ISSN 0971 - 8508

JOURNAL OF TECHNICAL AND VOCATIONAL EDUCATION

VOLUME 27 ISSUE 1

JANUARY 2026

NATIONAL INSTITUTE OF TECHNICAL TEACHERS TRAINING AND RESEARCH
Institution Deemed to be University under Distinct Category
A Centrally Funded Technical Institute, Ministry of Education, Govt. of India
Taramani, Chennai - 600 113.

EDITORIAL AND ADVISORY BOARD MEMBERS

Editorial

Volume 27, Issue 1 - January 2026

The January 2026 issue of the *Journal of Technical and Vocational Education* brings together a diverse yet thematically coherent set of scholarly contributions that reflect the evolving landscape of technical education, vocational training, educational leadership, and interdisciplinary technological research. This issue foregrounds the growing convergence of policy reform, pedagogical innovation, professional development, and advanced engineering applications in shaping future-ready education systems.

Several contributions focus on teacher professional development and educational leadership, emphasizing the human dimension of institutional transformation. Dr. K. Devisri and D. Seetharaman, in *Improving Teacher Effectiveness: A Guide to Professional Development*, provide a comprehensive synthesis of contemporary professional development models, highlighting continuous professional development, collaborative learning communities, and action research as key levers for enhancing teaching effectiveness. Complementing this perspective, Sivaselwam Arulnesan's conceptual paper, *Innovative Teaching for Workforce Readiness*, examines how transformational leadership and sustained teacher professional development jointly influence student adaptability, employability, and workforce readiness in TVET institutions.

The issue also presents empirically grounded studies addressing teacher well-being and holistic development. Dr. Y. Pavanya Balaji's study, *Influence of Yoga-Based Professional Development on B.Ed. Trainee Teachers*, offers compelling evidence that yoga-integrated professional development significantly reduces stress and enhances well-being among trainee teachers. This work reinforces the growing international discourse on embedding wellness-oriented practices within teacher education frameworks.

Responding to the imperatives of digital pedagogy and policy-driven reform, Sandeep Kumar Chouksey's article, *Transformational Process and Policies in Technical Education*, critically examines the impact of NEP 2020, Skill India initiatives, and Industry 4.0 on ITIs and polytechnic institutions. Drawing on a detailed case study of Divisional ITI Bhopal, the paper demonstrates how structured CNC-based training and industry collaboration translate policy intent into measurable improvements in employability and institutional performance.

The domain of technology-enhanced learning is further strengthened by an empirical investigation into the integration of e-content with professional practices in teacher education for English grammar learning among high school students in the Nilgiris District. This study highlights how digital instructional resources, when aligned with reflective teaching and classroom practice, significantly improve learner engagement and academic outcomes, while simultaneously equipping teacher trainees with essential digital competencies.

Extending beyond education into advanced engineering and applied research, this issue features technically rigorous contributions on microgrids, optimization, and digital twin technologies. Notably, the article on AI-driven digital twin–based security automation presents the TwinSOC framework, demonstrating how counterfactual verification and formal safety contracts can enhance trust and resilience in automated security operations. Similarly, the work on Q-learning and Differential Evolution–based optimization of fractional-order controllers

addresses emerging challenges in islanded microgrid frequency stability, reflecting the journal's interdisciplinary reach.

Collectively, the articles in this issue underscore a shared commitment to evidence-based reform, pedagogical innovation, and technological advancement. The Editorial Board hopes that this issue will stimulate scholarly dialogue, inform policy and practice, and inspire further research that bridges education, technology, and societal needs.

Industry–Academia Collaboration as a Catalyst for Operational Excellence in Vocational Education

Sundar M[1], Sakthivel Murugan S[2]

[1]Research Scholar, Management, NITTTR Chennai

mahalingamsundar@rediffmail.com

[2]Professor, Department of Electronics & Communication Engineering,

NITTTR Chennai

Abstract:

Industry–academia partnerships have become a central driver of operational excellence in vocational (TVET) education. Structured collaborations align technical curricula with industry requirements, modernize laboratories and infrastructure, enhance faculty capabilities, and improve student employability and institutional outcomes [1][2]. Yet, OECD data indicate that only about 45% of students in upper-secondary VET programs participate in substantial work-based learning [3], underscoring the need for stronger engagement between educators and employers. This paper reviews policy initiatives and case studies to examine how sustained partnerships strengthen curriculum relevance, equipment availability, teacher training, and graduate placement. For instance, an AICTE faculty fellowship immerses technical teachers in industry [4], while a UNESCO Global Education Coalition initiative connects students with corporate mentors to enhance workplace readiness [5]. The analysis suggests that when industries co-design curricula, offer hands-on training, and invest in facilities, vocational institutions deliver more market-relevant skills and achieve higher placement rates [1][2]. Collaborative governance structures, such as sector skill councils, further support applied research and ongoing curriculum updates [6]. The paper concludes with recommendations for policymakers and educators to institutionalize these collaborations through formal frameworks, incentives, and shared governance, thereby improving efficiency, resource utilization, and student outcomes in TVET.

Keywords: Industry–Academia Collaboration; Vocational Education; Curriculum Relevance; Faculty Development; Infrastructure Modernization; Employability.

I. Introduction

Technical and vocational education and training (TVET) is a cornerstone of workforce development: in OECD countries, nearly one in three young adults holds a vocational qualification [3]. These programs are particularly vital in rapidly developing economies such as India, where the demographic dividend can be realized only if young people acquire market-ready skills. Yet, a persistent "skills gap" continues to separate academic training from employer expectations. India's National Skill Development Corporation (NSDC) explicitly seeks to "train youth in skills that are aligned with industry requirements and bridge the skills gap in the workforce" [7].

In this context, industry–academia collaboration is increasingly recognized as an enabler of operational excellence in vocational institutes. Operational excellence refers here to the efficient and effective delivery of competency-based education that meets labor-market needs. Structured partnerships allow institutions to refresh curricula with current technologies, upgrade laboratory infrastructure, and strengthen faculty expertise in line with real-world practices [1][2]. For example, AICTE has acknowledged that low employability rates stem partly from outdated curricula and has introduced faculty–industry immersion programs as a corrective measure [4].

This paper reviews established models and outcomes of such collaborations in TVET. Section 2 surveys the literature on industry–academia linkages; Section 3 outlines the methodology; Section 4 presents case examples; Section 5 discusses implications; and Section 6 concludes with recommendations.

II. Literature Review

Prior studies highlight a range of models for industry engagement in vocational training. Traditional dual-apprenticeship systems and cooperative education blend classroom instruction with workplace exposure. In India, initiatives such as Sector Skill Councils (SSCs) and public–private partnerships contribute to curriculum design and training standards [6][7]. NSDC, for instance, promotes internships and apprenticeships to expand practical learning opportunities [7]. The Confederation of Indian Industry emphasizes that employer-led SSCs play a decisive role in updating curricula with industry input, keeping training relevant [1].

Academic research similarly demonstrates that joint curriculum development significantly improves educational outcomes in industry-aligned programs [8]. Global agencies also advocate for closer private-sector involvement. UNESCO-UNEVOC initiatives, including the Global Skills Academy, encourage employers to participate in both training design and quality assurance [5]. Despite these efforts, international evidence shows persistent gaps: only about 45% of upper-secondary vocational students in OECD countries gain significant work-based experience [3]. Researchers consistently argue that stronger, institutionalized partnerships create practice-oriented pedagogy, applied learning environments, and enhanced employability [8].

III. Methodology

This study adopts a qualitative review approach, combining secondary data analysis with the author's professional experience in project governance. Sources include official reports, policy documents, and case studies from AICTE, NSDC, UNESCO-UNEVOC, CII, FICCI, and OECD. Case examples were chosen to illustrate different dimensions of collaboration: faculty training, curriculum development, infrastructure investment, and placement strategies. Findings synthesize outcomes such as curriculum relevance and faculty capability rather than present new primary data. The triangulation of multiple sources strengthens reliability and provides insights into best practices and policy implications.

Case Examples and Findings

Faculty Development: The AICTE Industry Fellowship Programme immerses technical educators in company environments for 6–12 months. By 2026, it aims to host 1,500 faculty annually [4]. The program targets low employability and outdated curriculum by creating a feedback loop that integrates industrial practices into teaching [9]. Early feedback indicates revised curricula now include advanced techniques drawn directly from industry settings [4].

Student Mentorship and Internships: A UNESCO-led program pairs 100 corporate mentors from KPMG with NSDC-trained graduates to improve workplace readiness [5]. Mentors coach students on interviewing, resume writing, and professional communication [10]. Similarly, NSDC and SSCs facilitate structured internships and apprenticeships, with internal data suggesting placement increases of 20–30% in institutions offering industry internships [7].

Curriculum and Infrastructure Modernization: Industry partners co-develop curricula and equip training centers. Employer-led skill councils ensure continuous updates [1]. Companies often establish Centers of Excellence in vocational colleges, equipping labs with advanced machinery. One polytechnic upgraded its lab through a corporate grant, resulting in a 50% increase in students trained on modern equipment. These collaborations often include structured placement pathways [7].

Faculty Capability Enhancement: Vocational instructors increasingly participate in industry-led workshops, sabbaticals, and cross-training. For example, a 2024 state program trained over 200 faculty in advanced manufacturing, leading to new syllabus modules on additive manufacturing. Such efforts broaden faculty expertise and directly enhance student learning.

Placement and Employability Outcomes: Institutions with strong industry ties consistently achieve higher placement rates. Symbiosis Skill University in Pune reports about 90% placement for graduates of NSDC-aligned programs [11]. Employers note that students from such programs require less on-the-job training and adapt more quickly to workplace demands.

IV. Discussion

The case evidence demonstrates that structured industry–academia linkages advance operational excellence in vocational education. Co-created curricula and training platforms ensure relevance, faculty immersion strengthens teaching capacity, and modernized labs enhance learning environments [1][2]. Graduates thus enter the workforce with job-ready skills, aligning institutional outcomes with national skill development goals.

Sustaining these benefits, however, requires institutionalization. Successful programs typically feature advisory boards with industry representation, systematic review cycles, and faculty sabbaticals in industry. Policymakers can accelerate collaboration by linking funding and accreditation to active industry engagement. Incentives such as grants for collaborative labs, tax breaks for corporate trainers, and accreditation standards tied to industry inputs can deepen partnerships [6].

Equally important is measurement. Sector bodies can use balanced scorecards to monitor partnership performance, tracking metrics such as curriculum revisions and placement rates.

Technology should also be leveraged through digital platforms for virtual internships and mentoring, extending access beyond geographic limits.

V. Conclusion and Recommendations

This study shows that industry–academia collaboration is a critical strategy for strengthening vocational education. When industries co-design curricula, provide modern equipment, and participate in teaching, vocational institutes become more agile and outcome-focused. Faculty acquire current expertise, students gain workplace-ready skills, and institutions improve placement rates and efficiency [1][2][11].

To embed these gains, the following actions are recommended:

- Establish formal industry advisory boards to guide curriculum review and resource planning.
- Expand faculty immersion and industry exchange programs [4][9].
- Integrate industry-linked metrics into accreditation frameworks.
- Support industry-sponsored infrastructure through grants and incentives.
- Broaden access to work-based learning opportunities, including digital platforms [5][7].
- Systematically monitor and share best practices across the TVET ecosystem [6].

By institutionalizing these practices, vocational education can deliver operational excellence and respond more effectively to evolving labor market demands.

VI. References

1) Confederation of Indian Industry (CII). (2021). *Creating a common foundation of cross-sector 21st century skills*. CII Policy Watch – Skills. Retrieved from https://www.cii.in/uploads/Policy%20Watch%20Skills665.pdf

2) Esangbedo, P., & Kwarbai, J. (2024). The role of industry–academia collaboration in enhancing educational opportunities and outcomes under the digital-driven Industry 4.0. *Journal of Infrastructure, Policy and Development, 7*(3), 71–82.

3) OECD. (2023, September 12). *Spotlight on Vocational Education and Training: Findings from Education at a Glance 2023*. OECD Publishing. https://doi.org/10.1787/acff263d-en

4) Rising Kashmir. (2025, June 18). AICTE launches industry fellowship programme to strengthen "Industry-Academia" collaboration. *Rising Kashmir*. Retrieved from https://risingkashmir.com/aicte-launches-industry-fellowship-programme-to-strengthen-industry-academia-collaboration/

5) UNESCO. (2023, January 27). UNESCO's Global Education Coalition member KPMG to launch new mentorship programme in India. *UNESCO News*. Retrieved from https://www.unesco.org/en/articles/unescos-global-education-coalition-member-kpmg-launch-new-mentorship-programme-india

6) Federation of Indian Chambers of Commerce and Industry (FICCI). (2022, January). *EduWrap: Industry–Academia linkages in 21st century education*. FICCI. Retrieved from https://ficci.in/public/storage/SPDocument/23555/FICCI-Eduwrap-Jan-2022.pdf

7) National Skill Development Corporation (NSDC). (n.d.). *NSDC – Maharashtra's first skill development university*. Retrieved from https://sspu.ac.in/nsdc/

8) Esangbedo, P., & Kwarbai, J. (2024). The role of industry–academia collaboration in enhancing educational opportunities and outcomes under the digital-driven Industry 4.0. *Journal of Infrastructure, Policy and Development, 7*(3), 71–82.

9) AICTE. (2025). *AICTE fellowship guidelines and objectives*. Retrieved from https://risingkashmir.com/aicte-launches-industry-fellowship-programme-to-strengthen-industry-academia-collaboration/

10) UNESCO. (2023). *Mentorship programme details: Global Education Coalition*. Retrieved from https://www.unesco.org/en/articles/unescos-global-education-coalition-member-kpmg-launch-new-mentorship-programme-india

11) Symbiosis Skill and Professional University (SSPU). (n.d.). *National Skill Development Corporation (NSDC) – Maharashtra's first skill development university*. Retrieved from https://sspu.ac.in/nsdc/

Improving Teacher Effectiveness: A Guide to Professional Development

Devisri K[1], Seetharaman D[2]

[1]Research Supervisor, Assistant Professor, Department of Curriculum Planning & Evaluation Tamil Nadu Teachers Education University, Chennai – 600 097

[2]Ph.D. Research Scholar, Department of Curriculum Planning and Evaluation, Tamil Nadu Teachers Education University, Chennai – 600 097

Abstract:

Improving the Teaching Effectiveness and Professional Development of educators is largely dependent on Professional Development (PD). The importance, methods, difficulties, and suggestions related to professional growth in teacher education are examined in this paper. Drawing on recent research, such as studies by Algahtani et al. (2020) and Chen Yueqin & Lubna Ali Mohammed (2024), the analysis highlights the value of Continuous Professional Development (CPD) in enhancing instructors' performance and instructional strategies. Along with the difficulties that impede the effective implementation of Professional Development, a number of popular strategies are covered, including action research, peer mentoring, online learning, and collaborative learning communities. To find out how important Professional Development is for teachers, this paper draws on current research and literature to look at its effects, typical approaches, implementation difficulties, and useful suggestions. In light of the changing nature of education, this study ends with practical suggestions for improving professional development's sustainability, inclusivity, and impact.

Keywords: Professional Development, Teacher Education, Reflective Practice and Teacher Performance

Definition of Key terms

Professional Development: The process through which people learn and train to improve their professional career-related skills, knowledge, and abilities is known as professional Development. In order to enhance job performance and progress one’s career, it places a strong emphasis on on-going self-awareness, application, and reflection. This can include

both official educations, like as classes or certifications and informal learning, such as independent study, attending conferences, workshops and mentorship.

Teacher Education: The process of equipping future teachers with the fundamental information, pedagogical abilities, and training required to confidently and preparedly enter the classroom is known as teacher education. Its main goal is to provide aspiring educators with knowledge of the subject matter, educational theories, and effective teaching techniques. The foundation for successful teaching practices is laid by teacher education, which usually takes place prior to full-time teaching.

Reflective Practice: Reflective practice in education enables educators to evaluate and improve their techniques, gain a deeper understanding of student learning, and modify their strategies for better results. It allows teachers to make deliberate, well-informed adjustments to their methods and can take place both during (reflection-in-action) and after (reflection-on-action) teaching scenarios.

Teacher Performance: A teacher's effectiveness, actions, and behaviours throughout the teaching process are referred to as their "teacher performance," which reflects their social, professional, and personal development. It includes all of the teacher's skills in teaching, classroom management, student engagement, and learning and growth. The success of students and the general results of education are thought to be significantly influenced by the performance of teachers.

Introduction

Professional development in teacher education plays a pivotal role in enhancing the effectiveness and quality of teaching practices. As educational landscapes evolve with new curricular demands, pedagogical advancements, and technological integration, continuous professional growth becomes essential for educators to meet these changes effectively. Professional Development is not limited to formal courses or workshops but encompasses lifelong learning approaches such as reflective practice, peer mentoring, self-directed learning, and collaborative professional communities. These diverse strategies enable teachers to stay current with research-based instructional methods, improve their classroom management, deepen student engagement, and ultimately foster better learning outcomes.

Moreover, on-going Professional Development supports teacher motivation, reduces burnout, and promotes career advancement, making it foundational to fostering resilient and capable teaching professionals. Generally, key approaches, challenges, and the significance of Professional Development in teacher education, highlighting the need for sustained, inclusive, and contextually relevant initiatives that empower educators as lifelong learners and leaders in their fields.

Literature review

Chen Yueqin and Lubna Ali Mohammed., (2024) conducted a study on "Exploring the Impact of Teacher Professional Development on Teachers Performance: A Literature Review Study". The purpose of this analysis is to conduct a comprehensive literature review in order to get insight into how teachers' professional development affects their performance. The main Objective of the study is to assess the impact of Continuous Professional Development (CPD) programs on Teachers' instructional practices. The conclusions drawn from this research will also be useful in guiding future assessments of the topic, ensuring that the analysis takes the proper course. In this regard, this investigation has been able to demonstrate that Professional Development for educators is seen as a crucial component of their capacity to provide high-quality instruction as well as in their engagement.

Algahtani et al. (2020), measured the perception of faculty members in medical universities located in the Western region of Saudi Arabia, regarding their Professional Development practices and the factors that determine their achievement. Through consecutive sampling technique, 210 faculty members were selected, based on work experience & a cross-sectional survey was carried out using pre-designed self-administered questionnaire based on five-point Likert scale. The statistical techniques: frequency, mean & standard deviation were employed to find the results. The results revealed that the faculty members believed that motivation to improve teaching skills is the most significant goal of the Professional Development program. This study also indicated that the practices to establish an optimistic atmosphere for teaching and learning & factors in support of a trained and devoted staff determine the achievement of Professional Development.

Cyclical Process of Professional Development

Professional development is depicted in the graphic as an on-going, cyclical process made up of interrelated phases. It identifies six crucial stages that facilitate continuous development and enhancement of professional abilities:

Cyclical Process

Mentoring: Getting advice and assistance from more seasoned co-workers to improve learning.

Consultation: Getting input and counsel from professionals to guide one's career development.

Practice: Using newly acquired information and abilities in practical situations.

Study/Improve: Constantly gaining knowledge and honing skills through both official and informal study.

Reflection: Examining past experiences to pinpoint areas of strength and improvement.

Learning: Taking in new knowledge and abilities that enhance one's general professional competency.

This cycle highlights that professional growth is a continuous, iterative process in which every phase builds upon and informs the others, promoting knowledge and long-term progress.

