital of the Philippines, continues to rely on traditional manual shoemaking methods that limit efficiency and global competitiveness. This study proposes the establishment of a Bachelor of Science in Mechatronics Engineering with a specialization in Footwear Robotics and Automation (BSMechE-FRA) at Marikina Polytechnic College (MPC), aligned with Republic Act No. 9289 and CHED Memorandum Orders No. 4 s.2018 and No. 20 s.2013. The objective is to integrate smart manufacturing and automation into heritage-based craftsmanship through an outcomes-based curriculum. A qualitative-descriptive approach was used, including curriculum review, stakeholder considerations, and documentary analysis. The study is limited by the availability of infrastructure and faculty capacity for implementation. Results show that MPC's existing facilities such as the Shoe and Leathercraft Development Center (SLDC), ReSOLES Technology Business Incubator (TBI), and Footwear Innovation and Technology Laboratory (FIT Lab) can support the program's technical and experiential components. Global best practices demonstrate that hybrid automation models can modernize production without replacing artisanal skills. The study concludes that the BSMechE-FRA program can strengthen the local footwear industry by producing innovation-driven graduates while preserving cultural heritage. It recommends further research on graduate employability, long-term industry impact, and expansion to other heritage-based industries in the Philippines.

Keywords: *Cultural heritage, curriculum design, footwear robotics and automation, shoemaking, smart manufacturing*

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INTRODUCTION

The rise of Industry 4.0 has already transformed global manufacturing; technologies such as automation, robotics, artificial intelligence, and cyber-physical systems are improving production efficiency and redefining the way industries function (Bai et al., 2020; Ferrández-Pastor et al., 2022). In many developed countries, these innovations have become essential in achieving sustainable industrial growth and maintaining competitiveness. However, in developing economies such as the Philippines, many heritage-based industries remain stagnant because of limited infrastructure, a shortage of skilled labor, and policies that are not fully aligned with digital transformation goals (Alshahrani, 2023).

Marikina City, widely recognized as the Shoe Capital of the Philippines, exemplifies this challenge. The city was once a leading contributor to the national and export footwear markets, producing high-quality leather products that gained both local and international recognition. Over the years, however, its footwear industry has suffered a decline in productivity and competitiveness due to the lack of modernization (Department of Trade and Industry [DTI], 2021). While global footwear companies have transitioned to digital modeling, robotic stitching, and automated quality control, many small and medium-sized enterprises (SMEs) in Marikina continue to rely on manual and labor-intensive processes. These traditional practices, while rich in cultural value, are no longer sustainable in terms of cost, speed, and quality.

In line with this, Marikina Polytechnic College (MPC) holds a strategic position in supporting the modernization of the footwear industry. According to Republic Act No. 9289 (2004, Section 2), MPC is mandated to serve as a national center for the development of the shoe and leathercraft industry while offering higher technical and professional education for community-based enterprises. Guided by this mandate, the proposed Bachelor of Science in Mechatronics Engineering with Specialization in Footwear Robotics and Automation (BSMechE-FRA) targets to integrate mechanical, electronic, and digital automation technologies into Marikina's heritage-based shoemaking practices.

The program will be guided with the Outcomes-Based Education (OBE) framework of the Commission on Higher Education (CHED, 2018). It will combine core mechatronics engineering competencies, such as mechanical design, electronics, robotics, and computer-aided control systems and with specialized modules for the footwear sector which it includes CAD/CAM-based footwear design, automation in stitching and cutting processes. The proposed program can share MPC's existing facilities as synergy, such as the Shoe and Leathercraft Development Center (SLDC), the Reinnovate Shoes and Other Leathercrafts for Entrepreneurship Startups (ReSOLES) Technology Business Incubator (TBI), and the Footwear Innovation and Technology Laboratory (FIT Lab.) in order to provide applied research platforms, prototyping spaces, and direct engagement with local industries.

Research on Industry 4.0 illustrates that the integration of digital technologies can enhance rather than diminish cultural authenticity in heritage sectors. Alviz-Meza et al. (2022) demonstrate that augmented reality, 3D modeling, and remote sensing improve both preservation and design capacity in heritage studies. Similarly, Shafi et al. (2020) note that introducing CAD/CAM systems and semi-automated production improves efficiency and competitiveness in traditional handicraft industries while maintaining cultural relevance. Maware and Parsley II (2023) further argue that digital transformation produces the best results

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when combined with lean manufacturing principles to improve sustainability and product quality in productions.

In the field of engineering education, Ferrández-Pastor et al. (2022) emphasize the importance of engineering programs that integrate robotics, IoT systems, and digital platforms to meet the demands of advanced manufacturing most likely in Marikina City. Despite these studies, there is still limited research focusing on localized programs in the Shoe Capital of the Philippines that combine Industry 4.0 skills with the preservation of heritage industries in developing countries.

The proposed BSMechE-FRA program aims to address the following objectives: (1) to assess Marikina Polytechnic College's capability to offer a Bachelor of Science in Mechatronics Engineering (BSMechE-FRA) with a Specialization in Footwear Robotics and Automation program in terms of faculty expertise, facilities, and existing resources; (2) to examine global best practices and academic models that successfully integrate traditional industries, such as shoemaking, into engineering education; (3) to identify the specific skills, knowledge, and technological competencies required by the local footwear and leathercraft industry in Marikina to meet current and future market demands; and (4) to design a clear and structured program framework, including specialized subjects, required tools and equipment, and a phased implementation plan that aligns with CHED policies and industry needs.

