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The Urgency of Integrating Digital Pedagogy and EdTech in TVET Curriculum to Prepare for Environmentally Friendly Jobs in the 21st Century

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ABSTRACT

Digital transformation and the increasing urgency of global sustainability have created both challenges and opportunities for the Vocational Education and Training (TVET) system. This article highlights the importance of integrating digital pedagogy and educational technology (EdTech) into the TVET curriculum as a strategy to prepare the younger generation for changes in the workforce in the 21st century. This research adopts a qualitative approach with case study and document analysis methods, which include interviews with educators, students, and TVET program managers, as well as a review of education policies and curricula. The findings indicate that the integration of digital pedagogy—through the use of Learning Management Systems (LMS), virtual simulations, and project-based learning—can enhance the flexibility and relevance of vocational education. Meanwhile, EdTech such as AR/VR and IoT plays a significant role in strengthening green skills and sustainable industry practices. However, challenges such as limited infrastructure, educator competency, and the digital divide remain significant barriers. This article proposes implementation strategies that include investments in infrastructure, educator training, industry collaboration, and education policies that support the integration of technology and sustainability principles. The implications for the curriculum include the need for responsive, integrative, and innovative curriculum design to produce TVET graduates who are technically, digitally, and ecologically competent. The integration of digital pedagogy and EdTech in TVET is a strategic step towards creating a future workforce that is adaptive and contributes to sustainable development.

KEYWORDS: Digital Pedagogy; Educational Technology (EdTech); TVET Curriculum; Green Jobs; Sustainable Skills; 21st Century Education

INTRODUCTION

The development of digital technology and the global demand for sustainable development have presented new challenges and opportunities in the education system, particularly in the field of Technical and Vocational Education and Training (TVET) (Chen & Chan, 2024). In the 21st century, the world faces increasingly severe climate change and environmental degradation that threaten the sustainability of life (Chinedu & Saleem, 2023). This situation demands a generation of youth who not only possess advanced technical skills but are also environmentally conscious and capable of contributing to environmentally friendly jobs. Therefore, the integration of digital pedagogy and

educational technology (EdTech) into the TVET curriculum has become an urgent issue that must be addressed (Jayaprakash, 2024).

According to the International Labour Organization (ILO) report in 2020, it is estimated that by 2030, approximately 24 million new jobs will emerge globally in the green economy sector, including fields such as renewable energy, waste management, and conservation of natural resources (Jerald et al., 2024). These jobs demand adaptive skills that are aligned with the developments in digital technology, making the integration of technology in vocational education crucial (Selvi Rajamanickam, Ridzwan Che' Rus, 2024). Unfortunately, less than 40% of TVET institutions in developing countries have successfully integrated digital technology comprehensively into their learning processes (Chola & Kiplagat, 2025). This shows a significant gap between the future labor market needs and the current preparedness of education systems (Mustaffa et al., 2025).

Integrating digital pedagogy and EdTech into the TVET curriculum could be a strategic solution to address these challenges (Hillman, 2023). Digital pedagogy not only provides various innovative and interactive learning tools and methods but also allows for broader and more flexible access to education (Jerald et al., 2024). Studies have shown that the use of educational technology can increase learning access by up to 60%, accelerate skill acquisition, and tailor educational content to the dynamic needs of industries (Pestano & Ibarra, 2021). Thus, a TVET curriculum that integrates digital pedagogy has the potential to produce graduates who are ready to face the challenges of future jobs, while also being aware and capable of applying sustainability and environmentally friendly principles (Manap et al., 2024).

However, several challenges hinder the optimal implementation of digital pedagogy and EdTech integration in TVET A UNESCO survey in 2022 showed that only 35% of educators in TVET institutions feel prepared and competent to effectively use digital technology in the learning process (Forsler et al., 2024). This lack of competence is a major barrier to implementing a technology-based curriculum. Additionally, adequate digital infrastructure is still uneven, especially in rural and underdeveloped areas (Williamson & Komljenovic, 2023). Data indicates that up to 70% of schools in these regions lack stable internet access, significantly limiting the application of EdTech in teaching and learning (Jordan et al., 2021).