Professional Development's Significance in Teacher Education

Professional development in teacher education is critically important because it equips educators with the latest knowledge, abilities and tactics to successfully satisfy the changing requirements of educational settings. It guarantees that teacher educators stay up to date on curricular modifications, new pedagogical developments, and technology integration. By empowering educators to use research-based practices, on-going professional development promotes reflective practice, increases instructional effectiveness, and eventually improves student outcomes. Additionally, it fosters collaboration within the teaching community, lessens burnout, and promotes career advancement and job satisfaction. Teacher educators set an example for lifelong learning by participating in professional development, which is crucial for developing future educators who are capable and flexible. It seeks to demonstrate how organized, thoughtful, and on-going professional development initiatives can enhance teaching quality and increase student learning outcomes through an examination of pertinent research and contemporary practices.

Common Approaches for professional development

The common strategies centre on making professional development pertinent, interesting, long-lasting, and closely linked to enhancing student outcomes and classroom practice.

Online learning: Professional development through online learning provides people with flexible, affordable, and easily accessible ways to improve their knowledge and abilities. It covers a wide range of courses, including leadership courses, industry-specific certifications, skill-based training, and soft skill development. Professionals may learn at their own pace and on their own time with these online courses, which makes juggling work and personal obligations easier.

Workshops and Seminars: In order to improve instructors' knowledge, abilities, and teaching methods, professional development workshops and seminars are organized learning events. These gatherings emphasize educational techniques as well as subject-specific content with the goal of enhancing student results and classroom efficacy. The HomiBhabha Centre for Science Education (HBCSE), Aditya Birla Education Academy, Auuro Educational Services, ITARI, and other professional education academies are a few examples of organizations that hold these kinds of courses. The goals of these workshops are capacity

building, on-going teacher development, and educational innovation adaptation.Micro-Credentialing: Focused, skill-based certificates, sometimes offered online, that attest to mastery of particular teaching modalities or regions.

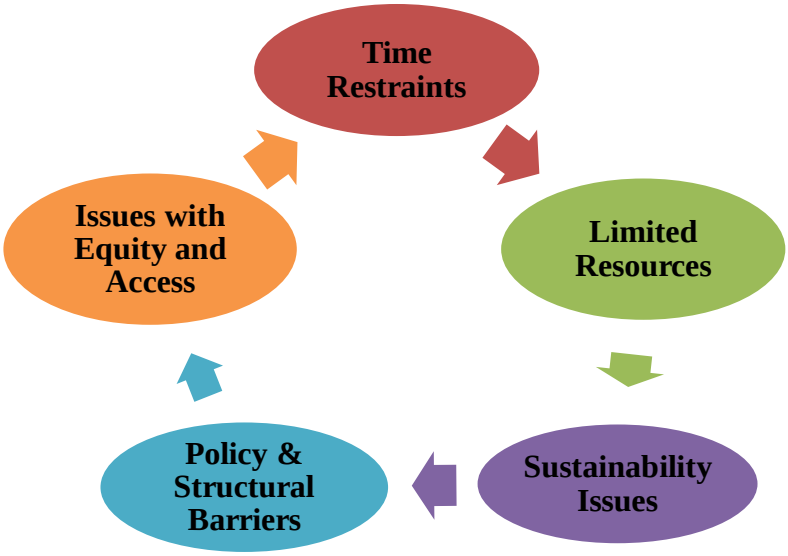
Observation and Feedback: In teacher education, observation and feedback are crucial tools for professional development that emphasize enhancing instructional strategies via methodical assessment and helpful dialogue. Observation entails methodically observing a teacher's methods of instruction, classroom management, and student participation. By examining teaching strategies, lesson planning, technology use, and student interaction, it assists in identifying areas of strength and growth. In addition to using checklists and rubrics, effective observation may involve peer observation as a cooperative model that promotes colleagues' professional development.

Self-Directed Development: In the context of teacher professional development, self-directed development is a process in which educators take charge of their own education and development. This method gives teachers the freedom to analyse their own needs, create meaningful goals, find and choose relevant learning materials, and track their own progress. Effective self-directed learning necessitates that educators "desire to learn, know how to learn, love learning, and persist in learning," with the help of institutional frameworks such as collaborative communities and mentorship that offer direction while encouraging self-reliance.

Challenges in implementing professional development

The challenges must be addressed through strategic planning, enough funding, policy support, opportunities for individualized and continuous professional development, and the

creation of a school culture that promotes and supports continuous teacher development.



Time Restraints: Time restrictions are one of the main barriers to teacher education professional development. Teachers usually have busy schedules that provide little time for extracurricular activities because of lesson planning, grading, instructional hours, and administrative duties. Due to their overwhelming workload, teachers find it difficult to set aside specific time throughout the school day for professional development.

Limited Resources: One of the biggest obstacles to establishing professional development for teacher education is a lack of resources. These limitations frequently consist of a lack of funds, restricted access to high-quality training resources, subpar facilities, and a scarcity of certified instructors or facilitators. Budget constraints make it difficult to plan extensive and continuous training programs, acquire modern technology, and offer continuing assistance like coaching and mentoring.

Sustainability Issues: Addressing sustainability in professional development requires a shift from one-time events to on-going, systemic professional learning that prioritizes collaboration, active participation, and exposure to real-world sustainability issues. It is crucial for teacher educators to provide an example of these behaviours and foster an environment that supports transformative education for sustainable development. Ultimately,

this approach equips teachers with the resources they need to assist students in developing into informed and accountable global citizens.

Policy and Structural Barriers: Professional development in teacher education is greatly impacted by policy and institutional hurdles, which erect structural impediments that restrict the efficacy and accessibility of training initiatives. Disjointed or poorly managed PD initiatives can be caused by inadequate policies, poor coordination, and a lack of systemic support.

Issues with Equity and Access: To promote equality in professional development, deliberate policies that remove institutional barriers, offer inclusive and accessible programs, allocate resources equitably, and take into account a variety of teacher needs are required. Creating inclusive professional networks can help teachers feel more competent and like themselves, and online learning and flexible scheduling are two tactics that can increase access.

Recommendations for Effective Professional Development

- Establish on-going, contextualized, cooperative professional growth.
- Schedule professional development activities for students on the school calendar.
- Make that professional development is in line with student learning outcomes and instructional goals.
- When creating PD agendas, take into account the opinions and preferences of teachers.
- Make use of technology to increase accessibility and customize education.
- Provide mechanisms for follow-up assistance, mentoring, and feedback.

Conclusion

In conclusion, professional development in teacher education is a fundamental component in maintaining and advancing the quality of teaching and learning within schools. Effective professional development equips educators with the latest knowledge, pedagogical skills, and reflective capabilities necessary to adapt to changing educational demands and diverse student needs. Despite its importance, the implementation of professional development faces challenges including time constraints, limited resources,

policy and structural barriers, sustainability issues, and inequities in access. Addressing these challenges requires strategic planning, adequate funding, supportive policies, and the creation of collaborative and technology-enabled learning environments. By centering professional development on continuous, relevant, and teacher-driven learning experiences, education systems can foster empowered educators who are better prepared to enhance student outcomes and contribute meaningfully to the evolving global education landscape.

Ultimately, investing in comprehensive and equitable professional development is critical to sustaining teacher effectiveness, advancing educational innovation, and shaping a future-ready teaching workforce. Hence, Professional Development is a remarkably accurate tool for improving school's education. Continuous learning is essential for an individual career advancement and organizational success. So, improving teacher effectiveness is very valuable to today's education system because it directly affects student learning outcomes, creates a happy classroom environment, and sets students up for success in the future.Funding continuous teacher development and support is therefore essential to building a strong and equitable educational system.

References:

1) ChenYueqin and Lubna Ali Mohammed., (2024).Exploring the Impact of Teacher Professional Development on Teachers Performance: A Literature Review Study. International Journal of Religion, 5(11): 5034-5042.
2) *Challenges and Opportunities in teacher training and Professional Development in Cameroon: A Comprehensive analysis - International Journal of Research and Innovation in Social Science*. (2024, October 2). International Journal of Research and Innovation in Social Science.
3) Darling-Hammond, L., Hyler, M. E., & Gardner, M. (2017).*Effective Teacher Professional Development*. Learning Policy Institute.
4) Erawan, P., &Erawan, W. (2024). Effective Approaches to teacher Professional Development in Thailand: case study. *Journal of Education and Learning*, *13*(2), 64.https://doi.org/10.5539/jel.v13n2p64
5) Hasan, H. (2025). Exploring the role of teacher educators in Promoting sustainable development goals through Environmental Education: Perspectives and

Practices.*International Journal of Environmental Sciences*, 60–76. https://doi.org/10.64252/gj35rm59

6) Professional development of teachers for teacher effectiveness.(n.d.).*Swadeshi Research Foundation*, *7–4*(2394–3580), 87–92. https://www.researchgate.net/publication/344835879_Professional_Development_of_Teachers_for_Teacher_Effectiveness
7) *Teacher Education and Professional Development — HomiBhabha Centre for Science Education, TIFR*.(n.d.).https://www3.hbcse.tifr.res.in/research-development/teacher-education

Integrating Professional Practices in Teacher Education with E-Content Effectiveness: Enhancing English Grammar Learning among High School Students in the Nilgiris District

BabyShalini V[1], Senthilkumaran M[2]

[1]Ph.D Research Scholar, Dept. of Educational Technology,
Tamil Nadu Teachers Education University

[2]Assistant Professor, Dept. of Educational Technology,
Tamil Nadu Teachers Education University

Abstract:

Teacher education plays a vital role in shaping effective classroom practices. In the digital era, professional practices in teacher education must be aligned with technology-enabled learning strategies. This chapter explores the integration of professional practices in teacher education with the effectiveness of e-content in learning English grammar among high school students in the Nilgiris District. The study examines how e-content can strengthen language acquisition while fostering reflective teaching practices. Drawing from theoretical frameworks and empirical studies, the chapter identifies the need, methodology, findings, and implications of combining teacher education with technology-driven pedagogy. The results highlight that professionally trained teachers, when empowered with e-content, can significantly enhance grammar proficiency among learners.

Keywords: *Professional Practices, Teacher Education, E-Content Effectiveness, English Grammar Learning, High School Students*

Introduction

Teacher education has traditionally emphasized professional practices such as lesson planning, reflective teaching, classroom management, and learner-centered pedagogy. With the rapid digital transformation in education, teachers are increasingly expected to integrate

technology into their instructional practices. English grammar, often perceived as challenging by high school students, requires innovative strategies for effective learning.In the Nilgiris District, where students come from diverse linguistic backgrounds, teaching English grammar through conventional methods often results in rote learning. To address this gap, e-content serves as an interactive and engaging medium. By integrating professional practices of teacher education with e-content, this study investigates how future teachers can adopt digital pedagogies to enhance English grammar learning outcomes.

Major Objectives

- To analyze the role of professional practices in teacher education for effective English grammar teaching.
- To assess the effectiveness of e-content in improving grammar learning among high school students in the Nilgiris District.
- To explore how integration of teacher education practices with e-content enhances student engagement and achievement.
- To provide recommendations for teacher educators and policymakers to strengthen technology-driven teacher training.

Review of Related Literature

Khojasteh, L. (2022)investigated on"E-*content development of English language courses: quality evaluation in an Iranian university"*. He revealed thatthe quality criteria and evaluation methods for e-content development in English courses useful for designing/assessing grammar E-content.

Lin, H. (2022) investigated on "*The Influence Mechanism of High School English Grammar Teaching Effectiveness"*. He investigated factors influencing grammar teaching effectiveness and offers a model that can be adapted when measuring e-content impact.

Bhattacharya, S. (2023) investigated on"*Assessment of qualities of pandemic-driven e-content for higher education students in India"*.He focused anempirical assessment of the quality of e-contents produced during COVID helps identify quality dimensions (clarity, interactivity, alignment) relevant to grammar e-content.

Kalita, S. (2025)investigated on "*Perception and Acceptance for e-content: A Study on High School Teachers"*.Heexplored teacher perceptions/acceptance of e-content in Indian schools directly relevant to integrating e-content into teacher professional practice.

(Author/Team) (2024) investigated on "*Understanding Student Needs for Effective Online English Grammar Learning: A Quantitative Descriptive Study"*.Heidentified the learner needs and barriers in online grammar classes useful for aligning e-content design with student requirements.

Parveen, S. et al. (2024)investigated on "*Impact of ICT Usage on Learning English Language"*.They did an empirical study on ICT integration and English learning outcomes offers instruments and measures you could adapt.

(PMC article) (2022)investigated on "*Effectiveness of digital education shifting (DES) model on high school students' learning"***.**Tested a digital learning model and reports on engagement and performance outcomes useful design comparison for e-content interventions.

Shravani, K. (2024) investigated on "***Revitalizing English Language Teaching in India: Integrating Role-Play and Technology for Enhanced Communicative Skills".***She discussed blended tech + pedagogy approaches for English teaching in India good for teacher-practice integration ideas.

Methodology

This study follows a descriptive and experimental research design.

- **Population and Sample**: High school students from government aided school in the Nilgiris District. A purposive sample of 120 students (60 experimental, 60 control) and 20 teacher trainees was selected.
- **Tools**: Researcher-developed e-content modules on English grammar (Tenses- Present, Past, Future). Pre-test and post-test were used to measure student achievement. A structured questionnaire was used for teacher trainees.
- **Procedure**: The experimental group received instruction using e-content integrated with teacher education practices such as lesson planning, reflective teaching, and collaborative activities. The control group received conventional grammar teaching.
- **Analysis**: Data were analyzed using mean, standard deviation, t-test, and thematic analysis for qualitative responses.

Need and Significance of the Study

- **Bridging gaps**: Traditional grammar teaching methods often fail to develop application skills; e-content addresses this limitation.
- **Professional empowerment**: Teacher trainees gain skills in integrating digital pedagogy with professional practices.
- **Rural relevance**: In the Nilgiris District, diverse student backgrounds require adaptive teaching methods.
- **Policy perspective**: Supports the National Education Policy (NEP 2020) emphasis on digital learning integration.

Statement of the Problem

Despite ongoing reforms in teacher education, there is limited emphasis on integrating professional practices with digital resources. High school students in the Nilgiris District face persistent challenges in mastering English grammar due to reliance on traditional teaching methods. Therefore, this study seeks to examine the effectiveness of e-content when integrated with professional practices in teacher education for enhancing grammar learning outcomes.

Operational Definitions

- **Professional Practices in Teacher Education**: In this study,Professional Practices in Teacher Educationrefers to the activities such as lesson planning, classroom management, reflective teaching, and evaluation undertaken by teacher trainees during their training.
- **E-Content**:In this study,E-Content refers to the digital designed instructional materials, including multimedia, animations, and interactive exercises, aimed at teaching English grammar.
- **Effectiveness**: In this study, Effectivenessrefers to thedegree to which e-content integration improves grammar proficiency, learner motivation, and teaching practices.
- **English Grammar learning:**In this study, *English Grammar Learning* refers to the acquisition and application of grammatical rules, structures, and usage in the English language by high school students. It is measured through their performance in grammar-based exercises, tests, assignments, and their ability to apply grammatical knowledge in writing and communication tasks.

- **High School Students:** In this study denote learners enrolled in standards IX and X (classes 9 and 10) of government, aided, and private schools in the Nilgiris District, Tamil Nadu. They fall within the age group of approximately 14 to 16 years.
- **Nilgiris District**: In this study, *Nilgiris District* refers to the geographical region in Tamil Nadu, India, where the study is conducted. For research purposes, it specifically includes the high schools functioning within the educational jurisdiction of the Nilgiris District.

Major Findings

- The experimental group showed significantly higher improvement in grammar scores compared to the control group.
- Teacher trainees reported increased confidence in using e-content alongside professional practices.
- Students demonstrated greater motivation, participation, and reduced grammatical errors.
- E-content proved particularly effective in teaching tenses, sentence transformation, and error correction.

Discussion

The findings align with earlier studies **Khojasteh, L. (2022),Lin, H. (2022),Bhattacharya, S. (2023)**,**Kalita, S. (2025),Parveen, S. et al. (2024),(PMC article) (2022),Shravani, K. (2024)** confirming that e-content positively influences grammar acquisition. What distinguishes this study is the integration of teacher education practices with digital pedagogy. The results suggest that teacher trainees not only gained technical competence but also applied reflective teaching practices more effectively. This integration supports the NEP 2020 emphasis on technology-enabled and learner-centered education. The success of the intervention indicates that similar strategies could be scaled across other districts and subjects.

Educational Implementation

- **Teacher Training Curriculum**: Incorporate mandatory modules on e-content development and usage.
- **School-Level Integration**: Provide infrastructure and resources for e-content delivery.

- **Collaborative Learning**: Encourage teacher trainees to co-create e-content in peer groups.
- **Assessment Practices**: Combine digital assessments with traditional evaluations for holistic outcomes.

Recommendations

- Teacher education institutions should integrate ICT pedagogy training into all professional practice components.
- State education boards should provide localized e-content in line with learners' contexts.
- Regular workshops on e-content creation and usage must be conducted for both in-service and pre-service teachers.
- Future research should explore the long-term impact of e-content integration on language proficiency and teacher effectiveness.

Conclusion

This study concludes that integrating professional practices in teacher education with e-content significantly enhances English grammar learning among high school students in the Nilgiris District. Teacher trainees become more effective facilitators when professional practices are supported with technology. The findings highlight the importance of preparing future teachers for digital pedagogy and ensuring that grammar teaching moves beyond memorization to meaningful application.

References:

1) Khojasteh, L. (2022). E-content development of English language courses: Quality evaluation in an Iranian university. *Journal of Language and Education Research, 8*(2), 45–57.
2) Lin, H. (2022). The influence mechanism of high school English grammar teaching effectiveness. *International Journal of English Language Teaching, 10*(4), 112–128.
3) Bhattacharya, S. (2023). Assessment of qualities of pandemic-driven e-content for higher education students in India. *Asian Journal of Education and E-Learning, 11*(1), 56–68.

4) Kalita, S. (2025). Perception and acceptance for e-content: A study on high school teachers. *Indian Journal of Educational Technology, 13*(2), 101–115.
5) [Author/Team]. (2024). Understanding student needs for effective online English grammar learning: A quantitative descriptive study. *Journal of Online Learning Research, 9*(3), 76–90.
6) Parveen, S., Kumar, R., & Ali, M. (2024). Impact of ICT usage on learning English language. *Journal of Educational Technology Studies, 12*(2), 22–34.
7) [PMC Article]. (2022). Effectiveness of digital education shifting (DES) model on high school students' learning. *Journal of Digital Education and Learning, 6*(1), 88–99.
8) Shravani, K. (2024). Revitalizing English language teaching in India: Integrating role-play and technology for enhanced communicative skills. *Indian Journal of English Language Pedagogy, 15*(2), 145–158.

Innovative Teaching for Workforce Readiness: The Role of Teacher Professional Development and Transformational Leadership in Student Development

Sivaselwam Arulnesan
PhD Scholar, School of Education
Christ University, Bengaluru, India
sivaselwam.arulnesan@res.christuniversity.in

Abstract:

The world of the twenty-first-century workforce of changing needs is becoming more prominent in demanding TVET institutions for producing adaptable graduates who are innovative and talented. Teaching in this situation is seen not simply as the giving of knowledge but also as a form of transformational leadership affecting student growth through creative teaching approaches. This paper aims to conceptualize the interlinkages of teacher professional development, transformational leadership, and innovative teaching as key channels toward increased student workforce readiness. The objectives are threefold: (i) to investigate how professional development prepares teachers for skills needed in innovative teaching, (ii) to examine the role of transformational leadership in teachers' development and student engagement, and (iii) to build a conceptual framework linking all these facets to student development outcomes. Being a theoretical study, a conceptual framework is constructed by integrating existing literature, leadership theories, and pedagogical models. Even though the findings are conceptual, they show that continuous development of teachers, sustained by transformational leadership, gives rise to innovative teaching strategies capable of directly developing the adaptability, employability, and all-around development of students. The paper contributes to the TVET discourse by providing a theoretical framework on which future empirical testing, policy design, and organizational strategy may be informed so that students may be prepared for a highly complicated and dynamic world of work.