This initiative seeks to position Marikina as a national example of how Industry 4.0 technologies can be integrated into heritage industries through contextualized engineering education. The program's development involves reviewing relevant academic frameworks, consulting with stakeholders, conducting pilot testing, and evaluating the curriculum to ensure that it addresses both industry and community needs.

METHODS

This study proposed a developmental research design organized into three key phases: (1) *Reviews related academic frameworks and local/international studies*, (2) *Curriculum Review and Framework Design*, and (3) *Validation and Implementation Planning*. Each phase is structured to ensure that the proposed program is academically rigorous, responsive to industry demands, and aligned with national education policies, particularly CHED Memorandum Order No. 20, s. 2013, which defines outcomes-based education standards for engineering and technology programs. It further supports the institutional mandate of Marikina Polytechnic College to advance industry-relevant and community-responsive academic offerings, particularly in shoe and leathercraft.

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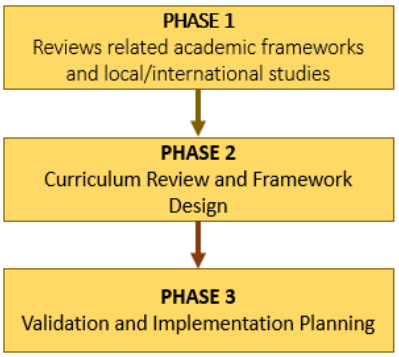

Figure 1. ***Illustrates the proposed Developmental Research Design Structured of a Mechatronics Engineering Integration Framework (FME-IF)***

The proposed developmental framework in this study is structured into three interconnected phases. The first phase, Review of related academic frameworks and local and international studies, identifies the specific gaps in Marikina's footwear industry while examining comparable studies that inform the program's direction. Understanding research gaps is necessary, as curriculum review must be based on the evidence drawn from both local and global contexts (Mawo et al., 2023). The second phase, Curriculum Review and Framework Design, translates the findings of the assessment into a structured program that integrates mechatronics, automation, and footwear-focused applications, ensuring alignment with CHED's outcomes-based education policies and competencies required by Industry 4.0 (Bai et al., 2020). The third phase is Validation and Implementation Planning which focuses on ensuring responsiveness, feasibility, and sustainability by incorporating expert evaluation, pilot testing, and institutional review. The Phased validation and stakeholder involvement are recognized approaches to maintaining academic rigor and ensuring relevance to industry needs (Alshahrani, 2023). Each phase builds gradually on the previous one which results in a program that is responsive to the needs of the community and the footwear sector while remaining academically sound and sustainable.

LITERATURE REVIEW

This phase focused on identifying gaps and opportunities in connecting mechatronics education with the footwear industry through a review of existing literature, industry practices, and international studies. By analyzing local challenges and international approaches to smart manufacturing, the study establishes a conceptual basis for a proposed curriculum that aligns with both the needs of the Marikina footwear sector and emerging global trends (Bai et al., 2020).

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Figure 2. ***Illustrates the proposed Reviews of Related Academic Frameworks and Local/International Studies of a Mechatronics Engineering Specialized in Footwear Robotics and Automation***

Figure 2 highlights the review findings showing that Marikina's footwear industry, despite its rich heritage as the "Shoe Capital of the Philippines," still has its manual production, outdated equipment, and limited scalability, reducing its competitiveness against imported footwear. International examples from Italy's luxury footwear sector, Germany's hybrid automation models, and Adidas' speed factory demonstrate how robotics, CAD/CAM systems, and AI-driven production enhance efficiency while preserving artisanal quality. Literature on localized mechatronics education supports the development of context-specific curricula aligned with CHED Memorandum Order No. 20, s. 2013, which emphasizes outcomes-based and industry-responsive learning. In addition, Industry 4.0 technologies will reshape the global footwear sector through smart manufacturing and mass customization. Marikina Polytechnic College's innovation hubs, including the ReSOLES Technology Business Incubator and the Footwear Innovation and Technology (FIT Lab.) Laboratory under the Shoe and Leathercraft Development Center (SLDC) providing a strong institutional base for merging mechatronics education with heritage-industry modernization.

A. Field Visits and Observations

Site visits to Marikina's SMEs confirmed reliance on manual processes and outdated machinery, reinforcing the urgent need for automation. This aligns with broader research showing that SMEs in traditional sectors face significant barriers to adopting smart technologies due to limited absorptive capacity and its innovation-resources (Van de Vrande et al., 2009). Even with the city's long-standing reputation as the "Shoe Capital of the Philippines," many small manufacturers struggle to compete with imported footwear due to inefficiencies in their production systems. These challenges underscore the urgent need for modernization through automation and robotics to enhance productivity. This is why the proposal for the Bachelor of Science in Mechatronics Engineering Technology (BSMechE-FRA) specialization it footwear

robotics and automation has been envisioned to support technological advancement while preserving the artisanal quality that defines Marikina's shoemaking tradition.

B. Stakeholder Focus Groups

Focus group discussions (FGDs) with SME owners, shoemakers, and sales personnel revealed that while they recognize the potential of robotics and automation, they are not familiar with these technologies mainly due to their high cost and limited accessibility. Stakeholders emphasized that any modernization effort must still respect traditional craftsmanship while gradually introducing affordable and practical Industry 4.0 solutions. This feedback highlights the need for a specialized academic program that bridges traditional shoemaking with emerging technologies, fostering innovation while preserving Marikina's rich shoemaking heritage.