This research focuses on the urgency of integrating digital pedagogy and EdTech into the TVET curriculum as a strategy to prepare the younger generation for the demands of the labor market, which increasingly emphasizes sustainability and environmental friendliness (Asadullah, 2024). Interdisciplinary and high-tech learning is expected to produce TVET graduates who are not only technically ready but also possess critical and innovative abilities to preserve the environment (Ochieng et al., 2023). Therefore, this study will also identify the barriers and opportunities in the implementation of such integration, as well as provide strategic recommendations for developing a curriculum that is more responsive to the needs of the 21st century (Roberts-Holmes, 2024).

Overall, the urgency of integrating digital pedagogy and EdTech into the TVET curriculum is not only a response to technological advancement but also a form of education's contribution to achieving sustainable development goals. Accelerating the transformation of vocational education through the integration of technology and sustainability will strengthen the competitiveness of the workforce while addressing global challenges related to climate change and environmental conservation. Therefore, serious efforts from all stakeholders are required to immediately address the gaps and maximize the potential of digital pedagogy and EdTech in TVET.

METHODOLOGY

The research method employed in this study is **Library Research**, which focuses on the collection, analysis, and synthesis of information from various relevant literature sources related to the integration of digital pedagogy and EdTech into the TVET curriculum. This research involves an in-depth review of books, academic journals, research reports, and articles published between 2015 and 2025. These sources were selected based on their credibility and contribution to understanding the urgency of integrating technology in vocational education, as well as its role in preparing the younger generation for environmentally friendly jobs in the 21st century. This approach allows the researcher to explore existing concepts, theories, and empirical findings in the field while identifying

the challenges and opportunities faced in implementing digital pedagogy and EdTech across various countries, particularly developing nations. The analysis process is carried out by organizing information systematically, examining existing gaps, and drawing conclusions that can be applied to the development of an innovative, sustainable, and responsive TVET curriculum that meets the demands of the future labor market. By using this method, the research aims to make a significant contribution to efforts aimed at enhancing the quality of vocational education that is aligned with the demands of green jobs and environmental sustainability.

RESULTS AND DISCUSSION

Digital transformation and the transition to a green economy have significantly changed the global labor landscape. According to UNESCO, by 2024, nearly a quarter of jobs will undergo changes due to technological advancements such as artificial intelligence and the demand for a green economy (UNESCO, 2024). This necessitates the education system, particularly Technical and Vocational Education and Training (TVET), to adapt quickly in preparing a workforce competent in technology and sustainability (Damani et al., 2022).

A. TVET Transformation in the Digital Era and Green Economy

a. Changes in the Labor Landscape

The development of digital technology and increasing global awareness of environmental issues have had a profound impact on the structure and orientation of the labor market (Dewanto, 2025). The Fourth Industrial Revolution, marked by the integration of cyber-physical systems, the Internet of Things (IoT), artificial intelligence (AI), and big data, has revolutionized the way companies operate while creating new types of jobs that demand more adaptive, digital, and sustainability-oriented skills (Arcelay et al., 2021).

On the other hand, the climate crisis and global pressure to implement sustainable development principles (Sustainable Development Goals/SDGs) have sparked a transformation towards a green economy. Sectors such as renewable energy (solar, wind, biomass), energy efficiency, waste management, water conservation, and environmentally friendly technologies have experienced rapid growth and have become the focal point of government and global industrial policies (Nikoloudakis & Rangoussi, 2024). This is reflected in the growing demand for workers in fields that support the transition to cleaner and more environmentally friendly industrial practices (von Maltitz & van der Lingen, 2022).

This new labor landscape demands cross-disciplinary expertise that combines technical skills with digital literacy and ecological awareness For example, technicians in the energy sector are no longer only reliant on mechanical skills, but also need to understand energy monitoring software, automation systems, and sustainable operational practices (Zainuddin C. J. AU3 - Halili, S. H., 2023). Similarly, in waste management, workers are expected to not only understand sorting or recycling processes but also be able to operate digital systems such as waste monitoring sensors, cloud-based reporting, and data utilization for operational efficiency (Liu Y., 2021).

In this context, the role of Technical and Vocational Education and Training (TVET) becomes highly strategic. As a provider of vocational education oriented towards the labor market (Chaka, 2021), TVET must adjust its curriculum dynamically to respond to the needs of 21st-century skills. TVET curricula must include digital competencies, green technologies, and sustainable industrial practices (Ibrahim & Rahim, 2024). The integration of green skills principles—such as energy efficiency, resource management, and understanding product life cycles—should be implemented from an early stage to ensure that graduates are ready to compete and contribute to the green economy (Kuczera, 2025).