Keywords: Teacher Professional Development, Transformational Leadership, Innovative Teaching, Student Development, Workforce Readiness

I. Introduction

This era is characterized by rapid technological change, shifting labor market demands, and increasing complexity of global economies. Now, in this everchanging world, TVET has become an alternative for providing students with knowledge, skills, and attitudes for survival in the world of work(UNESCO). Traditional education systems mostly consider academic knowledge, while TVET focuses on practical skills, applied competencies, and employability attributes that help learners make the transition into different sector occupations(Okolie et al.). One of the biggest challenges the TVET program has faced traditionally is to keep its pedagogy and institutional setup relevant and innovative so as to respond to changes in rivalry and needs of the workforce(Varma and Malik).

Teachers are central actors in this process. Teachers do not merely deliver curricula: they frame learning environments, embody professional behavior, and mentor students for their complete development. As the scholars argue, the professional development of teachers is directly linked to student learning outcomes, particularly in practice-oriented fields such as TVET(Villegas-Reimers). Continuous professional development gives teachers new pedagogical strategies, content knowledge, and the ability to try different teaching approaches with the intention of fostering students' adaptability and creativity(Leithwood and Jantzi). However, professional development may find it difficult to unleash the transformational power of a teacher unless it is paired with an effective leadership practice that motivates possibilities for change and innovation(Khan Alias Khalid Malokani et al.).

Regarding this, transformational leadership has received genuine attention in educational research. Transformational leaders are able to draw a compelling vision, collaborate with others, and empower colleagues and students beyond expectations(Bass and Riggio). Within the context of TVET, transformational leadership influences institutional culture and motivates teachers to adopt; in other words, implement innovative pedagogies targeted for diverse student needs and labor market expectations(Leithwood and Jantzi). Linking teacher professional development with transformational leadership would create an opportunity for establishing programs that would offer an environment that nurtures, supports, and sustains innovation as a core element of teaching and learning(Saif et al.).

The importance of this relationship appears clearer when it is juxtaposed with student development and workforce readiness issues. Modern employers are looking increasingly for graduates who would not only have technical knowledge, but also have critical thinking,

problem-solving, and interpersonal skills (Schleicher Andreas). These attributes may be nurtured through innovative teaching methods such as project-based learning, technology-enhanced teaching, and problem-solving through collaborative effort(Guven). Hence, to move forward with TVET's mandate of equipping students for the challenges awaiting them in the future, it is essential to understand the dynamics involved between teacher professional development and transformational leadership in relation to innovative teaching(Philogene et al.).

This paper intends to describe the interrelated roles of teacher professional development, transformational leadership, and innovative teaching in nurturing student development and workforce readiness. In particular, it aims to: (i) discuss how professional development prepares teachers to engage in innovative pedagogy; (ii) examine the ways transformational leadership nurtures environments conducive to professional development and innovation; and (iii) suggest a conceptual framework connecting these processes to student development outcomes. Theoretically, the study takes on a conceptual/theoretical approach whereby insight from leadership theory, professional development models, and pedagogical innovation literatures are synthesized to offer new theoretical perspectives. Hence, the paper should contribute to both scholarly and policy dialogues regarding how TVET systems could better strengthen their present role in preparing an adaptable, skilled, and innovative workforce for the twenty-first century.

II. Literature Review and Theoretical Foundations

Teacher Professional Development in TVET

Research in professional teacher development in TVET focuses on some central effectiveness issues. Developing aspiring teachers' capabilities, notably through professional and skill development, is strongly related to teaching quality, with self-efficacy and professional skills relating strongly to teaching delivery and personal capability(Shodipe and Ogbuanya).Technology integration forms the core concern, wherein professional development workshops foster TVET teachers' beliefs about technology-enriched instruction, with perceived usefulness and ease of use as determinants of teachers' intentions to use the technology (Salleh). Effective professional development provides for reflection and engagement in professional communities of practice and specific approaches to address individual VET teacher needs, supporting the transfer to practice through a learning experience and transformative leadership (Siliņa-Jasjukeviča et al.). When appropriately

designed, professional development programs for Industry 4.0 and STEM competencies improve teachers' knowledge, perceptions, and competencies and establish collaborative school cultures with positive attitudes for TVET (Akgunduz and Mesutoglu).

Teacher professional development (CPD) is generally held to be a pivotal lever in systemic improvement of education(Darling-hammond et al.). In the domain of TVET, CPD holds a distinct meaning because of the field asserting that each teacher must keep abreast with new industrial practices, new technologies, and changing occupational standards(Okolie et al.). TVET teacher CPD should not be a one-off workshop; instead, it should be a continuous, collaborative effort occurring within the school itself that provides ample opportunities for deep reflection and actual application of newly acquired skills. In terms of the actual skills being developed, the programs should really concentrate on instructional competencies related to practical instruction, curriculum contextualization, and industry-relevant technologies(Herlinawati et al.).

The literature asserts that high-quality CPD is a condition for teachers to shift from the traditional model of knowledge transmission to innovative approaches based on student-centered learning(Villegas-Reimers).Yet, if little or no systematic investment goes into teacher development, TVET institutes run the risk of falling back on curricula and teaching methods that converge with the needs of the old labor market and do not equip the worker with the adaptive and critical-thinking skills of the present-day working world(Prakasha et al.). Thus, the motor for TVET teacher development with emphasis on the continuous acquisition of pedagogical agility, the ability to innovate, adapt, and respond to changes in student needs and industry(Ghosh and Ravichandran).

Transformational Leadership in Education

Bass and Riggio were the ones who introduced the theory behind transformational leadership in 1986. It focuses on four stages: idealized influence, inspirational motivation, intellectual stimulation, and individualized consideration(Bass and Riggio). A transactional leader offers rewards or punishments for good or bad behavior, whereas a transformational leader inspires his or her followers to go beyond their self-interests for the good of the organization, builds an environment of trust, and stimulates curiosity (Leithwood and Jantzi).

Transformational leaders in higher education serve as forerunners of change and innovation so that, under their aegis, new technologies such as artificial intelligence, virtual reality, and data analytics can be embraced (Bohari et al.). Such leaders possess magnetic visions,

emotional intelligence, and a commitment to their own professional development while engaging diverse cultures and employing the new technology to create inclusive learning environments affecting student engagement and systemic unfairness (Assefa and Mujtaba). A phenomenological approach to research on the transformation leaders in the human administration field has uncovered the "lived experiences," which further provide clues and insights into the profile and efficacy of such transformation leaders(Sathiyaseelan). It has been proposed that creative transformation leadership, which incorporates transformation and creative leadership, shall be the answer for higher education institutions wrestling in fast-changing globalized environments to deal with current contextual constraints and potentials (Smith and Vass).

This leadership style has primary and direct importance for creating organizational learning and the culture of innovation within TVET institutions, where a transformational leader sets ground rules for teachers to freely try out new technologies and methodologies without fear of failure(Dianawati et al.). It is said that when principals or heads of academic departments are transformational leaders, teachers feel more efficacious professionally, they are more committed, and more willing to embrace innovations in their teaching (Bass and Riggio). The significance of this leadership style is, however, in the leadership itself that ensures that knowledge acquired during professional development activities will be transferred and applied in class, thus closing the gap between training and application.

Innovative Teaching in TVET

Innovative teaching in TVET is defined as the intentional application of innovative pedagogical alternatives to those conventional ones with an objective to engage the students in their learning and in the development of high-order skills for employment(Jonathan). These include, but are not limited to, Project-Based Learning (PBL), instruction supported with technology (e.g. virtual reality for skill practice), competency-based training, and integrated curricula blending theory with simulated work experiences (Guven).

These innovations intend to give higher-order tasks to students that include complex problem-solving, collaborating, and critical thinking, instead of having them memorize procedures. For TVET to meet its objective of becoming a skilled and adaptive workforce, the teaching should be at par with the complexity and collaborative nature of a real-world workplace(Varma and Malik). There is always empirical evidence in literature that suggests that conventional, passive methods of teaching cannot supply the workers with the agility and

resilience needed for career success in the twenty-first century (Schleicher Andreas). Thus, it shows that innovation is not just a luxury but a necessity to ensure the relevance of TVET.

As per (Wulansari et al.), there was an added gain in problem-solving skills and learning outcomes imparted to TVET students when Computer Assisted Instruction (Computer Assisted Instruction) was combined with case method-flipped classroom methods compared to conventional methods. Promoting a similar line of argument,(Zhang et al.) identified that these innovative pedagogies stood more efficacious than conventional pedagogy in enhancing computer craft practices among technical college students. (Hassan et al.), through a systematic literature review, identified a considerable gap in ICT integration across the TVET system, commenting on the areas where technology adoption was in a particularly low state, namely monitoring, evaluation, career guidance, and teacher training(Inderanata and Sukardi). They all strongly stressed the need to pay greater attention to emerging technologies such as IoT, robotics, and artificial intelligence. Furthermore, according to (Tee et al.), developing teachers' inventive problem-solving skills is crucial, as the results of their study indicated that although Design and Technology teachers recognize the importance of creative thinking styles, many still have difficulty identifying problems and could benefit from shadowing specialized modules relating to integrating these approaches within their teaching practice.

Student Development and Workforce Readiness

Student development and workforce readiness emphasize multiple strategies that prepare learners for professional careers. At the secondary level, the 4-H Summer of STEM acts as a gateway to demonstrate how a hands-on approach, mentoring, and industry connection synergize to foster career readiness and STEM interest(Ellison and Harder). Regarding tertiary education, experiential learning programs that embed self-reflection and portfolio-building create effective bridges between academic knowledge and employability. They enhance students' capacity to communicate what they can do (Shore and Dinning). A survey conducted among health profession students shows that students feel mostly prepared for patient-centered competencies and less so for system-related competencies, where clinical placements and peer support come in and act as major enablers of confidence(Malau-Aduli et al.). Similarly, evidence from Indonesia shows that internships and soft skills programs, in particular under the MBKM program, largely assist in bridging the gap between graduate competencies and labor market demands(Nugroho et al.).

Some might say that student development in TVET is a truly multi-dimensional concept. It subsists in the realm of acquiring hard skills like occupation-specific competencies, on the one hand; and the demand for soft skills like communication, teamwork, and critical thinking on the other(Varma and Malik). The ultimate expression of successful student development is workforce readiness that is measured by the graduate's ability to find employment and stay in it; find new roles; and, contribute positively to organizational productivity(UNESCO).

One side of literature argues that a holistic face of readiness is most likely to be influenced largely by what goes out in the classroom. If teachers apply innovative, student-centered pedagogies supported by professional development and transformational leadership, then students stand to develop adaptive expertise desired by industry (Schleicher Andreas). For instance, under a PBL regime, the students are required to manage projects, work in teams, and solve ill-structured problems, all of which are direct representations of real-life workplace demands. Hence, investing in teacher PD and leadership is indirectly but potently investing in enhancing employability capital of the student(European Union).

Theoretical Framework: Justification for Conceptual Integration

The existing literature often treats teacher professional development initiatives (PD), transformational leadership, pedagogical innovations, and student outcomes as separate variables, usually investigating the bivariate relationship between any two of them, rather than their combined synergistic effects (Leithwood and Jantzi)Therefore, there is a significant conceptual gap when it comes to looking at an integrated appreciation of the systemic channel available for TVET outcome optimization(Okolie et al.). Namely, the literature is missing a firm explanation on how transformational leadership acts as the key enabling or mediatory force by which investments in PD translate into sustained, high-fidelity innovative teaching practices crucial for realizing desired student development and workforce readiness(Guven).

This study, therefore, takes on a conceptual/theoretical approach in advocating for the redesign of the framework addressing previously known deficits. The methodology employed is one of synthesizing the core premises of Transformational Leadership Theory(Bass and Riggio)with evidence-based models of Effective Teacher Professional Development(Darling-hammond et al.).This kind of conceptual synthesis seeks to go beyond simply stating correlations to propose a coherent theoretical mechanism, which explains how a supportive and inspiring institutional culture fostered through transformational leadership becomes

conducive to the application of new competencies learned through PD in effective ways that create quality learning environments through innovation in teaching (Leithwood and Jantzi). Ultimately, this mechanism is theorized to produce enhanced student growth and Workforce Readiness results that better position TVET education to tackle increasingly complex labor market demands (UNESCO). The following section undertakes the elaboration of this proposed framework while providing analytical discussions of the causal and reciprocal relations existing among its major components.

III. Research Design

This study implements a conceptual research design suitable for working with theoretical relationships instead of handling empirical findings. Conceptual research integrates and interprets previous works to create new frameworks and perspectives (Jaakkola). By combining information from leadership theory, professional development models, and student development and workforce readiness literature, this paper puts forth a theoretical framework that believes in the contributory role of teacher professional development and transformational leadership in innovative teaching and student outcomes within TVET.

The methodology composed a critical literature review, interspersed with concept analyses covering four key areas: (i) teacher professional development, (ii) transformational leadership within education, (iii) innovative pedagogical practices that foster student engagement, and (iv) student development frameworks concerning employability. Sources consisted of articles from peer-reviewed journals, books, and policy reports, which either concern TVET or contribute to core theory and present-day discussions on the subject. The review is integrative, meant to analyze and integrate concepts from across disciplines, rather than simply reviewing past research (Snyder).

A theoretical view imparted structure to the synthesis. Transformational leadership theory (Bass and Riggio) offers a perspective on how leadership practices can stimulate innovation and collaboration. Models of professional development (Guskey) gave insight into how teachers develop and sustain new teaching skills (Darling-Hammond et al.). The literature on student employability and global workforce skills (Schleicher Andreas; UNESCO) provided the foundation for analyzing what is of most significant relevance to TVET.

The three-step analytical procedure proceeded as follows: mapping recurring themes that appear in the literature; synthesizing the connections that exist between professional development, leadership, and innovative pedagogy; and finally developing a conceptual

framework that combines these three components. This framework promotes the growth of any professional development package whose implementation of cutting-edge teaching practice is mediated by transformational leadership. It thus contributes to student development and workforce readiness. The product of this methodology is not an empirical data set but a theoretically informed model that not only extends the scholarly discourse but also has practical implications for TVET institutions and policymakers. This conceptual design lays the groundwork for future empirical investigation and helps develop approaches to student preparation for success in dynamic labor markets.

IV. CONCEPTUAL FRAMEWORK AND ANALYTICAL DISCUSSION

The Proposed Conceptual Model is presented in this section as the main theoretical contribution of this paper. It presents an integrated framework that interlinks Teacher Professional Development, Transformational Leadership, and Innovative Teaching toward improving Student Development and Workforce Readiness in TVET. An analytical discussion will then closely theorize the pathways and linkages amongst these constructs, giving the required scholarly underpinning for a conceptual discussion (Bass and Riggio; Darling-hammond et al.). The central thesis is that TL is a significant factor that, with sustainability, converts the skills acquired in PD into IT in actual teaching practices. We elaborate further on how PD develops innovation capacities and TL creates the culture and motivation for it. Hence, IT is the immediate channel through which upgraded teaching skills translate into hard and soft skills essential for preparing students to meet the pressing challenges of a dynamic world of work. This discourse thus anchors further relevance on the model for research and policy design.

Teacher Professional Development and Innovative Teaching

Transitioning toward innovative teaching cannot occur spontaneously; rather, it is a resultof sustained, relevant professional development (Villegas-Reimers). The core argument here is that PD builds capacity for innovation in certain ways:

Skill Acquisition and Specialization: TVET PD would thus prepare the teacher not only in general pedagogy but also in specialized skills, such as technology-enhanced instruction, curriculum integration with industry needs, and the facilitation of complex problem- or inquiry-based learning (Okolie et al.). Without training in Project-Based Learning and competency-based assessment, teachers will plainly not have the technical skills to handle such methodologies.

Cognitive Shift and Teachers' Efficacy: Collaborative, particularly reflective, PD challenges what teachers believe about teaching and learning processes. Such experiences enhance pedagogical efficacy: the teachers' belief in their ability to influence student learning(Leithwood and Jantzi). This efficacy may be considered psychologically necessary for them to attempt teaching strategies that may be quite risky or unfamiliar.

Alignment with Content Knowledge: PD is a process that keeps teachers abreast of the rapid evolution undergone in industry in terms of technical content knowledge. The clear alignment is critical because innovative teaching in TVET requires that teachers function as authentic industry consultants, which is impossible for an outdated teacher.

PD is, therefore, the initiator for innovations; it forms the foundation of knowledge and confidence needed by teachers to willingly adopt and adapt new pedagogical practices for the workforce-ready student.

Transformational Leadership, A Catalytic Force

While PD gives the capacity for innovation, Transformational Leadership gives the enabling context and motivation; it is the crucial catalyst that ensures the sustenance of the practice in PD investment. This type of leadership facilitates innovation through a critical mediating role:

Creating a Climate for Intellectual Stimulation: Transformational leaders encourage teachers to question existing practices, try out new methods, and take intellectual risks (Bass and Riggio). The importance of this encouragement lies in the fact that innovative teaching involves the fear of failure, especially in high-stakes TVET situations.

Providing Individualized Consideration and Support: By recognizing individual needs of teachers and providing resources accordingly, transformational leaders relieve some of the stress related to change. Psychological safety is vital for teachers to maintain difficult and novel practices such as industry simulations or large-scale practicum projects (Guven).

Providing Inspirational Motivation for the Vision: Leaders articulate a compelling vision of the TVET institution as a center of excellence for industry practice and student-oriented development. Such inspirational motivation gives a common larger goal of preparing adaptable graduates to the often-isolated efforts of PD, hence galvanizing the teachers in commitment and ownership of innovative end goals(Leithwood and Jantzi).

Thus, transformational leadership acts as a mediator in the PD-Innovation relationship by transforming capacity into practice. Without the intervention of such leadership style, gains through PD will remain theoretical, lacking the organizational support that innovation requires to actually thrive in a classroom setting.

Impact on Student Development

The paramount intention of combining leadership, PD, and innovation is to have measurable enhancements in Student Development and Work Readiness. Innovative teaching represents the concrete means whereby increased teaching capacity translates into better student outcomes.

The problem with passive lecture-based teaching is that rather than foster outcomes required by the world of work today, an active, innovative pedagogical heart innovates at: (Schleicher Andreas).

Employability (Hard and Soft Skills): Instructors utilizing innovative methods such as competency-based approaches and experiential curricula (Inderanata and Sukardi) provide students with opportunities to practice and demonstrate technical (hard) skills as well as the much-needed soft skills (e.g., communication, teamwork) within simulated or real-world settings.

Adaptability and Resilience: Project- and inquiry-based teaching immerse students into situations that are ambiguous and require them to work on novel problems to develop adaptive expertise demanded by employers. They nurture resilience and generalized transfer capacity.

Critical Thinking and Problem-Solving: Innovative teaching put the student in the midst of a problem and thus shapes a more autonomous student in formulating solutions rather than presenting algorithms for prescriptive solutions. Inherently, this nurtures the higher-order critical-thinking and complex-job-related problem-solving aptitudes that one must acquire to tackle a career (Ellison and Harder).

With strengthening engagement-driven learning environments, innovative teaching thus PMTs an all-encompassing readiness of the student for a dynamic workplace, which hence fulfils the core mission of TVET itself (UNESCO).