C. International Studies in Footwear Automation and Smart Manufacturing

International experiences show how traditional footwear industries can integrate automation while maintaining the value of artisanal skills. In Spain and Portugal, research demonstrates the effectiveness of robotic work cells for tasks like sole digitization, glue dispensing, and sole handling; key steps toward Industry 4.0 readiness (Oliver et al., 2021). In Italy's IDEA-FOOT project, fully integrated CAD/CAM-based plant designs have been developed to automate shoe production, balancing design precision with traditional craftsmanship (IDEA-FOOT Consortium, 2012). Collaborative robotic systems for shoe polishing have been successfully implemented, showing that human-centric robotics can support final artisanal finishing (Chiriatti et al., 2022). These examples show that carefully implemented automation can complement and elevate traditional shoemaking rather than replace it, offering a practical reference for modernizing Marikina's footwear industry while safeguarding its artisanal identity.

D. Localized Mechatronics Engineering Education

Studies on education-industry collaboration emphasize that curricula tailored to local industry needs are more effective (Mo et al., 2008). Competency-based program design and field-aligned pedagogy support responsive workforce development. In the Philippines, CHED Memorandum Order No. 20, s. 2013, and RA 9289 legally support the creation of specialized programs to serve industry demands. Complementing this policy, Republic Act No. 9289 (2004) mandates Marikina Polytechnic College (MPC) to function as a center for the development of the shoe and leathercraft industry and to provide higher technical and professional education for community-based enterprises. These combined policy and legislative directives envisioned a strong foundation for offering a mechatronics engineering specialization that directly supports the modernization of Marikina's footwear sector while preserving its cultural identity.

E. Industry 4.0 and the Footwear Sector

Global footwear manufactures are adopting CAD/CAM, robotics, and AI to enable mass customization, speed, and consistency. These hybrid systems preserve artisanal elements while leveraging digital technology (Forlini et al., 2024; Oliver et al., 2021). Hybrid workflows that combine digital

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technologies with human skill are increasingly being adopted in leading manufacturing hubs, demonstrating the potential for combining tradition and innovation in heritage-based industries.

F. Academic-Industry Linkages

Academic incubators and university–SME partnerships facilitate the adoption of new technologies in traditional industries. Effective alliances accelerate innovation, capacity building, and relevance to local conditions (Santos & Cruz, 2023; Lugones et al., 2024). Considering this framework, MPC's innovation ecosystem, including the ReSOLES Technology Business Incubator and the Footwear Innovation, SLDC and its Technology (FIT) Laboratory which provides an ideal platform for integrating applied mechatronics education with real-world industry needs (Department of Science and Technology, 2023).

Curriculum Review and Framework Design

Building on the insights gained from the needs assessment and international literature reviews, Phase 2 focused on the development of the curriculum structure and the corresponding academic-industry integration framework for the proposed BSMechE-FRA Specialization in Footwear Robotics and Automation. This phase ensured that the program would not only comply with national policies but also respond directly to the modernization needs of Marikina's footwear sector.

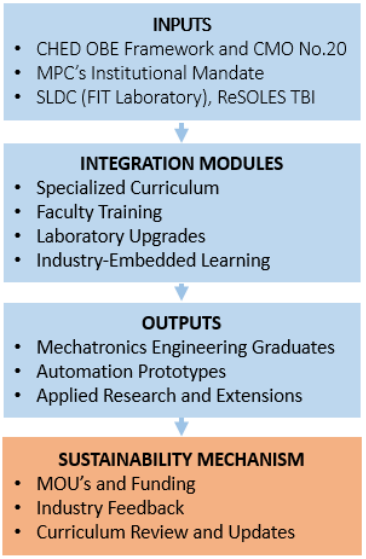

Figure 3. ***Illustrates the Curriculum and Integration Framework for BSMechE-FRA Footwear Robotics and Automation Specialization***

Figure 3 illustrates the structured design of Phase 2, which focuses on the curriculum and integration framework for the proposed BSMET specialization in Footwear Robotics and Automation. At its core, national academic policies and CHED's Outcomes-Based Education (OBE) framework serve as the regulatory and pedagogical foundation for curriculum development. The structure is rooted in CHED's

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Outcomes-Based Education (CMO No. 20, s. 2013) and is aligned with MPC's institutional mandate as established under Republic Act No. 9289 (2004). This is reinforced by Marikina Polytechnic College's institutional mandate and the support of specialized facilities such as the Shoe Development and Leathercraft Center (SLDC), the Footwear Innovation and Technology (FIT) Laboratory, and the ReSOLES Technology Business Incubator (TBI). The framework incorporates modular curriculum design, faculty upskilling in Industry 4.0 technologies, and the upgrading of laboratory infrastructure with robotic systems and smart manufacturing tools. These components are intended to produce graduates equipped with both technical expertise and an understanding of footwear production, while also generating prototype solutions tailored for SMEs. Continuous innovation loops and collaborative academic–industry partnerships ensure the sustainability of these outcomes. Ultimately, the framework seeks to modernize Marikina's footwear industry while preserving its cultural craftsmanship through technology-driven education under the proposed BSMechE-FRA program.