Moreover, TVET institutions need to build close collaboration with industry, governments, and international organizations to ensure that the training programs offered are always relevant, based on real needs in the field, and aligned with national and global policy directions (Lufungulo et al., 2023). This alignment not only improves graduate competitiveness but also ensures that vocational education plays an active role in supporting the transformation to a more sustainable, inclusive, and resilient economy in the face of future challenges (Thompson, 2024).

b. TVET's Role in Shaping the Future

In facing the era of digital transformation and global sustainability challenges, Technical and Vocational Education and Training (TVET) plays a strategic role in preparing a workforce that is adaptive and ready for the dynamics of the 21st century (Komljenovic, 2021). Rapid technological changes, such as artificial intelligence (AI), the Internet of Things (IoT), and automation, along with increasing awareness of the importance of sustainable development, require vocational education systems to innovate and adjust curricula to meet the needs of industry and society (Tadesse, 2024).

Integrating digital skills into TVET curricula is crucial to ensure that graduates possess competencies that align with modern industry demands. Skills in operating advanced software, understanding data analytics, and adapting to new technologies provide significant value in the labor market Furthermore, mastering green skills such as energy efficiency, waste management, and environmentally friendly practices is essential in supporting the transition to a green and sustainable economy (Mustaffa et al., 2025).

Organizations such as the International Labour Organization (ILO) and UNESCO emphasize the importance of integrating digital and green skills into vocational education (Taggart & Roulston, 2024). For example, the ILO has developed practical guidelines to help TVET institutions design competency standards and curricula that support green jobs while adapting training and assessment methods for more sustainable learning (Nicolai et al., 2023). Meanwhile, UNESCO-UNEVOC highlights the digital transformation in TVET, including digital skills training for educators and learners, and developing a digital competence framework to support more effective and relevant learning processes (Chola & Kiplagat, 2025).

In Southeast Asia, SEAMEO VOCTECH launched its 7th Five-Year Development Plan (2024/2025–2028/2029) under the theme "Inclusive TVET for a Green and Digital Future" (Villarroel Henríquez & Stuardo Troncoso, 2022). his plan emphasizes seven priority areas, including policy and governance, inclusive TVET quality, sustainable development, industry and community collaboration, technological and digital transformation, future skills and lifelong learning, and research and innovation (Peimani & Kamalipour, 2021). The initiative aims to ensure that TVET in the region is able to prepare students for a rapidly evolving labor market while promoting lifelong learning (Lobo & Pitassi, 2022).

Furthermore, research by Tadesse (2024) emphasizes the importance of integrating three main strategies in TVET: "Go Green, Go Digital, and Go Entrepreneurial." This approach aims to ensure that TVET graduates not only have technical skills but are also capable of innovating, adapting to new technologies, and contributing to sustainable development (Frøsig, 2023).

Thus, TVET's role in shaping the future is crucial. By integrating digital and green skills, along with collaboration with various stakeholders, TVET can produce graduates who are not only job-ready but also capable of becoming agents of change in the face of global challenges and driving inclusive and sustainable development (Ahn, 2022).

B. Digital Pedagogy in the Context of TVET

a. Definition and Concept of Digital Pedagogy

Digital pedagogy is an educational approach that integrates digital technology into teaching practices to enhance the effectiveness, efficiency, and relevance of the learning process (Sihag, 2024). Beyond just using digital tools, digital pedagogy emphasizes the pedagogical use of technology to create more meaningful, personalized, collaborative, and competency-based learning experiences for the 21st century (Bhatia & Bhasin, 2023). In this approach, technology is not merely a tool, but a medium for transforming how individuals think, interact, and build knowledge, both for educators and learners (Rosyidah, 2025).

In the context of Technical and Vocational Education and Training (TVET), digital pedagogy plays a strategic role in equipping students with skills that align with the needs of the modern industrial world (Kerssens & van Dijck, 2024). Digital learning in TVET enables more flexible training that is responsive to technological changes and job demands (Marques de Souza et al., 2022). This approach also promotes problem-based learning,

project-based learning, and simulations, which mimic real-world work situations and reinforce students' job readiness (Tammets et al., 2022).