Proposed Conceptual Model

The previous discussion is summarized in an integrating framework model depicting the theoretical relationship within the TVET context.

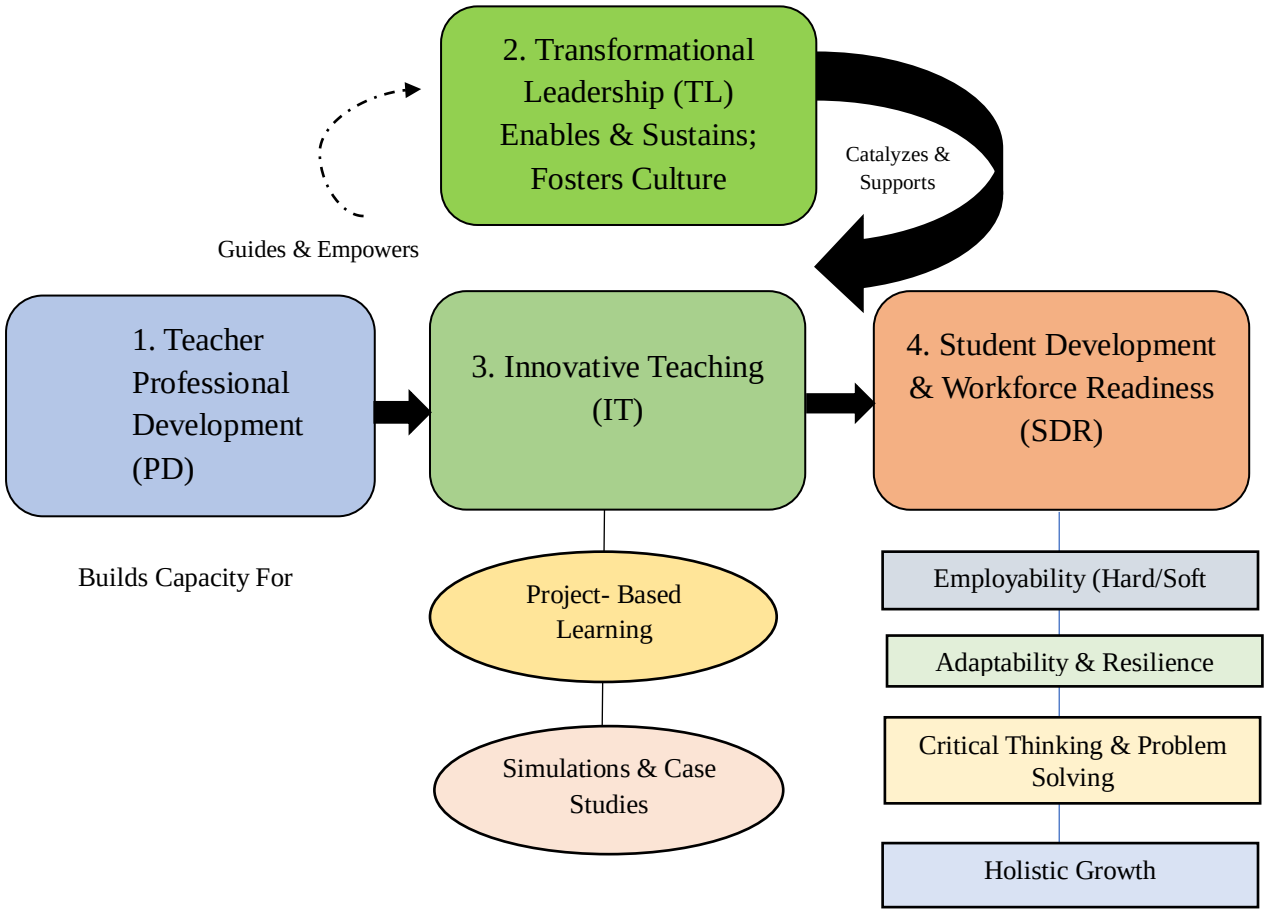


Figure 1. Model for Driving Workforce Readiness

V. IMPLICATIONS FOR EDUCATION POLICY, PRACTICE

The conceptual framework that was presented by the framework was based on heavy-developing forces that restructure the Technical and Vocational Education and Training system to ensure a higher level of student development and employability. These areas found slightly widened fields in policy reform, institutional practice, and global strategies.

Policy Implications

Reforms must be geared to optimally benefit the synergy between leadership, professional development, and innovation along three lines:

1. Teacher Training Systems

Teacher-training policy needs to depart from an episodic and fragmented set of activities to one that views Continuous Professional Development (CDP) as a sustained activity within the context of the school itself (Darling-hammond et al.).

Require Contextualized PD: Policy should require PD programs to focus specifically on innovative TVET pedagogies (e.g., competency-based training, digital twin technology, hybrid learning) rather than generic educational theory.

Allocate Ring-Fenced Funding: National or ministry governments will have to guarantee a dedicated budget for professional development as well as ensuring that technical-vocational training institutions can use these funds for release time of teachers, payment of fees to external resource persons, and purchase of needed technologies.

Reform Certification: Teacher licensing and performance appraisal systems should carry indicators to assess the degree of adoption and performance of innovative teaching practices and reflective growth of professionals to promote implementation of newly acquired skills.

2. Leadership Development Programs

With it being well-established that Transformational Leadership acts as the main agent of change, policies must be focused on the development of leaders who can nurture an innovation culture (Bass and Riggio).

Focus on Instructional Leadership: Leadership training curricula need to emphasize instructional strategies, change management, and building teacher efficacy instead of focusing solely on administrative training.

Create Mentorship Pathways: Funding and recognition should be provided by policies for mentorship programs where highly experienced, transformative TVET leaders would mentor and guide soon-to-be and new principals/directors.

Decentralize Authority: Leaders should be vested with limited autonomy for curriculum adaptation and budget allocation for innovation so that they may respond rapidly to local industry needs and tailor PD accordingly (Leithwood and Jantzi).

3. Institutional Reforms

System-level policy must promote structural changes for innovation and collaboration across the TVET colleges.

Curriculum Flexibility: Policies should allow for flexible delivery of curricula (e.g., block scheduling for project-based learning) and maintain regular feedback loops with industry partners so as to maintain the relevance of the curricula.

Performance Metrics: Funding and accreditation for institutions need to be linked, at least partly, to outcomes metrics beyond graduation rates, such as employability of graduates and surveys of employer satisfaction (UNESCO).

Practical Strategies for Implementation

TVET colleges are therefore bestowed with an immediate responsibility to effectuate the conceptual framework on the institutional level.

1. Building Professional Learning Communities

PLCs form the organizational arrangements for sustaining innovation. Teachers need to be clustered into multidisciplinary groups intent on common student outcomes.

Collaborative Lesson Study: PLCs should dedicate time collaboratively to lesson planning, peer observation on the use of innovative techniques, reflecting upon student data, thus embedding PD within the regular practice.

Peer Coaching: Teachers who are proficient in a certain innovative method (e.g., simulation software) should be encouraged to become peer coaches for others, thereby satisfying the need for individualized consideration, one of the elements of transformational leadership.

2. Integrate Innovation into Curricula

Teaching innovations should gradually neither become an anomaly nor an exception.

Mandate Industry Projects: Make aware that industry- or problem-based projects that demand collaboration and critical thinking are an integral part of major final-year courses, the very requirements identified as experiential learning(Inderanata and Sukardi).

Skill-Specific Technology Integration: In every TVET program, technologies (e.g., CAD software, virtual labs) should be used together with the industrial partners so as to inculcate the hard and soft skills that are required for employment in the industry (Ellison and Harder).

Global Perspective and Reflection for Sri Lanka

The holistic approach of the framework gives relevance to countries on the uneven spectrum, catering to the resource demands of developing nations and the rapid technological adaptation of developed countries.

Developed Contexts: In economies such as Germany or Singapore, which industrialize TVET up to the final stage (Schleicher Andreas), the model gives emphasis to the Transformational Leadership wherein there is a culture of continuous change and investment in the state-of-the-art PD (e.g., training teachers in Industry 4.0 technologies).

Developing Contextual Issues (e.g., Sri Lanka): For the developing nation of Sri Lanka, which is oriented toward fast human capital development and mass youth employment, the model accentuates efficiency and targeted investment(Weligamage). From the ordinary spacing-out-of-resources perspective, policy must focus on College Principals receiving Transformational Leadership training and on cost-effective PD largely through internal PLCs. By developing these leaders' understanding of their catalytic role, Sri Lanka will be better able to harness the capacity of existing teachers who are pivotal in innovative teaching to ensure their graduates are well-aligned to fast changes in both local and international job markets; hence creating TVET to be the strongest motor for national economic growth.

VI. CONCLUSION

This conceptual paper successfully developed and presented an integrated theoretical framework that conceptualizes the evolving relationship between Teacher Professional Development (PD) and Transformational Leadership in Innovative Teaching toward Workforce Readiness. The study’s core contribution is the establishment of Transformational Leadership as the primary link or agent of change. This leadership style creates a supportive institutional climate to ensure the pedagogical capacity gained through sustained PD is effectively used to translate innovative teaching consistently in the classroom. Thus, the framework illustrates that two areas, i.e., teacher competence and organizational culture, provide the best opportunity for the development of students holistically to meet the demands of the twenty-first-century labor market, i.e., adaptability, critical thinking, and resilient problem-solving.

These theoretical insights of the framework greatly impact the field of practice and policy in education. Policymakers must look ahead of scattered training to develop transformational

leadership that is able to advocate for innovative pedagogies and bring in resources to implement them. At the practical level, educational institutions should focus on implementing PLCs as local organizational units charged with converting macro-vision leadership and micro-skill PD into daily innovative practice. Through this combination, TVET and other skills-based education systems can strategically position their educational output in alignment with the unpredictable demands of the global workforce, thereby maximizing investment in human capital.

This framework, although quite robust theoretically, still needs to be thoroughly empirically investigated to confirm the proposed relationships. Future research should direct its attention to large-scale, quantitative studies verifying the hypothesized mediating effect of Transformational Leadership in different educational settings. Also, qualitative research is compelling, so that the "lived experiences" of teachers and leaders in the implementation of these changes are explored, allowing an understanding of specific contextual barriers and factors for success. Finally, longitudinal studies tracking graduate career outcomes ought to be undertaken to confirm the direct causal links between the adoption of this integrated framework and the long-term employability and adaptive success of students.

VII. REFERENCES

1) Akgunduz, Devrim, and Canan Mesutoglu. “Science, Technology, Engineering, and Mathematics Education for Industry 4.0 in Technical and Vocational High Schools: Investigation of Teacher Professional Development.” *Science Education*

International, vol. 32, no. 2, 2021, pp. 172–81, https://doi.org/10.33828/sei.v32.i2.11.

2) Assefa, Easaw Alemayehu, and Bahaudin G. Mujtaba. "Exploring Transformational Leadership in Education by Leveraging Diversity and Technology for Inclusive Practices." *International Journal of Public Leadership*, 2025, https://doi.org/10.1108/IJPL-10-2024-0112.
3) Bass, Bernard M., and Ronald E. Riggio. *T R a Nsfor M At Iona L L E Ade R Sh I P*. *Transformational Leadership: Second Edition*, 2006, https://www.taylorfrancis.com/books/9781135618896.
4) Bohari, Asmah, et al. "Transformational Leadership's Role in Shaping Education 4.0 within Higher Education." *Journal of Infrastructure, Policy and Development*, vol. 8, no. 8, 2024, pp. 1–21, https://doi.org/10.24294/jipd.v8i8.4900.
5) Darling-hammond, Linda, et al. "C_Teacher_Professional_Development_REPORT.Pdf." *Learning Policy Institute*, vol. 6, no. June, 2008, pp. 0920–24.
6) Dianawati, Roswina, et al. "Exploring Leadership Styles and Their Impact on Innovation in TVET: Insights from a Systematic Analysis." *IJORER : International Journal of Recent Educational Research*, vol. 6, no. 1, 2025, pp. 183–205, https://doi.org/10.46245/ijorer.v6i1.750.
7) Ellison, Stacey, and Amy Harder. "Contributing or Clocking In: A Study of Work Engagement." *Journal of Extension*, vol. 60, no. 3, 2022, https://doi.org/10.34068/joe.60.03.03.
8) European Union. *Investing in Our Future : Quality Investment in Education and Training*. no. October, 2022, https://doi.org/10.2766/45896.
9) Ghosh, Lisa, and R. Ravichandran. "Emerging Technologies in Vocational Education and Training." *Journal of Digital Learning and Education*, vol. 4, no. 1, 2024, pp. 41–49, https://doi.org/10.52562/jdle.v4i1.975.
10) Guskey, Thomas R. "Professional Development and Teacher Change." *Teachers and Teaching: Theory and Practice*, vol. 8, no. 3, 2002, pp. 381–91, https://doi.org/10.1080/135406002100000512.
11) Guven, U. *The Influence of the Hosford Exponent on the Critical Major Strain of a Sheet Metal*. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol. 223, no. 4, 2009, https://doi.org/10.1243/09544054JEM1403.
12) Hassan, Rana Hammad, et al. "ICT Enabled TVET Education: A Systematic

Literature Review." *IEEE Access*, vol. 9, 2021, pp. 81624–50, https://doi.org/10.1109/ACCESS.2021.3085910.

13) Herlinawati, Herlinawati, et al. "The Integration of 21st Century Skills in the Curriculum of Education." *Heliyon*, vol. 10, no. 15, 2024, p. e35148, https://doi.org/10.1016/j.heliyon.2024.e35148.
14) Inderanata, Rochmad Novian, and Thomas Sukardi. "Investigation Study of Integrated Vocational Guidance on Work Readiness of Mechanical Engineering Vocational School Students." *Heliyon*, vol. 9, no. 2, 2023, p. e13333, https://doi.org/10.1016/j.heliyon.2023.e13333.
15) Jaakkola, Elina. "Designing Conceptual Articles: Four Approaches." *AMS Review*, vol. 10, nos. 1–2, 2020, pp. 18–26, https://doi.org/10.1007/s13162-020-00161-0.
16) Jonathan, Olelewe Chijioke. *In Utilizing Innovative*. no. October 2019, 2020.
17) Khan Alias Khalid Malokani, Dodo, et al. *Investigating The Transformational Leadership Impact On Student Engagement: Mediating Role Of Student Expectation*. vol. 21, no. S9, 2024, pp. 498–510, www.migrationletters.com.
18) Leithwood, Kenneth, and Doris Jantzi. "The Effects of Transformational Leadership on Organizational Conditions and Student Engagement with School." *Journal of Educational Administration*, vol. 38, no. 2, 2000, pp. 112–29, https://doi.org/10.1108/09578230010320064.
19) Malau-Aduli, Bunmi S., et al. "Readiness to Enter the Workforce: Perceptions of Health Professions Students at a Regional Australian University." *BMC Medical Education*, vol. 22, no. 1, 2022, pp. 1–11, https://doi.org/10.1186/s12909-022-03120-4.
20) Nugroho, Novianto Eko, et al. "A Systematic Review of Indonesian Higher Education Students' and Graduates' Work Readiness." *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, vol. 8, no. 1, 2024, pp. 350–63, https://doi.org/10.22437/jiituj.v8i1.33073.
21) Okolie, Ugochukwu Chinonso, et al. "Improving Graduate Outcomes : Implementation of Problem-Based Learning in TVET Systems of Nigerian Higher Education." *Higher Education, Skills and Work-Based Learning*, vol. 11, no. 1, 2021, pp. 92–110, https://doi.org/10.1108/HESWBL-12-2018-0140.
22) Philogene, Manirahari, et al. "Teacher Professionalism Development in TVET System: Preparedness, In-Service Trainings and Challenges." *Journal Evaluation in Education (JEE)*, vol. 5, no. 3, 2024, pp. 107–17, https://doi.org/10.37251/jee.v5i3.967.

23) Prakasha, G. S., et al. "Teachers' Professional Development on Student Achievement: Perceptions of District Superintendents of Schools in USA." *Journal of Education and Learning (EduLearn)*, vol. 19, no. 4, 2025, pp. 1795–804, https://doi.org/10.11591/edulearn.v19i4.23295.

24) Saif, Naveed, et al. "Influence of Transformational Leadership on Innovative Work Behavior and Task Performance of Individuals: The Mediating Role of Knowledge Sharing." *Heliyon*, vol. 10, no. 11, 2024, p. e32280, https://doi.org/10.1016/j.heliyon.2024.e32280.

25) Salleh, Sallimah. "Examining the Influence of Teachers' Beliefs towards Technology Integration in Classroom." *International Journal of Information and Learning Technology*, vol. 33, no. 1, 2016, pp. 17–35, https://doi.org/10.1108/IJILT-10-2015-0032.

26) Sathiyaseelan, Saravanan. "Transformational Leaders in Higher Education Administration: Understanding Their Profile through Phenomenology." *Asia Pacific Journal of Education*, vol. 43, no. 4, 2023, pp. 1091–106, https://doi.org/10.1080/02188791.2021.1987185.

27) Schleicher Andreas. "The Future of Education and Skills: Education 2030." *OECD Education Working Papers*, 2018, p. 23, http://www.oecd.org/education/2030/E2030 Position Paper (05.04.2018).pdf.

28) Shodipe, Olabanji Taiwo, and Chinyere Theresa Ogbuanya. "Building Aspiring Teachers' Capabilities, Professional and Skill Development: Auspice to Quality Teaching Practice in Technical Vocational Education and Training Institutions." *European Journal of Education*, vol. 59, no. 3, 2024, pp. 1–25, https://doi.org/10.1111/ejed.12677.

29) Shore, Adam, and Track Dinning. "Developing Student's Skills and Work Readiness: An Experiential Learning Framework." *Journal of Work-Applied Management*, vol. 15, no. 2, 2023, pp. 188–99, https://doi.org/10.1108/JWAM-02-2023-0016.

30) Siliņa-Jasjukeviča, Gunta, et al. "Promoting Effective Vocational Education and Training Teacher's Professional Development and Its Transfer to Practice: A Systematic Review." *Education Sciences*, vol. 15, no. 5, 2025, https://doi.org/10.3390/educsci15050596.

31) Smith, Melanie K., and Vilmos Vass. "Towards Creative Transformational Leadership in Higher Education: Challenges and Opportunities." *Zbornik Instituta Za Pedagoska Istrazivanja*, vol. 51, no. 1, 2019, pp. 238–84,

https://doi.org/10.2298/ZIPI1901238S.

32) Snyder, Hannah. "Literature Review as a Research Methodology: An Overview and Guidelines." *Journal of Business Research*, vol. 104, no. March, 2019, pp. 333–39, https://doi.org/10.1016/j.jbusres.2019.07.039.

33) Tee, Tze Kiong, et al. "Design and Technology Teacher in Tvet: A View on Thinking Style and Inventive Problem-Solving Skill." *Journal of Technical Education and Training*, vol. 12, no. 1 Special Issue, 2020, pp. 197–203, https://doi.org/10.30880/jtet.2020.12.01.021.

34) UNESCO. "Strategy For Technical and Vocational Education and Training (TVET) (2016-2021)." *United Nations Educational, Scientific and Cultural Organization 7, Place de Fontenoy, 75352 Paris 07 SP, France*, 2016, pp. 860–860, https://unesdoc.unesco.org/ark:/48223/pf0000245239.

35) Varma, Charu, and Saroj Malik. *Perspective Chapter: TVET in the 21st Century – A Focus on Innovative Teaching and Competency Indicators*. 2024, pp. 1–24, https://doi.org/10.5772/intechopen.112516.