A. Outcomes-Based Education Alignment

The proposed curriculum follows CHED's Outcomes-Based Education (OBE) framework, ensuring competency-based learning aligned with industry needs. It adheres to CHED Memorandum Order No. 20, s. 2013, which sets minimum standards for engineering technology programs while allowing customization for specific industries. To remain relevant, the program will include specialized modules in footwear automation, CAD/CAM, and smart manufacturing. Ortega-Dela Cruz (2022) emphasized that students respond positively to OBE when it connects classroom learning to real-world applications and career opportunities. Thus, integrating industry-driven content not only builds technical skills but also enhances student motivation, making the program both academically sound and culturally aligned with Marikina's footwear sector. Examine below the OBE-Framework of the Institute of Engineering at Marikina Polytechnic College (MPC).

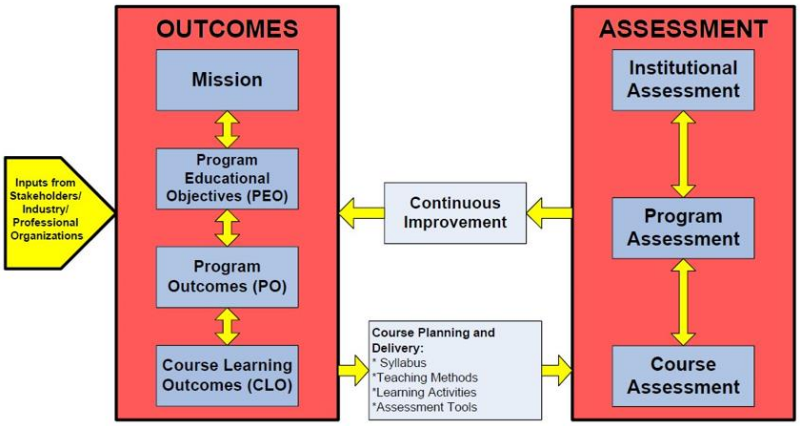

Figure 4. ***Outcomes-Based Education Framework of the Institute of Engineering, Marikina Polytechnic College (MPC), as the Basis for the Proposed BSMechE-FRA Program***

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The Outcomes-Based Education (OBE) Framework of the Institute of Engineering at Marikina Polytechnic College serves as a guiding structure to align academic offerings with industry expectations by translating institutional goals into measurable program and course outcomes. In the case of the proposed BS Mechatronics Engineering specialization in Footwear Robotics and Automation, the framework directs the design of a curriculum that emphasizes hands-on technical expertise, innovative design, and sustainable manufacturing practices. Collaboration with key stakeholders, including local footwear producers and professional bodies, ensures the program remains responsive to real-world needs. Regular assessment and evaluation processes further support continuous curriculum enhancement, producing graduates who are industry-ready and capable of driving technological advancements in the footwear and leathercraft sectors.

B. Curriculum Structure

The curriculum balances general education, core mechatronics, and specialty footwear automation courses, culminating in industry immersion and capstone projects (Santos & Cruz, 2023) linked to MPC facilities such as the FIT Laboratory and ReSOLES TBI. The proposed BS Mechatronics Engineering with Specialization in Footwear Robotics and Automations (BSMechE-FRA) curriculum comprises a total of 188 units, structured into two major components: Technical Courses (138 units) and Non-Technical Courses (50 units), with 4 units allocated for Industry Immersion or On-the-Job Training (OJT) under Technical Courses. This proposed structured is flexible program design and shows that engineering graduates are not only technically skilled and innovative but also grounded in ethical, social, and professional responsibilities, ready to lead the transformation of the Philippine footwear and smart manufacturing sectors that will be produced by MPC.

Table 1. ***Summary of Curriculum Components and Units – BS Mechatronics Engineering with Specialization in Footwear Robotics and Automations (BSMechE-FRA)***

Curriculum Component	**Units**
I. Technical Courses	
A. Mathematics	12 units
B. Natural / Physical Sciences	11 units
C. Basic Engineering Sciences	11 units
D. Allied Courses	44 units
E. Professional Courses	
1. Core Courses	50 units
2. Elective Courses	6 units
F. OJT / Industry Immersion	4 units
Subtotal – Technical	138 units
II. Non-Technical Courses	
A. General Education	24 units
B. Filipino / Literature	12 units
C. Physical Education	8 units
D. NSTP	6 units
Subtotal – Non-Technical	50 units
GRAND TOTAL	**188 units**

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C. Framework Design

Marikina City, widely well-known as the "Shoe Capital of the Philippines," stands at the intersection of tradition and technological disruption as the global footwear industry rapidly embraces Industry 4.0 innovations such as robotics, CAD/CAM systems, and AI-driven quality control. Despite its rich cultural heritage, the local shoemaking sector struggles to remain competitive due to limited access to automation expertise and modern manufacturing systems. To address this gap, Marikina Polytechnic College (MPC) proposes the Bachelor of Science in Mechatronics Engineering Technology (BSMET) with a specialization in Footwear Robotics and Automation, a program designed to merge artisanal craftsmanship with smart manufacturing technologies. Anchored on CHED policies and supported by MPC's established innovation ecosystem, including the ReSOLES Technology Business Incubator (TBI), the Shoe and Leathercraft Development Center (SLDC), and the Footwear Innovation and Technology (FIT Lab.) Research Laboratory, the proposed program seeks to cultivate a new generation of technologists equipped to revitalize Marikina's footwear industry. Through contextualized mechatronics education and strengthened academic–industry partnerships, the program will bridge traditional craftsmanship with modern automation. MPC's existing facilities and expertise provide a strong foundation for successfully implementing and sustaining this specialized initiative.