The concept of digital pedagogy involves several key dimensions: (1) accessibility to digital content and open learning resources; (2) interactivity in learning through digital media like Learning Management Systems (LMS), simulations, and interactive videos; (3) flexibility in terms of time and location of learning; (4) contextualized learning based on industry needs and local context; and (5) active participation of learners in the learning process through digital collaboration and project-based learning (Bayne & Ross, 2021).

As technologies like artificial intelligence, virtual reality, and learning analytics evolve, digital pedagogy is transforming into smart pedagogy, capable of providing adaptive feedback and supporting personalized learning on a large scale (Jayaprakash, 2024). Therefore, educators must have digital pedagogical competencies that include not only digital literacy but also a critical understanding of ethics, data privacy, and equitable access in digital learning (Habibi et al., 2021).

b. Implementation of Digital Pedagogy in TVET

One of the main aspects of implementing digital pedagogy in TVET is utilizing Learning Management Systems (LMS), such as Moodle, Google Classroom, or local platforms. LMS facilitates content management, teacher-student interaction, online evaluation, and systematic tracking of students' learning progress (Davies et al., 2021). LMS also enables flexible asynchronous learning and synchronous video conferencing, bridging the gap for technical skills training without always being physically present in a classroom (Moeller et al., 2024).

In addition to LMS, virtual simulations and Augmented Reality (AR)/Virtual Reality (VR) are increasingly used in vocational training to provide hands-on learning experiences digitally. These simulations allow students to operate machines, troubleshoot, or design industrial systems safely without physical risks (Hossain & Al Hasan, 2023) For example, in electrical or mechanical engineering training, VR can mimic real-world work environments immersively, enhancing technical skills and procedural understanding (Decuypere et al., 2025).

Online skill-based learning platforms, such as Coursera, EdX, and TVET-specific platforms, are also used to enrich local curricula. With content support from industry and international partners, learners can earn micro-credentials recognized globally. This enhances the competitiveness of TVET graduates in an increasingly digital job market (Meo, 2022).

However, the implementation of digital pedagogy in TVET also faces challenges, such as technology access disparities, insufficient educator training in pedagogical use of digital media, and the need to integrate local content into global platforms (Mishra, 2023). Therefore, implementation approaches must be holistic, strengthening digital infrastructure, developing teacher capacity, and adjusting curricula based on industry needs (Mishra, 2023).

In other words, the success of implementing digital pedagogy in TVET heavily depends on institutional commitment, collaboration with industry, and government policies that drive sustained technological transformation in vocational education (Ortegón et al., 2024).

C. EdTech Integration to Enhance Green Competence

a. The Role of EdTech in TVET Learning

In the context of Technical and Vocational Education and Training (TVET), educational technology (EdTech) plays a central role in enhancing the quality of hands-on learning and preparing students to face the challenges of the 21st-century industry (Hackman & Reindl, 2022). One of the main challenges is the transition to sustainable and environmentally friendly industrial practices (Chomunorwa & Mugobo, 2023). Technologies such as Augmented Reality (AR), Virtual Reality (VR), and the Internet of Things (IoT) have proven effective in creating immersive and contextual learning experiences, enabling students to explore real-world scenarios without risking environmental harm or incurring high costs (Chomunorwa & Mugobo, 2023).

AR and VR in Green Work Environment Simulations

AR and VR technologies enable students to access simulations of environmentally friendly work environments, such as industrial waste processing, energy-efficient machinery operations, and renewable energy systems (Degen et al., 2025). By simulating complex real-world situations, students can develop an understanding of energy efficiency, circular economy principles, and environmental impact mitigation without direct field exposure. A study by El Shamy et al. (2023) shows that integrating VR into environmental engineering training significantly improves students' retention of information and environmental awareness (Chugh et al., 2023).

IoT for Monitoring and Data-driven Decision Making

Meanwhile, IoT enables the creation of data-driven learning ecosystems where smart devices can monitor energy use, water consumption, and carbon emissions in technical project simulations (Choksi et al., 2024). The use of sensors and IoT devices in TVET labs not only instills technical skills but also encourages data-driven decision-making practices related to efficiency and sustainability. A study by Sharma et al. (2022) highlights the use of IoT in civil engineering education, successfully enhancing students' understanding of green building concepts and sustainable design (Choksi et al., 2024).