36) Villegas-Reimers, Eleonora. *Teacher Professional Development: An International Review of the Literature*. 2003.

37) Weligamage, S.S. "Human Capital Valuation and Development: Prospects and Challenges in Sri Lanka." *Journal of Desk Research Review and Analysis*, vol. 1, no. 2, 2023, pp. 31–52, https://doi.org/10.4038/jdrra.v1i2.16.

38) Wulansari, Rizky Ema, et al. "Computer Assisted Instruction (CAI) Integrated Case Method-Flipped Classroom: Innovative Instructional Model to Improve Problem-Solving Skill and Learning Outcome of TVET Students." *Journal of Technical Education and Training*, vol. 15, no. 4, 2023, pp. 100–13, https://doi.org/10.30880/jtet.2023.15.04.009.

39) Zhang, Abei, et al. "Effects of Innovative and Traditional Teaching Methods on Technical College Students' Achievement in Computer Craft Practices." *SAGE Open*, vol. 10, no. 4, 2020, https://doi.org/10.1177/2158244020982986.

Twin SOC: Counterfactual Digital-Twin Verification for AI-Driven Incident Response

Ramya S[1], Sinthuja V[2], Hemalatha G[3]

[1]Assistant Professor, [2]Assistant Professor, [3]Assistant Professor

Department of Cyber Security

Paavai Engineering College (Autonomous), Namakkal, Tamil Nadu, India.

Abstract:

Artificial intelligence increasingly drives detection and response in modern security operations centers, yet the industry lacks a rigorous mechanism to validate AI-recommended actions before they touch production systems. The proposed system introduces TwinSOC, a counterfactual verification framework in which machine-learning detectors and an LLM-based remediation planner operate in tandem with a high-fidelity digital twin of the enterprise environment to test proposed responses before execution. TwinSOC binds every AI decision to a reproducible counterfactual experiment inside the twin, uses temporal-logic safety contracts to ensure that isolation, identity, and network policy changes respect organizational constraints, and emits cryptographic attestations that record the exact models, data summaries, and policy versions that produced each pass-or-fail verdict. Actions only proceed to the orchestration layer when the counterfactual proves that service-level objectives and access boundaries will hold with high confidence, while failed proposals return actionable explanations to human analysts. We present the system architecture, modeling and validation methods, and an evaluation plan that measures detection lift, response correctness, analyst workload, and safety violations prevented on both replayed attack traces and live pilot deployments. TwinSOC advances cybersecurity and AI by converting opaque recommendations into verifiable, policy-safe interventions that can be audited end-to-end.

Keywords: cybersecurity; artificial intelligence; incident response; digital twin; counterfactual simulation; explainability; trusted execution; provenance; SOAR.

I. Introduction

Security teams have rapidly adopted machine-learning detectors and large language models to triage alerts, summarize incidents, and recommend containment steps, but they remain reluctant to grant these systems broad autonomy because the consequences of an erroneous action can be severe. Blocking a legitimate service, revoking the wrong identity role, or isolating a critical network segment without advance verification can precipitate outages that eclipse the harm of the original threat. TwinSOC addresses this trust gap by requiring every AI-generated response to be validated as a counterfactual in a digital twin that mirrors identity relationships, network topology, and policy semantics. Rather than executing a remediation directly, the system first simulates the action in the twin, checks temporal-logic safety contracts that express organizational policies, and only then decides whether to promote the action to the production orchestrator or return it to an analyst with an explanation. This architecture preserves the speed benefits of AI while providing a principled safety layer that translates recommendations into verifiable, auditable interventions.

II. Background and Related Work

Contemporary security operations combine rule-based correlation, anomaly detection, supervised classifiers, and increasingly LLM-assisted triage to manage high alert volumes. Digital-twin techniques have matured in cyber-physical domains but are under-explored for enterprise security, where identity graphs, routing policies, and access controls change continuously. Automated response platforms can execute playbooks at scale, yet their safeguards typically rely on static approvals or coarse pre-checks rather than formal contracts tied to the exact proposed action. Research on explainable AI has improved analyst understanding of model outputs, but explanations alone do not guarantee that a recommended change will satisfy service-level objectives or respect least-privilege principles at runtime. TwinSOC integrates these strands by coupling detectors and LLM planners with a live twin that can evaluate counterfactuals under the same policy semantics as production, thereby creating a closed loop in which recommendations are tested, constrained, and attested before they reach the environment they are meant to protect.

III. Problem Statement and Objectives

The central problem is to design a security automation system that can transform AI recommendations into safe actions with guarantees that matter to operators. The system must construct counterfactual experiments that are faithful to production state, express organizational policies as machine-checkable temporal contracts, and quantify uncertainty so decisions remain conservative under partial knowledge. It must also generate evidence that links data, models, policies, and outcomes so that every decision can be audited long after the incident has closed. The objectives of TwinSOC are to raise detection quality through ensemble learning, to convert remediation plans into constrained action sets that satisfy policy contracts in the twin, to promote only those actions whose simulated effects keep availability and access within bounds, and to reduce analyst workload by returning explanations that pinpoint the failing preconditions when a recommendation is rejected.

IV. System Overview and Design

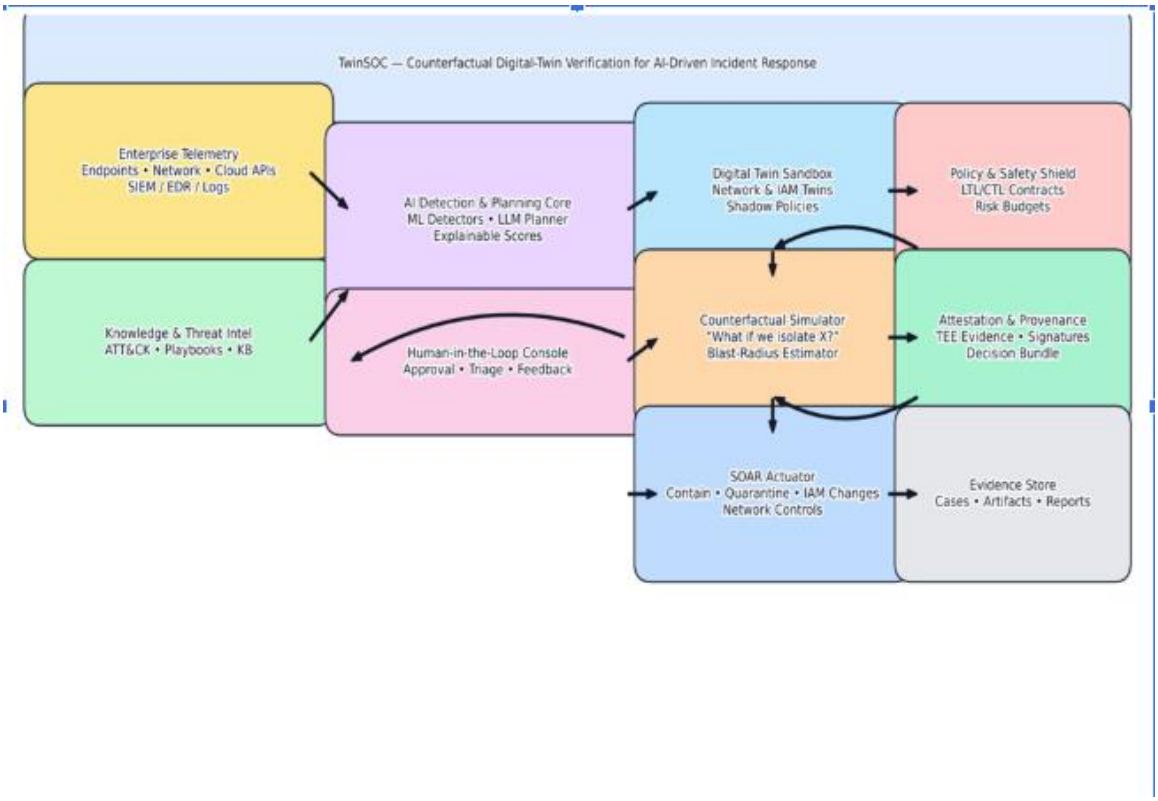


Figure 1: TwinSOC architecture showing the flow from telemetry and intelligence into AI detection and planning, counterfactual verification inside a digital twin, policy-safe decisioning with attestations, and controlled execution through the orchestration layer.

TwinSOC is organized around five cooperating subsystems integrated with existing telemetry and orchestration stacks. An ingestion layer consolidates endpoint, network, and cloud control-plane signals and refreshes a digital twin that encodes identity relationships, routing, and access policies at a level of abstraction appropriate for counterfactual simulation. A detection and planning core combines supervised models with an LLM that synthesizes candidate response plans from alerts and playbooks while emitting explanations that reference the evidence chain. A counterfactual engine executes proposed actions inside the twin, computes blast-radius metrics, and evaluates temporal-logic safety contracts that capture invariants such as mandatory reachability, least-privilege constraints, and segregation of duties. A policy and safety shield consumes these results and issues a pass or fail verdict with calibrated confidence, and a provenance component running in trusted execution environments signs a decision bundle that binds model hashes, policy versions, data summaries, and the final verdict to a case identifier. Only when the verdict passes with sufficient confidence is an action forwarded to the orchestration layer for execution in production; otherwise, the system returns a structured explanation to the analyst console that describes which contract failed and how the plan can be adjusted.

V. Modeling, Contracts, and Verification Methods

Reliable counterfactuals require models and contracts that reflect operational realities. The digital twin captures service dependencies, access control graphs, and network segments as typed relations so that actions such as isolating a host, revoking a role, or tightening an egress rule can be simulated with fidelity. Temporal-logic contracts describe invariants over these relations, including that specific health checks must remain reachable, that privileged identities cannot obtain broader access as a side effect of a change, and that cross-segment isolation preserves required east-west paths for critical

workflows. The counterfactual engine executes proposed actions against snapshots of twin state, evaluates contracts with a model checker, and computes risk metrics such as predicted service impact and residual exposure. Uncertainty arising from incomplete inventory or delayed telemetry is handled through conservative bounds and targeted queries that request fresh evidence before a verdict is issued, thereby keeping the system safe under realistic data conditions.

VI. Integration with Security Orchestration and Human Oversight

TwinSOC integrates with existing security information and event management, endpoint detection and response, and orchestration tools so that adoption does not require a wholesale replacement of the toolchain. Promoted actions are executed by the orchestrator using standard connectors, while the analyst console provides an approval workflow that can require human sign-off for high-risk changes or during early stages of deployment. Feedback from analysts is looped back to the planning models and playbooks so that the quality of recommendations improves over time, and the system maintains a case-centric evidence store that links alerts, simulations, contracts, decisions, and outcomes for later investigation and compliance reporting.

VII. Experimental Design and Evaluation

The evaluation of TwinSOC should demonstrate improvements in detection quality, response correctness, analyst efficiency, and safety. A trace-replay study can benchmark the system on representative attack scenarios by mirroring traffic and control-plane events into the twin, issuing model-generated plans, and observing pass or fail outcomes under the safety shield before comparing them with ground-truth impact measurements in a staging environment. Live pilot deployments can measure the reduction in erroneous actions, the number of policy violations prevented by the shield, changes in mean time to respond, and analyst workload as reflected in case handling time and cognitive load surveys. Statistical analysis should report confidence intervals for each outcome and include ablations that remove the counterfactual engine or relax contracts to quantify the specific contributions of verification to overall performance.

VIII. Results and Discussion

A well-implemented TwinSOC deployment is expected to show that AI recommendations can be transformed into safe, auditable actions without sacrificing response speed. Counterfactual verification should prevent classes of outages caused by overly aggressive isolation or misapplied role changes, while explanations and evidence bundles should improve analyst trust and facilitate post-incident reviews. The discussion should interpret observed improvements in terms that matter to operations, such as avoided minutes of service unavailability, reduction in improper privilege grants, and decrease in escalations, and it should examine the trade-offs between stricter contracts and the throughput of automated actions.

IX. Threats to Validity and Limitations

Digital twins inevitably approximate reality and may miss configuration drift or ephemeral dependencies, which can lead to false assurances; mitigation requires continuous synchronization and conservative contracts that favor safety when doubt exists. The quality of AI recommendations depends on training data and prompt design, and model drift can degrade performance over time; regular evaluation and fallback to human-only workflows preserve resilience. Formal contracts may be incomplete or too strict at first, so organizations must iterate on their specification and monitor for unintended blocking of legitimate responses. Finally, the attestation mechanism must protect sensitive information while remaining verifiable by authorized stakeholders, which motivates the use of trusted execution environments and careful redaction policies.

X. Ethical, Legal, and Pedagogical Considerations

Automated defenses influence user access and service availability, so the system must operate under clear governance with accountable human oversight and transparent evidence for every decision. TwinSOC provides such transparency by attaching explanations and signed provenance to each action, enabling audits and appeals where necessary. From an educational standpoint, the framework unifies core Computer Science and Engineering themes such as modeling, formal specification, machine learning, systems design, and security compliance into a coherent, hands-on project that can be reproduced in academic laboratories without exposing real production systems.

XI. Conclusion

TwinSOC reframes AI-driven security automation as a verifiable process in which recommendations are validated as counterfactuals inside a faithful digital twin, constrained by explicit safety contracts, and promoted to production only when evidence supports a positive verdict. By combining detection, planning, formal verification, and provenance in a single pipeline, the framework delivers practical assurances that help security teams adopt AI responsibly while maintaining availability and compliance. The architecture and methods described here can be implemented incrementally on top of existing tools, creating a path from advisory AI to trustworthy, policy-safe autonomy in incident response.

References

1) M. Naeem, “Contract-based Verification of Digital Twins,” arXiv preprint arXiv:2506.10993, Jun. 2025.
2) D. Allison, “Digital Twin-Enhanced Incident Response for Cyber-Physical Systems,” in Proc. ACM Conf. (ACM Digital Library), 2024/2025.
3) K. E. Kampourakis, “Digital Twin-Enabled Incident Detection and Response,” Journal / Springer Article, 2025.
4) A. Perišić, “Digital Twins Verification and Validation Approach through Systems-Engineering Processes,” Electronics, vol. 13, 2024.
5) M. Homaei, et al., “The Dark Side of Digital Twins: Adversarial Attacks on AI-Driven Water Forecasting,” arXiv preprint arXiv:2504.20295, Apr. 2025.
6) Author(s) unknown at index) “Integrating digital twin security simulations in the SOC,” ACM Digital Library / Conference Paper, (work on process-based security frameworks for SOC integration).
7) ABS, “Guidance Notes on Verification and Validation of Models, Simulations, and Digital Twins,” ABS Publication, Nov. 2024.
8) S. T. Mulder, et al., “Dynamic Digital Twin: Diagnosis, Treatment, Prediction Applications in Healthcare,” Frontiers / PMC, 2022.
9) M. Homaei and coauthors, “A review of digital twins and their application in cybersecurity and AI,” Artificial Intelligence Review / Survey, 2024.

10) M. Bordukova, “Generative artificial intelligence empowers digital twins,” Journal (Taylor & Francis), 2024.
11) “Digital Twins for Incident Detection and Response,” ResearchGate (systematic/position pieces summarizing DT role in incident detection & response).
12) (TechRxiv) “AI-Driven Digital Twin Framework for Security Threat Simulation, Compliance & Optimization,” preprint/tech report (AI-driven DT framework for threat simulation and incident triage).

Influence of Yoga-Based Professional Development on B.Ed. Trainee Teachers with special reference to N.K.T National College of Education for Women

Pavanya Balaji Y

Directress of Physical Education,

N.K.T. National College of Education for Women

Triplicane, Chennai-05, Tamil Nadu

Abstract:

This study investigates the integration of yoga into Professional Development (PD) programs for trainee teachers in N.K.T. National college of Education for Women. Using a quasi-experimental design with two groups a Yogic Practice Group and a Control Group data was collected through the Perceived Stress Scale (PSS) and a Well-Being Questionnaire. An Analysis of Covariance (ANCOVA) was conducted, controlling for Baseline scores to assess differences in Outcome Evaluation stress levels. Results showed a statistically significant effect of yoga-based PD, with the Yogic Practice Group demonstrating lower adjusted stress scores than the Control Group. Findings underscore yoga's effectiveness in enhancing teacher resilience and well-being, suggesting the institutionalization of yoga-infused PD models in teacher education.

Keywords: Yoga, Professional Development, and Body.

Introduction:

Teacher education requires a delicate balance between pedagogical preparation and the holistic well-being of educators. Trainee teachers frequently experience stress arising from academic demands, time management pressures, and personal responsibilities. Prolonged stress not only hampers professional effectiveness but may also lead to burnout and attrition from the teaching profession. Globally, Professional Development (PD) programs are shifting toward holistic frameworks that emphasize teacher wellness alongside academic competence. Yet, most PD models continue to overlook the emotional and psychological needs of teachers, focusing instead on instructional strategies.

Stress is a natural aspect of life. Life is a dynamic process that is demanding and always changing. Acute stress causes our body to release substances. This is referred to as the body's fight-or-flight reaction, which is triggered by adrenaline and other stress hormones. It includes physiological changes like elevated blood pressure (BP) and rapid breathing, tense muscles, increased blood sugar, dry mouth and dilated pupils.

Stated differently, stress is the condition of elevated alertness required for an organism to protect itself under a threat. In addition to adrenaline, other chemicals that alter hormones in the body include human growth hormone and testosterone. Stress might be good for you up to a point.

Yoga helps to promote psychosomatic health and give peace to the mind. It works well as a vaccine to prevent psychosomatic illnesses and mental stress. Our mind and body have a close relationship and are always influencing one other. Dhyana and Asanas have an impact on our bodies and minds. Yoga has the potential to offer enormous benefits, including the alleviation of stress and the production of positive results.

Yoga offers a multidimensional pathway to address this gap. By combining physical postures, controlled breathing, mindfulness, and self-reflection, yoga promotes mental resilience, stress reduction, and enhanced emotional regulation. Yoga practices such as Pranayama, Bhujangasana, Tadasana, Shankha Mudra, Makarasana etc have proven to reduce the stress levels. Scientific evidence confirms yoga's benefits across diverse populations, including teachers and students, highlighting its potential for structured inclusion in PD programs. This study evaluates the impact of an eight week yoga-based professional development intervention on B.Ed. trainee-teachers' stress and well-being.

Objective Of The Study

To investigate the impact of yoga-based professional development on B.Ed. Trainee Teachers.

Review of Related Literature

Patel et al. (2024)reported reduced teacher stress during COVID-19 through online yoga interventions.

Metri et al. (2023) demonstrated that workplace yoga improved mental health, reduced musculoskeletal pain, and enhanced sleep quality among female teachers.

Telles et al. (2019) The teachers participated in residential yoga programsshowed increased mental well-being and reduced anxiety.

These findings collectively strengthen the case for yoga-based PD as a sustainable model for teacher education institutions

Methodology

Forty B.Ed. Teachers Trainees from N.K.T. National College of Education for Women, Triplicane, Chennai, between the ages of 22 and 25, were chosen at random to serve as subjects in order to accomplish the goals of the random group experimental study. Each participant willingly agreed to participate in the study by signing an Informed Consent Form. To achieve the purpose of the study, the subjects are randomly selected and divided into two groups. There are 20 subjects each in Control group and Experimental group. For eight weeks, experimental group I participated in 30-minute yoga and mindfulness sessions five days a week. The second control group received active rest instead of any training.

The Measures used were:

1. Perceived Stress Scale (PSS)
2. Well-Being Questionnaire

Both instruments were administered at Baseline and Outcome Evaluation.