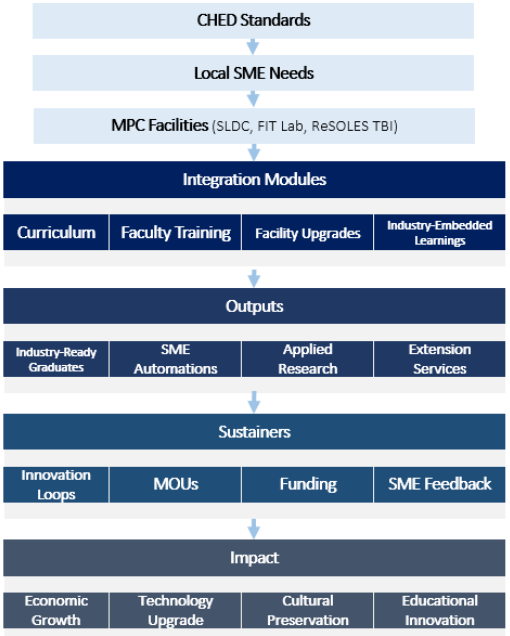

Figure 5. ***Illustrates the proposed Footwear Mechatronics Engineering Integration Framework (FMechE-IF)***

Figure 5 illustrates the Footwear Mechatronics Engineering Integration Framework (FMechE-IF), a structured academic–industry partnership model incorporated into the proposed BSMechE–FRA specialization at Marikina Polytechnic College (MPC). The framework starts with institutional and regulatory

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foundations, including CHED Memorandum Order No. 20, s. 2013, which outlines the required mechatronics competencies, and MPC's mandate to advance footwear and leathercraft education. It aligns with the college's existing innovation ecosystem, particularly the Shoe and Leathercraft Development Center (SLDC), the ReSOLES Technology Business Incubator, and the Footwear Innovation and Technology (FIT) Research Laboratory, which are equipped with advanced tools for robotics, CAD/CAM, and smart manufacturing (Marikina Polytechnic College, 2025). From these inputs, the FMET-IF transitions into integration modules, which include:

- Specialized curriculum development for footwear automation, IoT-enabled production, and AI-driven quality control;
- Faculty development in Industry 4.0 technologies;
- Laboratory upgrades to integrate robotic arms, CNC cutting/stitching machines, and computer vision systems for footwear inspection; and
- Industry-linked learning models, such as internships and co-developed capstone projects with local SMEs (Kim et al., 2022).

The framework produces tangible outputs, including graduates with niche mechatronics skills tailored to footwear manufacturing, SME-focused automation prototypes, and MPC's establishment as a national model for digitalizing heritage industries (Department of Science and Technology, 2023). To sustain these outputs, the framework relies on innovation loops, including Memoranda of Understanding with SMEs, funding support from CHED, DOST, and LGUs, and continuous industry feedback mechanisms. Lastly, the impact areas of FMET-IF span economic growth through improved SME productivity, technological advancement via localized Industry 4.0 adoption, cultural preservation by complementing artisanal shoemaking with automation, and educational innovation by creating a scalable model for revitalizing other heritage-based industries in the Philippines (Forlini, Rossi, & Bianchi, 2024; Asian Development Bank, 2021).

D. Faculty Development and Infrastructure Upgrade

Faculty development focuses on robotics and automation pedagogy, building capacity to deliver Industry 4.0-aligned curriculum. Infrastructure upgrades prioritize robotic arms, CNC cutters/stitchers, and computer-vision systems even for footwear-specific applications (Kim et al., 2022). The successful implementation of the program requires systematic faculty development focused on Industry 4.0 technologies, particularly robotics, IoT-enabled manufacturing, and advanced quality control systems. Faculty members must undergo retooling and specialized training to effectively deliver both theoretical and practical components of the curriculum. The program can also leverage the expertise of allied engineering programs such as BSCpE, BSECE, BSEE, and BSME, which provide complementary technical knowledge and shared laboratory resources.

In addition, laboratory upgrades are essential to ensure hands-on training that meets industry standards. Key facilities include robotic arms, CNC cutting machines, collaborative robots, and computer vision systems designed for footwear-specific applications. These investments are aligned with international best practices, such as Italy's luxury footwear sector, which integrates automation with artisan-led

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customization, and Germany's hybrid smart manufacturing models that combine precision engineering with flexible production systems (Costa & Godinho, 2021; Lu et al., 2020).

E. Integration with MPC's Innovation Ecosystem

The program is strategically designed to leverage MPC's existing facilities:

- The Shoe and Leathercraft Development Center (SLDC) will serve as the main hub for creating and refining footwear prototypes, focusing on design, craftsmanship, and production techniques. This will be complemented by the BS Entrepreneurship program with a specialization in Shoe and Leathercraft Marketing, which equips students with practical knowledge in marketing, finance, and product management. By linking technical development with business strategies, these initiatives ensure that footwear prototypes can be successfully transformed into competitive and sustainable market offerings.
- The ReSOLES Technology Business Incubator (TBI) will support student-led automation projects for SMEs.
- The Footwear Innovation and Technology (FIT) Laboratory, recently inaugurated as a robotics and smart manufacturing hub, will provide advanced learning environments for Industry 4.0 applications (Marikina Polytechnic College, 2025).

Program delivery aligns with MPC's institutional ecosystem, linking the technical and entrepreneurial learning in the FIT Laboratory and ReSOLES TBI to broader heritage preservation efforts at the SLDC (Department of Science and Technology, 2023; Armas & Moralde, 2022). This integration ensures a seamless transition between academic learning and real-world industry application, fostering applied research and innovation.