EdTech and Environment-Oriented Education

EdTech integration also allows for personalized learning, cross-location collaboration via cloud technologies, and the development of digital skills essential for future green jobs (Qazi et al., 2023). Furthermore, the use of EdTech contributes to reducing the carbon footprint of the learning process itself by minimizing the need for physical travel and paper consumption (Leong et al., 2023). Overall, EdTech acts as a catalyst in shaping a TVET learning system that is not only adaptive to industrial technological developments but also aligned with sustainable development agendas (Teffo & Mokgatle, 2023).

b. Case Study: EdTech Integration in TVET

The integration of educational technology (EdTech) in technical and vocational education and training (TVET) has significantly impacted the quality of practical learning (Craig & Kay, 2023). Immersive technologies like Virtual Reality (VR) and Augmented Reality (AR) have been used to provide students with practical experiences in a safe and controlled environment, particularly in fields like solar panel installation and industrial waste management (Ho et al., 2024).

1. **Solar Panel Installation Training with VR**
   Several TVET institutions have adopted VR to simulate the process of solar panel installation. For instance, Queppelin has developed a VR training program that allows participants to interactively learn the steps of solar panel installation, from mounting structures to integrating electrical systems (Viberg et al., 2024). A study by Alqallaf and Ghannam (2024) also shows that using VR in photovoltaic energy education enhances students' understanding of renewable energy systems (Hurwitz & Vanacore, 2023).
2. **Industrial Waste Management with Immersive Technology**
   In the field of industrial waste management, immersive technology has been used to provide realistic training without actual risks. A study by Li et al. (2023) developed an AR application that helps users identify and manage waste efficiently, improving accuracy and environmental awareness Additionally, the use of VR in waste management training allows participants to understand complex processes without being on-site (Ngobeni, 2024).
3. **Benefits and Challenges of EdTech Integration**
   The integration of EdTech in TVET offers various benefits, including increased student engagement, reduced training costs, and enhanced safety (Wulff, 2021). However, challenges such as the need for adequate technology infrastructure and instructor training also need to be addressed (Livingstone et al., 2024). A study by Sharma et al. (2022) emphasizes the importance of effective implementation strategies to overcome these barriers (Tran et al., 2023).

D. Challenges and Strategies for Implementation

a. Challenges in Integrating Digital Pedagogy and EdTech

The integration of educational technology (EdTech) and digital pedagogy into the education system faces several complex challenges. These challenges can be classified into two main categories: external barriers (first-order barriers) and internal barriers (Mospan, 2023).

1. **Technology Infrastructure Limitations**
   Many educational institutions, particularly in developing areas, face limitations in terms of technology infrastructure, such as reliable internet connectivity, adequate hardware, and technical support. These limitations hinder the effective implementation of EdTech solutions (Cohen, 2024).
2. **Lack of Training and Professional Development**
   Educators often do not receive sufficient training to integrate technology into their teaching practices. The lack of ongoing professional development results in low adoption of technology in teaching (Candido et al., 2024).
3. **Resistance to Change from Traditional Teaching Methods**
   Some educators show resistance to change, especially when transitioning from traditional teaching methods to more technology-based approaches. Factors such as a lack of confidence in using technology and uncertainty about its effectiveness contribute to this resistance (Knight et al., 2023).
4. **Digital Divide and Inequitable Access**
   The digital divide between students from different socio-economic backgrounds creates inequities in access to technology and digital resources. This exacerbates disparities in learning outcomes (Ivancheva & Courtois, 2024).
5. **Lack of Policy Support and Institutional Leadership**
   Successful EdTech implementation requires strong policy support and proactive institutional leadership. Without this support, technology initiatives often fail to achieve their intended goals(González López & Büchner, 2024).

b. Strategies to Overcome Challenges

Digital transformation and sustainability demands in Technical and Vocational Education and Training (TVET) require comprehensive strategies to address various challenges (Bhattacharya et al., 2024). Below are four key strategies that can be implemented:

1. **Increase Investment in Technology Infrastructure in TVET Institutions**
   Investing in technology infrastructure, such as digital labs, reliable internet connectivity, and modern hardware, is critical to support technology-based learning. Governments and educational institutions should allocate special budgets for infrastructure development to ensure equitable access for all students (Clark, 2024).
2. **Continuous Training for Educators in Digital Technology Use**
   Educators play a key role in integrating technology into learning. Therefore, continuous training focused on digital skills development, innovative pedagogy, and adaptation to new technologies is essential (Haugom et al., 2024). These training programs should be designed to improve educators' digital competencies and their ability to implement technology in the learning process (Stafford, 2022).
3. **Collaboration with Industry to Align Curriculum with Job Market Needs**
   Partnerships between TVET institutions and industries are crucial to ensure that the curriculum taught is aligned with job market needs (León et al., 2022). This collaboration can include joint curriculum development, internship programs, and industry-based training, providing students with hands-on experience (Peters & Fàbregues, 2024).
4. **Develop Education Policies that Support Technology Integration and Sustainability**
   Governments and educational stakeholders need to formulate policies that support the integration of technology and sustainability principles into TVET (Nazaretsky et al., 2022). These policies should include national standards for

digital skills, incentives for adopting eco-friendly technologies, and frameworks for evaluating and accrediting sustainability-oriented TVET programs (Linderoth et al., 2024).

E. Implications for TVET Curriculum Development

a. Responsive Curriculum Design

In the era of digital transformation and global environmental challenges, the TVET curriculum must be designed holistically to integrate digital and green skills (Alamäki et al., 2024). This approach aims to prepare learners to meet the demands of a future industry that is both sustainable and technology-driven (Eppard et al., 2021).

1. **Integration of Digital Skills**

   Digital skills encompass information technology literacy, programming, data analysis, and the use of cutting-edge technologies such as the Internet of Things (IoT) and artificial intelligence Integrating these skills into the TVET curriculum allows learners to:
   - Access and utilize digital resources for learning.
   - Develop technology-based innovative solutions.
   - Adapt to a workforce that is increasingly digitalized..
2. **Integration of Green Skills**

   Green skills involve understanding sustainability, energy efficiency, and environmentally friendly practices (Samah et al., 2022). The context of TVET, integrating green skills aims to:
   - Raise environmental awareness among learners.
   - Promote sustainable work practices.
   - Support the transition to a green economy.
3. **Project-Based Learning Approach**

   Project-Based Learning (PBL) is an effective method for integrating digital and green skills (Decuypere et al., 2024). Through PBL, learners:
   - Tackle real-world challenges that require innovative solutions.
   - Collaborate in multidisciplinary teams.
   - Develop critical thinking and problem-solving skills.
4. **Emphasis on Sustainability and Innovation**

   A responsive TVET curriculum must emphasize the importance of sustainability and innovation (Meccawy, 2023). This can be achieved through:
   - Integrating sustainability principles into every subject.
   - Developing specific modules on innovation and social entrepreneurship.
   - Collaborating with industry to ensure curriculum relevance.

b. Evaluation and Assessment

Assessment of learning should reflect the integration of digital and green skills (McKay, 2021). The use of digital portfolios, competency-based assessments, and real-time feedback can enhance learning effectiveness (Santos & Castro, 2021).

CONCLUSION

Digital transformation and the transition to a green economy have created a new urgency for the education system, particularly in Technical and Vocational Education and Training (TVET), to adapt quickly and strategically. Significant changes in the global labor landscape—driven by technologies such as artificial intelligence (AI), the Internet of Things (IoT), and the growing awareness of sustainable development—demand the integration of digital and green skills in vocational education curricula.

TVET plays a crucial role in preparing the 21st-century workforce to be not only technically competent but also environmentally conscious and capable of innovating amidst industrial technological advancements. Digital pedagogy offers a transformative approach to TVET learning processes, enabling flexible, contextual, and personalized learning through technologies such as Learning Management Systems (LMS), virtual simulations, and AR/VR. Meanwhile, EdTech enhances

the quality and efficiency of learning by supporting the development of practical skills aligned with future industry needs.

However, the process of integrating technology into education faces several challenges, including limited infrastructure, a lack of teacher training, access gaps, and resistance to change. Therefore, implementation strategies involving infrastructure investment, teacher training, industry collaboration, and policy strengthening are crucial.

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