A quasi-experimental design was employed, and data were analysed using ANCOVA to adjust for baseline (Baseline) differences.

Results and Discussions:

ANCOVA Findings:

Group Effect: $F(1,37) = 35.4$, $p < 0.001$

Baseline Covariate: $F(1,37) = 1.06$, $p = 0.31$ (not significant)

This indicates that Outcome Evaluation stress levels were significantly lower in the Yogic Practice Group, even after controlling for baseline differences.

TABLE-I

Baseline and Outcome Evaluation Means of Yogic Practice Group and Control Group on Stress Life Event

Criterion Variables	Baseline Mean	Outcome Evaluation Mean
Yogic Practice Group	18.7	13.9
Control Group	19.2	17.9

Table I shows the Baseline mean and Outcome Evaluation mean of the stressful life event of both groups. It was determined that the Group 1 – Yogic Practice group showed an improvement in the performance of stressful life events while the Controlled group had no significant improvement.

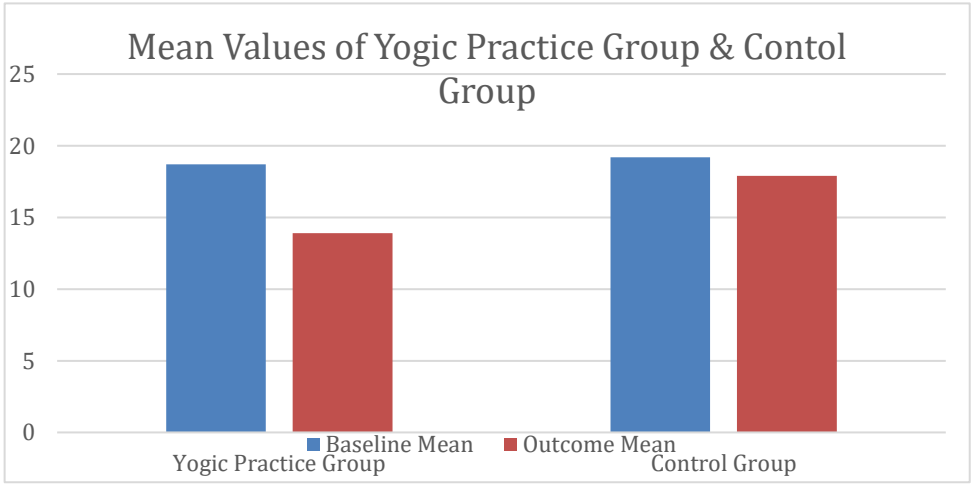


Figure I

The analysis of Covariance of stressful life event of Yogic Practice group and Control Group has been analysed and presented below:

Table-II: ANACOVA on Experiential set and Control Set on Stressful Life Event

Criterion Variable	**Adjusted Outcome Evaluation Means**		**Sum of Squares**	**df**	**Mean Squares**	**F Ratio**
	Group I (Yogic Practice)	**Group II (Control)**				
Stressful Life Event	14.2	17.8	127.1	1	127.1	35.4
			132.8	37	3.5	

From the above table, the obtained 'F' ratio value for a stress filled life event, for adjusted Outcome evaluation means were greater than table value 4.11 for df 1 and 37 and significant at 0.05 level of confidence. This study shows the notable variations between the experimental group and the control group adjusted Outcome Evaluation mean, regarding the emergence of stressful life events.

Discussion:

The ANCOVA analysis strengthens the evidence that yoga-based PD significantly reduces stress among trainee teachers. The non-significant effect of Baseline scores suggests that initial differences between groups did not influence the outcomes, thereby validating the intervention's impact.

The results are consistent with previous research, affirming that yoga improves resilience, enhances emotional well-being, and fosters reflective practice in teacher trainees. Furthermore, the slight differences between raw and adjusted means demonstrate the reliability of findings and support the broader applicability of yoga in educational contexts.

Conclusion:

Yoga-based PD interventions are highly effective in reducing stress and enhancing well-being in trainee teachers. By controlling for baseline variations through ANCOVA, this study provides robust evidence of yoga's impact. The integration of yoga into B.Ed. curricula offers a sustainable, low-cost, and culturally relevant strategy to prepare resilient, mindful, and

effective educators. Institutional support will be critical for scaling and sustaining such programs.

References:

1) Patel, D.H., Gohel, M.K., Phatak, A.G. (2024). Effectiveness of yoga interventions on stress and anxiety levels of school teachers during COVID-19 era. International Journal of Community Medicine and Public Health.
2) Metri, K.G., Raghuram, N., et al. (2023). Impact of workplace yoga on pain measures, mental health, sleep quality, and quality of life in female teachers. Work: A Journal of Prevention, Assessment & Rehabilitation.
3) Telles, S., Sharma, S.K., Gupta, R.K., et al. (2019). Increased mental well-being and reduced state anxiety in teachers after participation in a residential yoga program. BMC Research Notes.

Identification of Dominant Frequencies in Lightning Impulse Voltage Signal Applied to Microbial Inactivation in Liquid Foods

Devi Selvakumar[1], Balasubramanian Madanmohan[2]

[1]Senior Lecturer, T. S. Srinivasan Centre for Polytechnic College and Advanced Training, TVS School Road, Vanagaram, Chennai-600095, E-mail: devi.s@cpat.co.in

[2]Senior Assistant Professor, School of Electrical and Electronics Engineering, SASTRA Deemed University, Tirumalaisamudram, Thanjavur, 613401.
E-mail: mbsmanian16@eee.sastra.edu

Abstract:

A non-thermal Pulsed Electric Field technique is one of the non-lethal processing techniques to preserve liquid and solid foods. Pulsed Electric Field is the advancement of breaking up the microbes by applying a few hundred impulse voltage pulses in a very short time interval without any increase in temperature. Electrolytic derivatives, the breakdown of food particles is diminished through the application of short, high-intensity electric pulses. The effectiveness of microbial inactivation is influenced by several factors, including the intensity of the electric field stress, voltage wave shape, treatment time, total number of pulses, frequency of applied signal and the test chamber design. This research work was mainly intended to utilise the Marx lightning impulse voltage generator for the inactivation of microbes present in liquid foods and to identify the dominant frequency components contributing to the microbial inactivation by performing Frequency Response Analysis on the measured impulse signal. Three parameters are considered for the treatment of water samples, which include the number of impulses, the rate of impulse injection, and the polarity of impulses. A low-energy level impulse generator is used with a maximum energy level of 0.249 kJ. The inactivation efficiency was verified by varying

the number of impulses, the rate of impulse injection and the polarity of the impulse. The number of impulses injected into the sample was varied from a minimum of 25 impulses to a maximum of 100 impulses, and the rate of impulse injection was varied from 22 impulses per minute to 41 impulses per minute. Finally, the transfer function-based frequency response analysis was proposed to understand the frequency compositions in impulse signals applied for microbial inactivation purposes.

Keywords: Pulsed Electric Field, Microbial Inactivation, Frequency Response Analysis, Impulse Injection.

Introduction

The Pulsed Electric Field (PEF) preservation method is a distinctive non-thermal food processing technology that serves as an alternative to traditional thermal techniques. PEF technology is widely used for food and biotechnology-related applications. Its effectiveness is shaped by a combination of factors, which can be broadly categorized into processing parameters, treatment medium characteristics, and biological attributes. A prior knowledge of these factors and their significance on inactivation rate is necessary in order to achieve a reliable outcome of the process. Dunn et al obtained U.S. patents to preserve liquid foods by electric pulse treatment. The patents outline two types of systems: a non-flow-through (batch) system and a continuous system, with experimental results primarily reported from the batch configuration [1–4]. Grahl et al. [5] observed that in the batch system, electric pulses reaching up to 26 kV/cm were delivered through the treatment chamber via a capacitor. According to Ayman H et al. [5], E. coli inactivation can be achieved at a minimum electric field stress of 0.43 kV/cm by increasing the number of impulses. Meanwhile, Shesha H. Jayaram et al. [6–10] have noted that in high-conductivity media, maintaining an optimal electric field exceeding 40 kV/cm necessitates the use of high-capacity generators. Several research studies have reported the treatment of water samples using a Marx lightning impulse generator with a high-energy impulse signal [11-16].

This study primarily aims to employ a Marx lightning impulse voltage generator for the inactivation of microbes in liquid food matrices. It also seeks to identify the dominant frequency components responsible for microbial inactivation through Frequency Response Analysis of the measured impulse signals. Typically, samples connected to the impulse generator exhibit varying

impedance levels to the applied signal. Hence, this research proposes leveraging the data on dominant frequency components within the impulse signal. The outcome of this research work will pave the way to obtain maximum microbial inactivation efficiency in different liquid foods by designating specific frequency compositions for specific food items. This outcome will reduce the quantum of efforts taken to improve food quality.

1. Preliminary Investigations and Their Outcome

1.1 Water samples treated with impulse voltage.

The experimental investigations carried out in this research work use a Marx lightning impulse voltage generator, which is capable of generating short-duration lightning impulse voltage. Three parameters are considered for the treatment of water samples, which include the number of impulses, the rate of impulse injection, and the polarity of impulses. A low-energy level impulse generator is used with a maximum energy level of 0.249 kJ. The inactivation efficiency is verified by varying the number of impulses, the rate of impulse injection and the polarity of the impulse. The number of impulses injected into the sample is varied from a minimum of 25 impulses to a maximum of 100 impulses, and the rate of impulse injection is varied from 22 impulses per minute to 41 impulses per minute. In addition, the effect of positive and negative polarity impulses on the inactivation efficiency is also analysed in this work. The results reveal that the treatment of water samples by injecting low-energy impulse voltage with varying impulse conditions is found to be effective in inactivating the microbes present in the water samples under consideration.

1.2 Description of experimental setup

Fig. 1 shows the experimental setup of the Marx Lightning Impulse Generator and the electroporation cuvette carrying a water sample. The impulse voltage is captured using a Yokogawa DLM 2022 Digital Storage Oscilloscope with a sampling rate of 1.25 GS/s and a bandwidth of 200 MHz. The generated impulse exhibits a front time of 1.2 µs and a fall time of 50 µs.

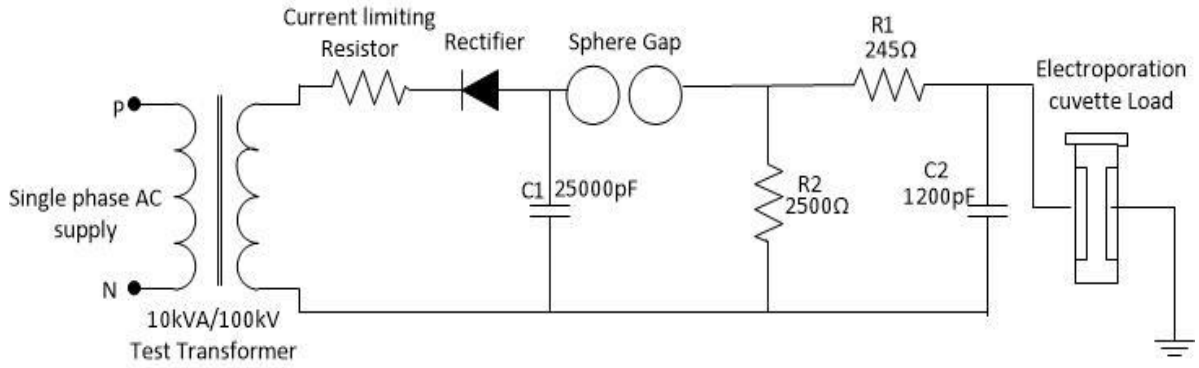


Fig.1 – Marx Lightning Impulse Voltage Generator setup for the injection of impulse voltage to the water sample

Fig. 2 shows the impulse wave shape under negative polarity and positive polarity. The magnitude of electric field strength at no load is maintained at 43 kV/mm, and at loaded conditions, it is maintained at 11.2 kV/mm for the Raw Groundwater sample and is maintained at 19.2 kV/mm for the chlorinated water sample.

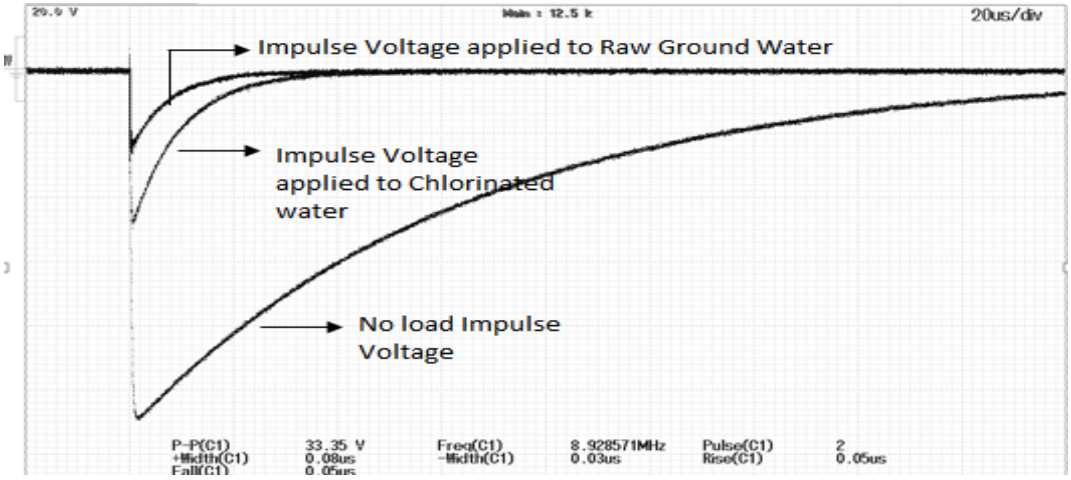


Fig. 2 - Negative polarity Impulse voltage wave under no load & loaded conditions

3.3 Results and Observations

3.3.1 Effect of varying number of Impulses on Raw Ground Water Sample and on Chlorinated Water Sample

Four different numbers of impulses [25, 50, 75, and 100] are used with negative polarity to inactivate naturally grown coliform bacteria E. coli. The electric field strength is maintained

constant at 11.2 kV/mm for the raw groundwater sample and is maintained constant at 19.2 kV/mm for the chlorinated water sample. Table 1 shows the results of colony-forming units/mL for different numbers of impulses on the raw groundwater sample.

Table 1 - Colony Forming Unit/mL for different numbers of impulses with negative polarity impulse voltage on the raw groundwater sample

	Number of colonies counted				
Dilution level for serial dilution method	Before Treatment	After Treatment			
		25 impulses	50 impulses	75 impulses	100 impulses
10^{-3}	210	160	120	45	19

The findings reveal that increasing the number of impulses enhances the degree of microorganism inactivation. Table 2 shows the inactivation level of naturally grown coliform bacteria.

Table 2 - Inactivation level of naturally grown coliform bacteria E. coli in raw ground water sample exposed to different numbers of impulses

Number of impulses	Percentage viability	Log Reduction	Inactivation Efficiency
25	76.19	5.6	19.05
50	57.14	5.95	42.8
75	21.43	6.217	78.57
100	9.05	6.28	90.95

Table 3 shows the results of colony-forming units/mL for different numbers of impulses on a chlorinated water sample, and Table 4 shows the inactivation level of naturally grown coliform bacteria.

Table 3 - Colony Forming Unit/mL for different numbers of impulses for negative polarity impulse voltage on the chlorinated water sample

	Number of colonies counted				
Dilution level for serial dilution method	Before Treatment	After Treatment			
		25 impulses	50 impulses	75 impulses	100 impulses
10^{-3}	250	200	100	1	1

Table 4 - Inactivation level of naturally grown coliform bacteria E.coli in chlorinated water samples exposed to different numbers of impulses

Number of impulses	% viability	Log Reduction	Inactivation Efficiency
25	80	5.7	20
50	40	6.17	60
75	0.4	6.4	99.6
100	0.4	6.4	99.6

It is evident from the results that the viability of coliform bacteria decreases with a higher number of impulses in both the Raw Groundwater sample and the Chlorinated water sample. Also, the log reduction and inactivation efficiency increase for a higher number of impulses for both water samples.

2. Frequency Response Analysis on the injected impulse signal

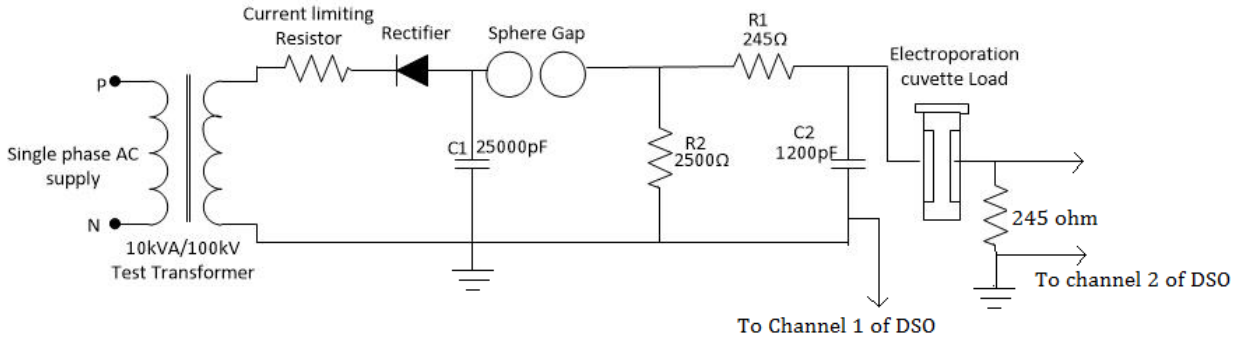


Fig. 3 – Experimental setup for impulse injection and measurement of impulse voltage and current signal

In general, frequency response analysis is used to identify faults and physical displacements in transformer windings [17-18]. In this research work, a similar kind of transfer function-based frequency response analysis is proposed to understand the frequency compositions in impulse signals applied for microbial inactivation purposes. Fig. 3 shows the experimental setup for impulse injection and measurement of the impulse voltage and current signal. The injected impulse voltage is captured in channel 1 of the oscilloscope, and the impulse current flowing through the sample is captured in channel 2 of the oscilloscope and the wave shape of the input-to-output ratio is obtained by dividing the voltage signal and current signal. The resultant impedance wave is subjected to FFT analysis, and the FFT wave representing the dB magnitude versus frequency is obtained to identify the dominant frequency components. This analysis is repeated for different samples, including water samples and different juice samples. It is also proposed to correlate the relationship between frequency compositions and inactivation efficiency. The outcome of this analysis can be used to treat specific food items with a specific range of frequency instead of applying different frequency test signals.