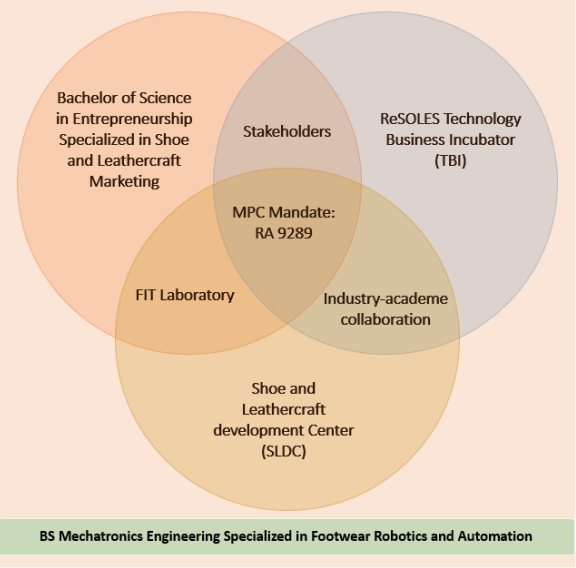

Figure 6. *Proposed Integrated Innovation and Heritage Framework for BS Mechatronics Engineering Specialized in Footwear Robotics and Automation (BSMechE-FRA)*

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Figure 6 illustrates the integrated framework that supports the proposed BS Mechatronics Engineering Specialized in Footwear Robotics and Automation (BSMechE-FRA) at Marikina Polytechnic College. It highlights the synergy among three key components: academic programs, innovation hubs, and heritage centers. The Bachelor of Science in Entrepreneurship specialized in Shoe and Leathercraft Marketing, together with the Footwear Innovation and Technology Laboratory, provides the academic and technical foundation needed to nurture entrepreneurial and engineering skills. The ReSOLES Technology Business Incubator serves as a platform for innovation, technology transfer, and industry partnerships, enabling local enterprises and startups to adopt modern manufacturing practices. Meanwhile, the Shoe and Leathercraft Development Center acts as a heritage-based hub for skills development, prototyping, and the preservation of Marikina's artisanal shoemaking traditions. Their common functions emphasize stakeholder engagement, industry-academe collaboration, and alignment with the institutional mandate of MPC under Republic Act 9289. Above all, these components are interconnected through BSMechE-FRA, serving as the unifying engineering discipline that bridges heritage craftsmanship with modern manufacturing technologies to strengthen the footwear sector of Marikina. This structured approach responds directly to industry demands while preparing graduates to lead modernization efforts in Marikina's footwear sector.

Validation and Implementation Planning

The final phase of this proposed program focuses on validation and planning for future implementation, ensuring that the Bachelor of Science in Mechatronics Engineering Technology (BSMechE-FRA) specialization in Footwear Robotics and Automation aligns with academic standards, industry needs, and cultural relevance. Since this study is a proposal and technical review, the validation strategies and implementation roadmap are presented as literature-based recommendations that will later be refined through consultations and feedback from key stakeholders.

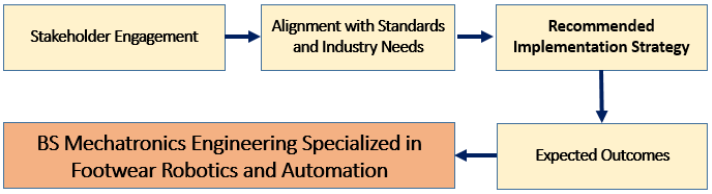

Figure 7. ***Illustrates the Validation and Implementation Roadmap for the BS Mechatronics Engineering Specialization in Footwear Robotics and Automation (BSMechE-FRA)***

Figure 7 shows the strategic roadmap for validating and implementing the proposed BSMechE-FRA specialization in Footwear Robotics and Automation at Marikina Polytechnic College. The roadmap is organized into three phases: the pre-implementation, pilot, and full implementation. It begins with securing institutional and regulatory endorsements, encouraging stakeholders to engage for feedback, and preparing faculty through targeted retooling programs and trainings in local and international practices. The pilot phase will focus on testing selected modules within MPC's innovation hubs, complemented by industry immersion activities to assess relevance and feasibility. The final phase involves full program rollout, including feedback

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from the pilot stage and formalizing partnerships with SMEs for sustained collaboration. This structured approach ensures that the program remains compliant with CHED policies, meets industry standards, and respects Marikina's cultural heritage while advancing technological innovation in the local footwear sector.

A. Anticipated Stakeholder Engagement

The validation process will involve key stakeholders such as local footwear SMEs, city government units, industry associations, CHED representatives, and technical experts. Illustration on established models from heritage industries in Europe and Southeast Asia, stakeholder engagement will ensure that academic content reflects real-world industrial demands (Esangbedo et al., 2024; Steghöfer et al., 2018). Through focus group discussions (FGDs) and consultative meetings, stakeholders are expected to provide feedback on the curriculum structure, specialization modules, and integration of Industry 4.0 technologies and ensures the program enhances rather than replaces traditional craftsmanship. This approach mirrors best practices in collaborative program design, where LUC's and SUC's act as catalysts for innovation while respecting local industry culture.

B. Alignment with Industry Needs and Academic Standards

The BSMechE-FRA specialization aligns with CHED Memorandum Order No. 20, s. 2013, supporting contextualized curriculum development for engineering and technology programs. It also propels the Marikina Shoe Industry roadmap, which prioritizes automation and workforce upskilling (DTI, 2021). The design draws on international literature review such as Italy's luxury footwear automation models and Adidas' Speedfactories where robotics and digital manufacturing complement artisanal work (Gajdzik & Wolniak, 2022; Nagy et al., 2018). By embedding Industry 4.0 technologies such as CAD/CAM, robotic automation, and AI-enabled quality control, the program anticipates bridging the skills gap in Marikina's footwear workforce.

C. Recommended Implementation Strategy

The roadmap is presented as a phased, flexible strategy. Pre-implementation includes securing approvals from CHED and MPC's academic board, conducting FGDs, expert reviews, and curriculum refinement, along with faculty development workshops in footwear automation and mechatronics. The pilot phase involves testing specialized modules at MPC's innovation hubs like; ReSOLES TBI, SLDC, and FIT Laboratory and placing students in SME-based capstone projects. Full implementation (Year 3 onward) includes scaling the program, continuous curriculum enhancement based on stakeholder feedback, and establishing MOUs with footwear manufacturers. This approach builds on adaptive curriculum design practices from Industry 4.0 education models (Esangbedo et al., 2024; Gajdzik & Wolniak, 2022).

D. Expected Outcomes of Validation and Planning

Once fully validated, the program is expected to achieve the following outcomes:

- Industry-ready graduates with specialized mechatronics expertise tailored to footwear manufacturing, capable of addressing modernization needs of heritage industries.

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- At least 3–5 prototype automation solutions for local SMEs developed through student-led capstone projects within the first three years of implementation.
- Strengthened academic–industry collaboration, with a minimum of five formal partnerships established with footwear companies and heritage-based manufacturing sectors.
- Graduates obtaining specialized certifications in mechatronics, industrial automation, or footwear engineering, enhancing employability and professional recognition.
- Increased research and innovation outputs, targeting at least two published studies or conference presentations annually focused on localized Industry 4.0 applications.
- Replication potential for other cultural and heritage-based industries, creating a model for digital transformation applicable beyond the footwear sector.

The Phase 3 emphasizes recommended pathways rather than fixed commitments, underscoring the importance of continuous stakeholder dialogue, compliance with academic policies, and iterative program development. This approach ensures the long-term success of the BSMechE-FRA specialization while fulfilling MPC's legislative mandate to serve as the center for the development of the shoe and leathercraft industry and to provide technological, professional, and occupational training for the advancement of appropriate technologies in community-based enterprises. The phased validation framework ensures compliance with CHED regulations and sustains MPC's mandate to advance the shoe and leathercraft industry through appropriate technologies and community-based training under Republic Act No. 9289 (2004).

RESULTS AND DISCUSSION

The findings conceptualized from literature synthesis, field observations, and international literature reviews which demonstrate that the intersection of tradition and technology offers a transformative pathway for revitalizing Marikina's footwear industry. Needs assessment, curriculum and framework design, and validation planning collectively highlight critical gaps such as the industry's reliance on manual production, and limited access to automation. To address these challenges, a contextualized mechatronics engineering education may offer a practical solution to the technological stagnation of heritage-based manufacturing sectors. By aligning with CHED's outcomes-based education policies and fulfilling Marikina Polytechnic College's mandate as the center for footwear and leathercraft development. Also the proposed curriculum emphasizes the integration of robotics, CAD/CAM technologies, and smart manufacturing systems as strategic technological interventions. The proposed engineering program aims to preserve cultural heritage while fostering economic revitalization, creating a scalable model for strengthening modern workforce capabilities and improving the competitiveness of other heritage-driven industries.

Modernizing a Heritage Industry through Contextualized Innovation

Marikina's footwear industry remains reliant on manual labor and on its manual shoe-making equipment which results in low production efficiency and vulnerability to global competition. It also shows that many SMEs face frequent production downtimes and limited scalability, compounded by a critical shortage of professionals who understand both shoemaking craftsmanship and modern automation technologies. This skills gap has become a major barrier to innovation, therefore, the proposed BSMechE-FRA specialization in Footwear Robotics and Automation will directly address this issue by integrating

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traditional shoemaking expertise with mechatronics competencies, ensuring that cultural heritage is preserved while adopting Industry 4.0 tools in the field of engineering. This kind of approach will not only drive technological modernization but also will promote inclusive growth by enabling small-scale manufacturers to adopt scalable automation models in footwear production.

Lessons from Global Best Practices

International examples from Italy, Germany, and Adidas' Speed-factories illustrate hybrid automation systems that support artisanal labor rather than replace it. In Spain and broader Europe, robotic systems—from sole digitization to glue application which demonstrate how automation can streamline repetitive tasks while preserving hand-finishing quality (Oliver et al., 2021; Chiriatti et al., 2022). For example, Italian luxury brands leverage CAD/CAM systems and robotic testbeds to streamline repetitive tasks while retaining hand-finishing techniques for premium products. These models show that automation need not erode cultural identity, instead, it can promote craftsmanship by enhancing precision, efficiency, and design flexibility. This international perspective underscores that Marikina City does not need to imitate full-scale industrial automation but rather adopt a "right-sized" hybrid automation model. This aligns perfectly with the program's vision of training mechatronics technologists who can design SME-focused automation solutions tailored for heritage industries focused on footwear technology.