4.1 Preliminary Results of Frequency Response Analysis applied to the water sample and the Mosambi Juice Sample

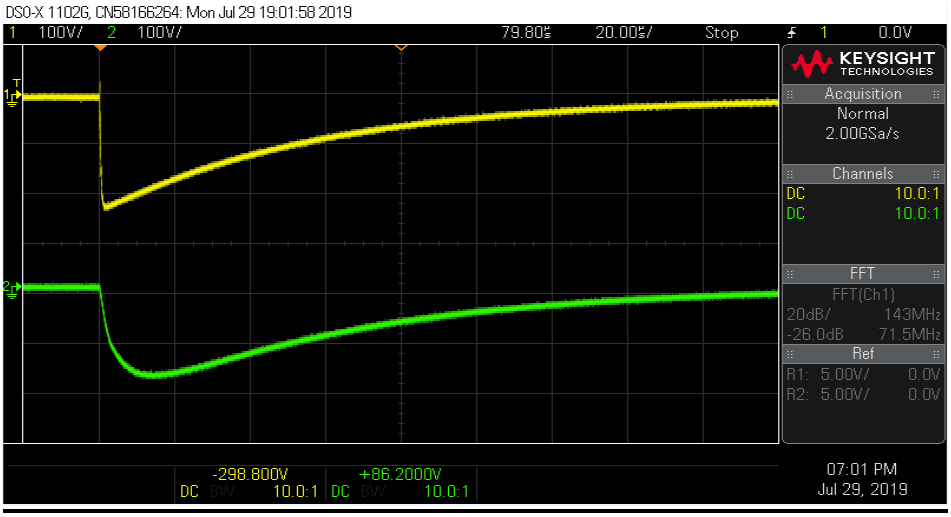


Fig. 4 - Lightning impulse voltage and impulse current measurement in a raw groundwater sample

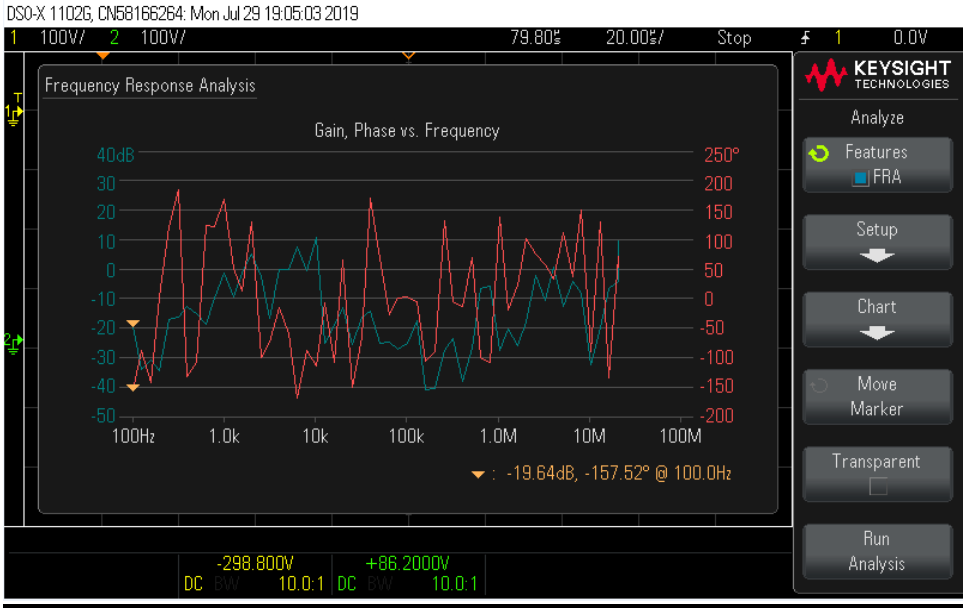


Fig. 5 - FRA on the measured impulse signals in the raw groundwater sample

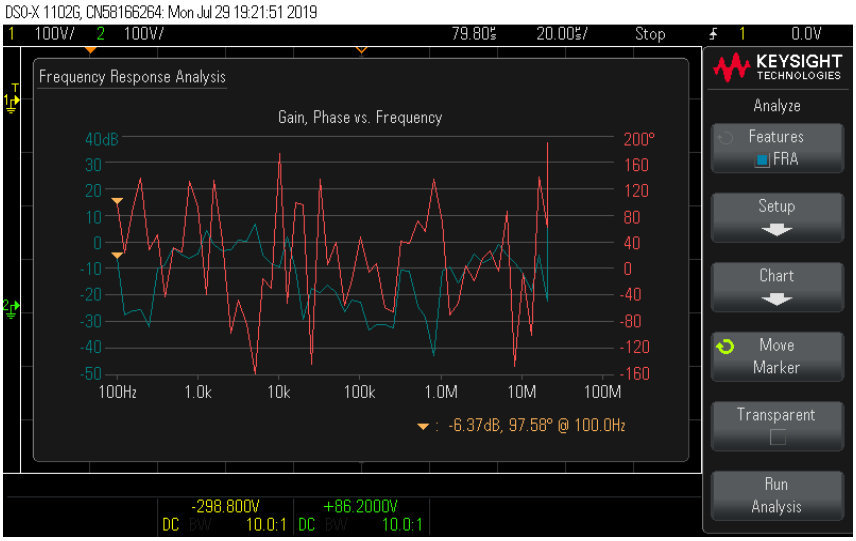


Fig. 6 – FRA on the measured impulse signals in the Mosambi juice sample

Fig. 3 shows the lightning impulse voltage wave applied to the water sample placed in a cuvette and the current flowing through the sample. Fig. 5 shows the Frequency Response Analysis on the measured impulse signal.

The FRA plot is obtained using the built-in function in the Keysight digital storage oscilloscope. Similarly, Fig. 6 shows the FRA plot for the mosambi juice sample. From the observation, it is clear that the impedance offered to the impulse signal by the water sample and the juice sample is different. Fig. 7 clearly shows the dB versus frequency plot for both samples. It is evident that there is an appreciable difference in frequency response in the juice sample when compared to the water sample.

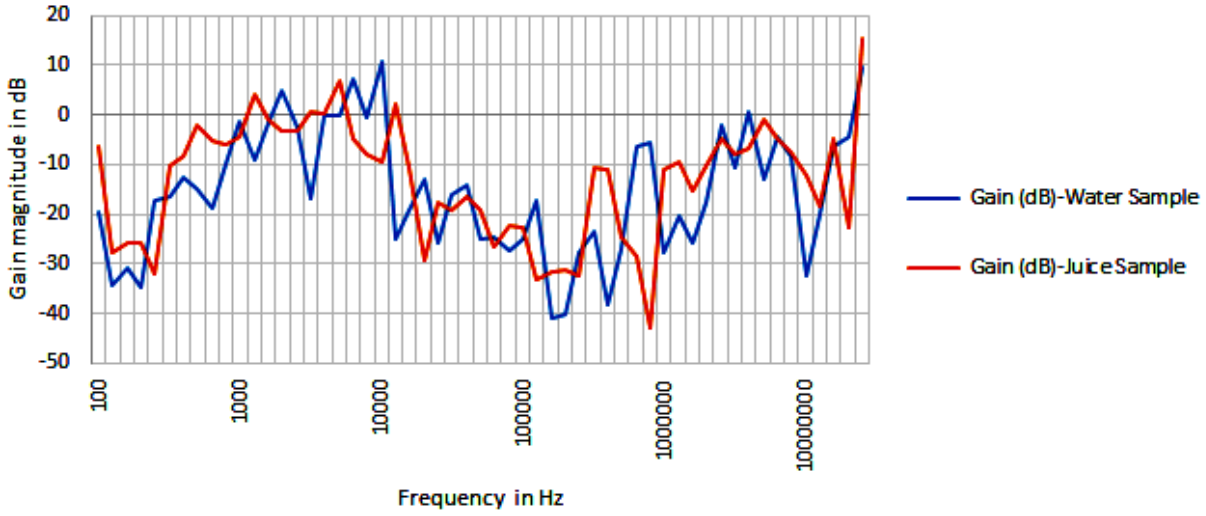


Fig. 7 – Comparison of dB magnitude for both water and juice samples

5. Conclusion

This research work is mainly intended to utilise the Marx lightning impulse voltage generator for the inactivation of microbes present in liquid foods and to identify the dominant frequency components contributing to the microbial inactivation by performing Frequency Response Analysis on the measured impulse signal. Three parameters are considered for the treatment of water samples, which include the number of impulses, the rate of impulse injection, and the polarity of impulses. A low-energy level impulse generator is used with a maximum energy level of 0.249 kJ. The inactivation efficiency is verified by varying the number of impulses, the rate of impulse injection and the polarity of the impulse. The number of impulses injected into the sample was varied from a minimum of 25 impulses to a maximum of 100 impulses, and the rate of impulse injection was varied from 22 impulses per minute to 41 impulses per minute. Finally, the transfer function-based frequency response analysis was proposed to understand the frequency compositions in impulse signals applied for microbial inactivation purposes. The outcome of this analysis can be used to treat specific food items with a specific range of frequency instead of applying different frequency test signals.

REFERENCES

1) Selvakumar D, Madanmohan B. Impact of Liquid Food Volumes and Treatment Chamber Design on a High-Voltage Bipolar Square Pulse Generator. Arabian Journal for Science and Engineering. 2025 Apr;50(8):6065-81.
2) B. L. Qin, G. V. Barbosa-Canovas, B. G. Swanson, P. D. Pedrow, and R. G. Olsen, "Inactivating microorganisms using a pulsed electric field continuous treatment system," *IEEE Trans. Ind. Appl.*, vol. 34, no. 1, pp. 43–50, 1998
3) A.H.Bushnell, J.E.Dunn, R.W. Clark, and J.S.Pearlman, "High pulsed voltage systems for extending the shelf life of pumpable food products," U.S. Patent 5,235,905, 1993.
4) J.E.Dunn and J.S.Pearlman, "Methods and apparatus for extending the shelf life of fluid food products," U.S. Patent 4,695,472, 1987.
5) T.Grahl, W.Sitzmann, and H. Markl, "Killing of microorganisms in fluid media by high voltage pulses," in *Conf. Rec. DECHEMA Biotechnology Conf.,* vol. 5, no. 1, pp. 675–678, 1992.
6) A. H. El-Hag, R. Dadarwal, O. R. Gonzalez, S. H. Jayaram, and M. W. Griffiths, "Survivability of inoculated versus naturally grown bacteria in apple juice under pulsed electric fields," *IEEE Trans. Ind. Appl.*, vol. 46, no. 1, pp. 9–15, 2010.
7) A. H. El-Hag, S. H. Jayaram, O. Rodriguez Gonzalez, and M. W. Griffiths, "The influence of size and shape of microorganism on pulsed electric field inactivation," *IEEE Trans. Nanobioscience*, vol. 10, no. 3, pp. 133–138, 2011.
8) R. Baba, C. J. Angammana, S. H. Jayaram, and L. T. Lim, "An IGBT-based pulsed power supply for fabricating noncontinuous nanofibers using electrospinning," *IEEE Trans. Ind. Appl.*, vol. 49, no. 4, pp. 1801–1807, 2013.
9) S. Jayaram, G. S. P. Castle, and A. Margaritis, "Kinetics of sterilisation of Lactobacillus brevis cells by the application of high voltage pulses," *Biotechnol. Bioeng.*, vol. 40, no. 11, pp. 1412–1420, 1992.
10) M. S. Moonesan, J. F. Zhang, and S. H. Jayaram, "IGBT-based HV pulse generator for high conductivity liquid food treatment," *Dig. Tech. Pap. Int. Pulsed Power Conf.*, pp. 1160–1164, 2011.

11) K. Shimizu, M. Yamada, M. Kanamori, and M. Blajan, “Basic study of bacteria inactivation at low discharge voltage by using microplasmas,” *IEEE Trans. Ind. Appl.*, vol. 46, no. 2, pp. 641–649, 2010.

12) K. H. Schoenbach, S. Katsuki, R. H. Stark, E. S. Buescher, and S. J. Beebe, “Bioelectrics-new applications for pulsed power technology,” *Pulsed Power Plasma Sci.*, vol. 30, no. 1, pp. 293–300, 2001.

13) T. S. and A. S. Yoichi Matsumoto, Norio Shioji, "Inactivation of Microorganisms by Pulsed High Voltage Application," *IEEE*, IEEE conference, pp. 652–659, 1991.

14) R. E. Bruhn, P. D. Pedrow, R. G. Olsen, G. V. Barbosa-Canovas, and B. G. Swanson, “Heat conduction in microbes exposed to pulsed electric fields,” *IEEE Trans. Dielectr. Electr. Insul*, vol. 5, no. 6, pp. 878–885, 1998.

15) A. H. El-Hag, O. R. Gonzalez, S. H. Jayaram, and M. W. Griffiths, “A performance study of a multilevel electrode treatment chamber for food processing,” *IEEE Trans. Ind. Appl.*, vol. 49, no. 3, pp. 1091–1097, 2013.

16) L. D. REINA, Z. T. JIN, Q. H. ZHANG, and A. E. YOUSEF, “Inactivation of Listeria monocytogenes in Milk by Pulsed Electric Field,” *J. Food Prot.*, vol. 61, no. 9, pp. 1203–1206, 2016.

17) R. Rajesh, M. Balasubramanian, and M. Rajappa, "Sweep frequency response analysis-based diagnosis of shorts within transformer windings," IET Gener.Transm.Distrib, 2017, Vol. 11 Iss. 17, pp. 4274-4281.

18) R. Rajesh, M. Balasubramanian, M. Rajappa and A.Kamalaselvan, “Interturn short diagnosis in small transformers through impulse injection: on-line on-load self-impedance transfer function approach,” IET Sci. Meas. Technol., 2017, Vol. 11 Iss. 8, pp. 961-966.

19) Saleh Alsuhaibain, Yasin Khan et al., “A review of Frequency response analysis methods for Power Transformer Diagnostics,” Energies, 2016, 9,879.

Awareness of Professional Development Practices among Teacher Educators

Yamuna M[1], Sivasakthi Rajammal T[2]

[1]Ph.D. Research Scholar, Department of Educational Psychology, Tamil Nadu Teachers Education University, Chennai-600097.

[2]Research Supervisor, Assistant Professor & Head, Department of Educational Psychology, Tamil Nadu Teachers Education University, Chennai-600097.

Abstract:

Professional development (PD) is a crucial component in enhancing the professional competence of teacher educators, who play a pivotal role in preparing prospective teachers. Awareness of professional development practices enables teacher educators to update their pedagogical knowledge, integrate innovative teaching strategies, and model lifelong learning. The present study aims to examine the level of awareness of professional development practices among teacher educators. A descriptive survey method was employed, and a stratified random sample of 150 teacher educators from government, government-aided, and private B.Ed. and M.Ed. colleges was selected. A structured questionnaire was developed by the investigator and validated by experts. The reliability of the tool was established using Cronbach's Alpha ($\alpha = 0.86$). Data were analyzed using t-test and one-way ANOVA. The findings revealed no significant difference in awareness of professional development practices based on gender, locality, or type of management. However, the study identified gaps in awareness of digital, research-based, and collaborative Professional development practices. The study highlights the need for structured professional development planning, enhanced digital orientation, and institutional support to strengthen teacher education.

Keywords: Professional Development, Teacher Educators, Awareness, Teacher Education, Teaching Strategies, Classroom Practices, Innovative Teaching, Pedagogical Skills, Continuous Learning.

I. Introduction:

Professional development plays a critical role in enhancing the knowledge, skills, and competencies of teachers. Teacher educators, who are responsible for training and mentoring

prospective teachers, must stay informed about the latest trends, methodologies, and programs in professional development. Awareness of professional development practices enables teacher educators to design effective teaching-learning processes, incorporate innovative strategies, and serve as role models for their trainees. Despite its importance, there is often a lack of systematic information on how aware teacher educators are of available professional development programs. Professional development is an essential component of teacher education, ensuring that educators remain updated with contemporary pedagogical approaches, assessment strategies, and technological advancements. Teacher educators play a dual role as instructors and mentors who guide prospective teachers. Their awareness and engagement with Professional Development programs directly influence the quality of teacher preparation. Globally, teacher education has shifted toward evidence-based practices, reflective teaching, competency-based learning, and ICT integration. Therefore, teacher educators must be knowledgeable about diverse Professional development opportunities, including seminars, workshops, MOOCs, action research, collaborative learning, and reflective journals. Despite the availability of Professional development initiatives, awareness levels among teacher educators vary. This study investigates the extent of this awareness and identifies gaps that institutions must address to improve teacher quality. Professional development is widely recognized as a key factor in improving the quality of education. In the context of teacher education, professional development ensures that teacher educators continuously enhance their knowledge, skills, and professional competencies. Teacher educators serve as mentors, facilitators, and role models for prospective teachers; therefore, their professional growth directly influences the quality of teacher preparation.

Rapid changes in curriculum frameworks, assessment practices, and instructional technologies demand that teacher educators remain professionally updated. Professional development practices such as workshops, seminars, refresher courses, online training programs, action research, and professional learning communities support continuous growth. Awareness of these practices is the first step toward meaningful participation and effective use. Despite the availability of numerous professional development opportunities, variations exist in the extent to which teacher educators are aware of such initiatives. Hence, the present study focuses on assessing the awareness of professional development practices among teacher educators. In the present educational scenario, teacher education institutions are expected to prepare teachers who are reflective, innovative, and responsive to diverse learner needs. Teacher educators therefore need continuous professional updating to cope with curricular reforms, technological integration, and competency-based education. Professional development helps teacher

educators enhance instructional planning, assessment strategies, classroom management, and research skills. Awareness of professional development practices influences not only individual growth but also institutional effectiveness. When teacher educators are aware of available Professional development opportunities, they are more likely to engage in professional learning activities, collaborate with peers, and adopt best practices. Hence, assessing awareness becomes an important step in strengthening teacher education programs.

II. Need of the Study:

Recognize how knowledgeable teacher educators are about professional development initiatives. Determine any knowledge or career growth activity participation gaps. Make sure teachers are professionally informed to increase the efficacy of teacher preparation programs. Make suggestions on how organizations might set up professional development programs that are both pertinent and easily accessible. Stress the importance of instructors in promoting a culture of lifelong learning and career advancement. Teacher educators are expected to model effective instructional practices. Their awareness of professional development determines how well they can: stay updated with emerging pedagogies, engage in reflective teaching, demonstrate research-based practices, integrate ICT and digital tools, mentor preserves teachers effectively. However, several studies have indicated inconsistent participation of teacher educators in Professional Development activities due to limited institutional support, lack of information, time constraints, and inadequate planning. Understanding their awareness level is therefore essential in: identifying existing knowledge gaps, designing relevant Professional Development programs, enhancing professional competencies, promoting a culture of lifelong learning in teacher education institutions. This study addresses these needs by assessing teacher educators' awareness of Professional Development practices.

Teacher educators are expected to demonstrate professional competence, reflective practice, and lifelong learning. Their awareness of professional development practices determines how effectively they can update their pedagogical skills, integrate ICT tools, engage in research, and guide prospective teachers.

Although professional development opportunities are provided through universities, regulatory bodies, and digital platforms such as SWAYAM and DIKSHA, participation remains inconsistent. Limited awareness, lack of institutional support, time constraints, and insufficient recognition of Professional Development outcomes often hinder effective engagement. Many teacher education institutions conduct professional development programs; however, participation often remains routine

rather than meaningful. In some cases, teacher educators attend programs only for certification or career advancement without fully utilizing the learning outcomes. This highlights the importance of awareness as a foundation for meaningful engagement. Further, rapid digitalization in education has introduced new professional development formats such as online courses, webinars, and virtual learning communities. Limited awareness of these emerging practices may restrict professional growth. Therefore, this study is essential to understand existing awareness levels and to recommend strategies for strengthening professional development among teacher educators.

III. Review of Related Literature:

a. International studies:

Ulvik & Guberman (2018). examined the professional development of higher education-based teacher educators and emphasized self-directed learning, collaboration, and research engagement as essential components of professional development. This study aims to identify influencing factors and affordances that support professional development while describing Themes from the interviews center on (i) self-directed career advancement, (ii) benefit of collaborating with peers and colleagues to advance one's career, (iii) acquiring chances to improve instructional strategies, (iv) Inseparable connection with research, teaching, thus, necessity of improving research skills. The induction time, navigational stress and irritation, haphazard professional development, and learning from and with one another are some of the topics that come up for discussion. Emphasized that teacher educators' professional development is influenced by self-directed learning, teamwork, and opportunities for improving research skills. The study also highlighted challenges such as fragmented professional development structures and unclear expectations and inconsistent Professional Development structures.