Academic-Industry Convergence through Innovative Curriculum

The curriculum design, will be develop in Phase 2, integrates outcomes-based education principles (CHED CMO 20, s. 2013) with the technical realities of footwear manufacturing. By introducing specialized courses in robotic shoemaking, CAD/CAM design, cyber-physical manufacturing systems, and smart materials, the program ensures that graduates will possess both theoretical and applied expertise. The curriculum's applied learning model leverages MPC's innovation ecosystem, particularly the ReSOLES Technology Business Incubator (TBI) and the Footwear Innovation and Technology (FIT) Research Laboratory as living laboratories where students collaborate with SMEs to develop real-world automation prototypes. This academic-industry synergy ensures that the program produces graduates who are not only job-ready but also innovation-driven, capable of launching their own startups or spearheading modernization within existing footwear enterprises. Moreover, the structured FMET-IF framework ensures graduates emerge from the program as innovation-driven professionals ready to contribute to local SMEs and the footwear sector (Esangbedo et al., 2024).

Anticipated Transformational Impact

The proposed program holds multidimensional impacts:

A. Economic Revitalization. By producing a skilled workforce in footwear automation, local SMEs can increase productivity and compete globally.
B. Technological Advancement. MPC becomes a regional hub for Industry 4.0 adoption, accelerating digital transformation in heritage manufacturing.
C. Cultural Preservation. By blending automation with craftsmanship, the program safeguards Marikina's artisanal identity while making it future-proof.
D. Educational Innovation. It serves as a replicable academic model for other Philippine heritage industries (e.g., weaving, woodcraft, leatherwork) facing similar modernization challenges.

This study reinforces the argument that context-specific, interdisciplinary education is essential to

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modernizing traditional industries. It further demonstrates that academic institutions, through strategic partnerships with industry, can serve as catalysts for heritage-industry renewal by mediating between global best practices and local contexts (Esangbedo et al., 2024).

Synthesis of Findings

In collaboration, the review and proposal findings highlight a strong alignment between local needs, international practices, and the institutional capacity of MPC. Marikina's footwear industry recognizes the pressing need for technological advancement but lacks the skilled workforce and technical expertise required for sustainable modernization. The proposed BSMechE-FRA specialization will address this gap by preparing engineering graduates who combine innovative mechatronics skills with an appreciation of traditional shoemaking. By tailoring mechatronics engineering education to the socio-economic and cultural context of Marikina City, MPC positions itself as a key driver of heritage-industry digitalization. This proposal also offers a scalable model for revitalizing other traditional industries, demonstrating that modernization and cultural preservation can effectively coexist through well-designed, responsive academic programs in MPC.

CONCLUSION AND RECOMMENDATIONS

The research technical review shows that revitalizing Marikina's footwear industry requires more than machinery upgrades and it also demands a transformative engineering educational response. The proposed Bachelor of Science in Mechatronics Engineering with a specialization in Footwear Robotics and Automation (BSMechE-FRA) at Marikina Polytechnic College (MPC) can address the skill gap preventing local SMEs from embracing Industry 4.0 practices. By aligning artisanal shoemaking heritage with advanced mechatronics competencies, the proposed program will create a hybrid model of cultural preservation and technological innovation. Through a phased developmental approach, the study demonstrated that the local and international literature review confirms a pressing local demand for automation-ready professionals, especially in SMEs where outdated equipment and manual processes limit scalability (Oliver et al., 2021); international reviews highlight hybrid automation systems that enhance rather than displace craftsmanship, such as collaborative robotics in Italy's luxury footwear industry and Germany's hybrid manufacturing models (Chiriatti et al., 2022); and curriculum and framework design integrate outcomes-based education with real-world industry linkages (Esangbedo et al., 2024) through MPC's innovation ecosystem, introducing its innovation ecosystem which includes the ReSOLES TBI and FIT Laboratory to provide applied learning and prototype development aligned with SME needs. The Footwear Mechatronics Engineering Integration Framework (FMechE-IF) illustrates that this specialization is not an isolated initiative but a sustainable, scalable academic program with tangible benefits for the local economy, cultural heritage, and the Philippine higher education landscape. By embedding students in applied research and SME-focused projects, the program positions MPC as a national leader in heritage-industry modernization while preparing graduates for employment.

To enable the successful implementation and long-term viability of this pioneering program, several recommendations are made. First, (1) program approval should adopt a phased rollout that allows initial testing of the curriculum and supports the gradual integration of industry partners. Second, (2) partnerships

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with local footwear SMEs and industry groups must be strengthened, as active collaboration ensures the program stays grounded in real-world production challenges while promoting technology adoption. Third, (3) faculty training in Industry 4.0 technologies and footwear automation is essential. Faculty retooling and cross-training will ensure the effective delivery of specialized courses and mentoring of students in emerging manufacturing practices, which may include pursuing National Certificate programs or micro credentials in footwear to maintain updated knowledge and industry-aligned competencies. Fourth, (4) upgrading laboratories with advanced technologies is crucial to provide hands-on, immersive learning experiences that directly translate into industry-ready skills. Fifth, regular review and updating of the curriculum must be implemented to meet evolving industry needs, ensuring alignment with CHED standards and global best practices. Finally, (5) documenting the program as a model for other heritage industries will capture valuable lessons that can be replicated in similar sectors undergoing digital transformation.

Marikina Polytechnic College can become a national leader in heritage-industry digitalization while shaping a new generation of mechatronics technologists who can sustain innovation in culturally significant industries in shoe and leathercraft. This model demonstrates how education can catalyze both economic revitalization and cultural preservation in the age of smart manufacturing in footwear technology.

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