Villanueva et al. (2021). Assessing the School Heads Leadership in the Towns of Nueva Ecija, Philippines: Inter-Relationship of Supervisory Skills, Interpersonal Skills and Leadership Skills**.** The study's findings showed that both the school and its instructors thought that school administrators had strong interpersonal, leadership, and supervisory abilities.

Reported that leadership and institutional support significantly influence participation in professional development activities. It was concluded that school heads' leadership was visible because the interrelationship of supervisory skills, interpersonal skills, and leadership skills revealed substantial correlations between the school head's administrative abilities in planning and organizing and their decision-making. Demonstrated that leadership and supervisory skills strongly influence participation

in professional development programs within schools, suggesting that institutional leadership affects Professional Development culture.

Klink & Kools (2017). The Belgian participant who wanted to spend some time to consider a successor because he was ready to retire raised the most impressive activity. For participants from the various nations, future professional growth plans appeared to be rather comparable. All of the participating countries' teacher educators had plans for future development, with the exception of the Israeli participant who was set to retire, and there were no discernible distinctions between them. Found that teacher educators across multiple countries engage in similar Professional Development activities collaboration, research, curriculum development, and instructional innovation highlighting the global need for consistent Professional Development planning.

b. Indian studies:

Selvaraj N, Alagukanna AS and Suganya M. (2015). Professional Development in Education in India: A View. . The goal of education is to shape people so that they develop integral multi-facet personalities and is able to carry out fully their social role by developing their intellectual, physical and spiritual capacities and encouraging remove elevated level of human feeling and aesthetic taste, thus turning the ideological principle into personal connections and habits of behavior. Survey of literature suggests various models of in service education or professional development prevalent in different countries. There are three dimensions of classroom environment - the physical dimension (the material order of things), the human dimension (the human actors i.e. the teacher/s, children), and the social dimension (the interaction amongst the actors). Classroom management involves managing this environment in all its dimensions for the goal of learning. The other important aspect of classroom processes is appropriate learning strategies to teach each of the constituents of literacy at the primary level reading, writing and mathematics/ numeracy.

Radhika Misquitta & **Rudri Joshi. (2022).** Professional development for inclusive education: insights from India. Data from questionnaires and audio-visual evidence suggest that participants were able to apply a range of strategies including attention grabbers, energizers, classroom management, and reading fluency strategies to their classrooms. Participants most appreciated the hands-on strategies and contextually relevant resources that were made available at no additional cost as part of the PDP. The

paper highlights the need to create and share open education resources (OERs) that all teachers can contribute to and extend the scope of PD programmes to provide follow-up support.

Stephanie L. Knight (2014). Professional Development and Practices of Teacher Educators. Using social network analysis on data obtained in 24 schools through surveys and interviews of novice teachers, the authors investigated beginning teachers advice and information seeking behaviors for math and literacy. The findings highlight the importance of formal organizational structures in the process , particularly grade-level teams, principals and instructional coaches. Reported that teacher educators show moderate awareness of Professional Development activities, with variation across institutional types.

Kaur, J. (2017). Self-concept and teaching competency of elementary teachers: A correlation study. Found a positive and significant correlation between teacher self-concept and teaching competency. Highlighted the relationship between teacher competencies and self-concept, pointing to the relevance of psychological preparedness in Professional Development engagement.

Sharma and Kumar (2018). Professional development practices among teacher educators. Found that teacher educators demonstrated moderate awareness of professional development practices, with variations across institutional types.

c. Gaps Identified:

Inconsistent access to Professional Development opportunities, Limited research on Professional Development awareness in Indian teacher education institutions, Lack of structured Professional Development frameworks, Need for enhanced theoretical understanding and digital competencies. This study attempts to bridge these gaps.

d. Theoretical Framework:

The study is anchored in two key theories:

- **Guskey's Model of Teacher Professional Development (1995) :** Guskey's model proposes that effective Professional Development influences teacher beliefs, classroom practices, and student outcomes. Awareness is the first step in the model, influencing motivation to participate in Professional Development programs.

- **Adult Learning Theory (Knowles, 1980) :** This theory states that adults learn best when Professional Development is relevant, problem-centered, self-directed, and experiential. Teacher educators, as adult learners, engage in Professional Development based on perceived usefulness, accessibility, and institutional support.

These frameworks justify the need to examine teacher educators' awareness of Professional Development practices as a precursor to meaningful participation.

e. Clarification of Terminology:

- **Awareness:** Knowledge and understanding of available professional development practices. In the present study, awareness refers to the extent to which teacher educators possess knowledge and understanding of various professional development practices available to them. This includes awareness of traditional professional development activities such as workshops, seminars, refresher courses, and orientation programs, as well as emerging practices like online courses, webinars, MOOCs, action research, and professional learning communities. Awareness does not necessarily imply participation but indicates familiarity with the purpose, nature, and availability of professional development opportunities.
- **Participation:** Actual involvement in professional development activities. Participation refers to the actual involvement of teacher educators in professional development activities. It includes attending workshops, seminars, training programs, online courses, conferences, and engaging in research-related activities. Participation reflects the extent to which teacher educators take advantage of available professional development opportunities. However, participation alone does not ensure professional growth unless the learning gained is meaningfully applied in professional practice.
- **Effective Use:** Application of knowledge and skills gained through professional development in teaching and mentoring practices. Effective use refers to the practical application of knowledge, skills and competencies acquired through professional development activities in teaching, mentoring, and academic practices. It involves integrating newly learned strategies into classroom instruction, adopting innovative teaching methods, improving assessment practices, engaging in reflective teaching and guiding prospective teachers more effectively. Effective use

represents the highest level of professional development, where learning outcomes lead to observable improvements in professional performance.

IV. Objectives:

- To determine if teacher educators' awareness of professional development procedures varies significantly based on factors including
  - Gender
  - Location
  - Types of Management.

V. Hypotheses of the Study:

- The awareness of professional development practices does not discernible differs between men and women teacher educators based on gender.
- The awareness of professional development practices does not discernible differs between rural and urban teacher educators based on locality.
- The awareness of professional development practices does not discernible differs between government, government aided and private teacher educators based on Types of Management.

VI. Methodology:

For the study, a descriptive survey approach was used. A stratified random sampling technique of 150 teacher educators from government, government-aided, and private B.Ed. and M.Ed. colleges was selected.

i. TOOLS USED FOR THE STUDY:

Professional Development Awareness Questionnaire (PDAQ) was constructed by the investigator, as there was no standardized tool for measuring teacher educators awareness of professional development practices. The items included in the scale attempts to measure the awareness of the teacher educators about the professional development practices. Initially, the scale was constructed with 76 items and the draft tool was subjected to the expert opinion. On the basis of the suggestions some of the items were deleted, some of the items were added and some were modified to arrive at the final tool consisting 60 items including positive and negative statements

relating to assess the professional development practices awareness that is the ability to work in a websites or applications and enable the teacher educators to share their knowledge , images, videos, audios, and the information through Facebook, Whatsapp, Twitter, Instagram, Skype, Snapchat, Youtube and Quora on a five point scale ranging from 'strongly agree' to 'strongly disagree'. Out of Sixty items, Fifty Six items were positive and Four items were negative.

ii. Description, Administration And Scoring Method Of The Tool:

- **Description of the Tool:**

Table 1

Dimensions of Awareness of professional development practices Scale and the Item numbers

S.No	DIMENSIONS	ITEMS	No. Of Items
1	Social media	1 to 10	10
2	Facebook	11 to 21	11
3	Whatsapp	22 to 30	9
4	Instagram	31 to 35	5
5	Twitter	36 to 41	6
6	Skype	42 to 45	4
7	Snapchat	46,47,48,50,53	5
8	Youtube	49,51,52,54	4
9	Quora	55 to 60	6
	TOTAL		**60**

Table 2

Positive and Negative items for Awareness of professional development practices Scale

Types of items	Items	No. Of items
Positive items	1 to 12, 15 to 27, 30 to 60	56
Negative items	13,14,28,29	4
TOTAL		**60**

- **Administration of The Tool:**

The Awareness of professional development practices Scale has a number of statements which people have been used to describe themselves in the mode of organisation level of awareness in professional development practices like Facebook, Whatsapp, Instagram, Twitter, Skype, Snapchat, Youtube and Quora. The administrator gave instructions for completing the measure and in particular using the 5 point scale. Respondents were emphasized that there are no right or wrong answers but they were instructed to go through these statements carefully. Teacher Educators were told that they could indicate how true each item was for them by placing a tick mark (✔) in one of five responses provided. This procedure lasted approximately for 30 minutes to complete the Scale.

- **Scoring Procedure:**

The Professional Development Awareness Questionnaire (PDAQ) consisted of 60 statements which were assigned a rating of 5 point scale such as Strongly Agree, Agree, Uncertain, Disagree and Strongly Disagree with a weight age score of 5,4,3,2 and 1 respectively for positive items only. The negative items were scored reversely. The maximum possible score was 300 and minimum score was 60.

- **Pilot Study:**

A pilot study was conducted to ascertain the time limit and also to establish the reliability and validity of the tools. A sample of 150 teacher educators from two colleges of education was chosen for pilot study. The investigator personally administered Professional Development Awareness Questionnaire to the sample by giving necessary instructions.

iii. RELIABILITY AND VALIDITY OF THE TOOL:

The degree of consistency an instrument or process exhibits—that is, the consistency with which it measures whatever it is measuring—is known as reliability. Validity is that quality of data-gathering instrument or procedure that enables it to measure what it is supposed to measure.

- **Reliability of Professional Development Awareness Questionnaire:**

The reliability of the Professional Development Awareness Questionnaire was calculated using Cronbach's alpha method and the coefficient of reliability is obtained to be ($\alpha = 0.86$) indicating high

reliability.

- **Validity of Professional Development Awareness Questionnaire:**

The square root of dependability has been used to calculate the validity index. The validity of Professional Development Awareness Questionnaire has been found and hence the scale considered to have high validity. Content validity was ensured through review by five experts in teacher education and educational psychology. Construct validity was verified through item-analysis.

iv. Statistical Techniques:

The t-test and F-test, two suitable statistical techniques, were used to test the developed hypotheses and objectives.

VII. Testing of Hypothesis:

Hypothesis – 1

The awareness of professional development practices does not discernible differs between men and women teacher educators based on gender.

Table 1

Details of t-Test Result

Category	Numbers	Average	SD	t-Results	Comment
Men	22	114.82	17.46	0.239	Not Significant
Women	128	114.98	13.58		

As seen in Table 1, the average score for Men (N= 22) is 114.82 with SD of 17.46 and the mean score for women (N = 128) is 114.98 with SD of 13.58. Based on these findings ($t = 0.239 < 1.96$), the awareness of professional development practices does not discernible differs between men and women teacher educators based on gender. It can be concluded that null hypothesis 1 is accepted.

Hypothesis – 2

The awareness of professional development practices does not discernible differs between rural and urban teacher educators based on locality.

Table 2

Details of t-Test Result

Category	Numbers	Average	SD	t-Results	Comment
Rural	22	49.92	10.26	0.198	Not Significant
Urban	128	50.05	9.76		

As shown in the Table 2, the mean score for Rural (N= 22) is 49.92 with SD of 10.26 and the mean score for Urban (N=128) is 50.05 with SD of 9.76. Based on these findings (t = 0.198 < 1.96), the awareness of professional development practices does not discernible differs between rural and urban teacher educators based on locality. It can be concluded that null hypothesis 2 is accepted.

Hypothesis – 3

The awareness of professional development practices does not discernible differs between government, government aided and private teacher educators based on Management Types.

Table 3

Result of One-Way ANOVA for Types of Management

Demographic Variable	Nature	Sum of Squares	Df	Mean Square	F	Remark
Types of Management	Between Groups	1469.93	2	325.06	1.092	Not Significant
	With in Groups	25216.71	147	103.95		
	Total	26685.64	149			

As shown in Table 3, the obtained value for F is 1.092; At the F- results (1.092) is less than the table value (3.84).The awareness of professional development practices does not discernible differs between government, government aided and private teacher educators based on Management Types. It can be concluded that null hypothesis 3 is accepted.

VIII. Results & Discussion:

The findings revealed no significant difference in awareness of professional development practices based on gender, locality, or type of management. This indicates a relatively uniform level of awareness among teacher educators. However, teacher educators showed greater awareness of conventional professional development practices such as workshops, seminars, and refresher courses. Awareness of emerging and digital practices was comparatively lower. The absence of significant differences in awareness across gender, locality, and management type indicates that professional development information is distributed uniformly among teacher educators. Common policies, centralized training programs, and regulatory guidelines may have contributed to this uniformity. However, awareness was largely limited to conventional professional development practices. Lower awareness of digital and research-based practices suggests the need for institutional initiatives to promote modern professional learning opportunities. These findings are consistent with earlier studies which reported moderate awareness and limited engagement in innovative professional development practices. Awareness of professional development practices is fundamental to improving teacher education quality. While teacher educators demonstrated moderate and uniform awareness, gaps exist in digital and research-oriented professional development practices. Strengthening institutional support and promoting continuous professional learning will enhance teacher educators' effectiveness and ultimately improve teacher preparation.

a) Interpretation:

- Both men and women had similar exposure to professional development opportunities.
- Urban and rural institutions offered comparable access to professional development information.
- Professional development awareness was relatively uniform across management types, indicating statewide dissemination of professional development initiatives.

b) Examples of Professional development Practices Known vs. Unknown to Teacher Educators:

Known	Unknown
Workshops and seminars	Professional learning communities (PLCs)
Orientation programs	Reflective journal-based Professional development
ICT-based training	Action research opportunities
Class management training	International webinars and certification programs
Micro-teaching & peer teaching	MOOCs (SWAYAM, NPTEL)

These findings emphasize the need to expand digital and research-oriented Professional development awareness.

IX. Educational Implications:

- Improving Teacher Education Programs - Helps institutions design more relevant and accessible professional development programs.
- Enhanced Training for Prospective Teachers - Ensures teacher educators can guide trainees effectively. Encouraging Continuous Learning.
- Motivates teacher educators to engage in lifelong learning.
- Policy Formulation - Provides insights for policymakers to frame professional development policies.
- Institutional Planning - Helps colleges prioritize workshops, seminars, and reflective practices.
- Strengthening Teacher Education Programs - Institutions should design structured annual Professional development calendars aligned with NCTE recommendations.
- Improving Digital Professional development Awareness - Colleges should promote online platforms such as SWAYAM, Diksha, and international MOOCs.
- Encouraging Reflective Practices - Reflective journals, mentoring circles, and peer observation should be institutionalized.
- Promoting Research Engagement - Teacher educators should be trained in action research and publication ethics.

- Policy Implications - Policymakers must ensure equitable Professional development access and mandatory Professional development participation credits.
- Institutions should design structured professional development plans.
- Teacher educators should be oriented toward digital Professional development platforms.
- Research-based and reflective practices should be encouraged.
- Policymakers should ensure equitable access to Professional development opportunities.

X. Conclusion:

Professional development is central to improving teacher education and ensuring high-quality teaching. Awareness of professional development practices among teacher educators is crucial, as they act as role models and facilitators for prospective teachers. This study emphasizes the need for regular training, workshops, and engagement in professional activities to strengthen awareness and participation. By identifying gaps and promoting continuous learning, institutions can ensure that teacher educators are equipped with current knowledge, skills, and attitudes. Awareness of professional development practices is a foundational requirement for quality teacher education. The study reveals moderate yet uniform awareness among teacher educators, with significant gaps in digital and research-based professional development knowledge. Strengthening institutional support, providing structured professional development plans, and integrating reflective and ICT-based training can enhance teacher educators' competencies. This will ensure that they model exemplary teaching practices for future teachers.

XI. References:

- **Marit Ulvik, Ainat Guberman (2018).** The professional development of higher education-based teacher educators: needs and realities. *Professional Development in Education*, 45(5) 848–861.
- **Marcel Van der Klink, Quinta Kools (2017).** Professional development of teacher educators: what do they do? Findings from an explorative international study. *Professional Development in Education*, 43(2) 163–178.
- **Aggarwal, J.C. (2018).** *Teacher and Education in Emerging Indian Society.* New Delhi: Vikas Publishing House.

- **Glickman, C.D., Gordon, S.P., & Ross-Gordon, J.M. (2007).** Super Vision and Instructional Leadership: A Developmental Approach. *Scientific Research an Academic Publisher.*
- **Kaur, G. (2017).** Teaching competencies of prospective teachers in relation to their self-concept. *International Journal of Research in Humanities, Arts and Literature,* 5(2), 45–52.
- **Sharma, R., & Kumar, P. (2018).** Professional development practices among teacher educators. *Journal of Educational Research and Extension,* 55(1), 12–21.
- **Aileen Asis Villanueva, Sandi Sanchez Disu, Kim Fe Pauleen Asis Villanueva. (2021**). Assessing the School Heads Leadership in the Towns of Nueva Ecija, Philippines: Inter-Relationship of Supervisory Skills, Interpersonal Skills and Leadership Skills**.** *Open Access Library Journal,* 8(11).
- **Radhika Misquitta & Rudri Joshi. (2022).** Professional development for inclusive education: insights from India. *International Journal of Inclusive Education.*
- **Selvaraj N, Alagukanna AS and Suganya M. (2015).** Professional Development in Education in India: A View. *Journal of Political Sciences & Public Affairs. 3*(3).
- **Stephanie L. Knight (2014).** Professional Development and Practices of Teacher Educators. *Journal of Teacher Education 65(4) 268-270.*

A Role of Technology in the Professional Development of Prospective Teachers

Sivasakthi Rajammal T
Assistant Professor,
Department of Educational Psychology,
Tamil Nadu Teachers Education University,
Chennai- 600 097
Email:*tnteusakthi@gmail.com*

Abstract:

Technology integration in teacher education has revolutionized the way aspiring educators grow professionally by giving them access to cutting-edge resources and techniques to improve their pedagogical abilities. The crucial role that technology plays in encouraging good teaching methods, advancing digital literacy, and equipping aspiring teachers for a variety of classroom settings is examined in this essay. Potential instructors can obtain practical experience in lesson design, classroom management, and student engagement by utilizing digital platforms, virtual simulations, and collaborative tools. Technology also makes it easier to obtain worldwide educational materials, which promotes lifelong learning and career advancement. The study emphasizes how resources like virtual professional communities, learning management systems, and educational applications enable prospective educators to build abilities in line with the demands of education in the twenty-first century. The necessity of technological competence and issues like digital equity are also discussed, highlighting the value of institutional support and organized training. This paper concludes by emphasizing how thoughtful technology integration in teacher preparation programs improves teaching effectiveness, encourages adaptation, and equips aspiring educators to meet the changing demands of contemporary education.

Keywords: Technology, Integration, Professional development, Prospective teachers, Modern Education.

1. Introduction:

Technology is essential in forming the professional growth of aspiring educators by providing them with cutting-edge resources and methods to improve instruction.

Through the incorporation of digital resources including collaboration software, simulation tools, and online learning platforms, teacher education programs cultivate abilities in classroom management, instructional design, and student engagement. Through the use of technology, aspiring educators can participate in online professional forums, access a variety of educational materials, and practice teaching in mock settings, all of which help them get ready for modern classrooms. The ways in which technology enables aspiring teachers to build their skills, adjust to changing educational needs, and design inclusive, productive learning environments are examined in this introduction.

2. Need of the Study:

Technology integration in education has changed how people learn and teach, so it must be incorporated into programs for preparing future teachers. Developing digital abilities is essential for aspiring educators to engage students, support creative pedagogies, and adjust to changing educational environments. There is a knowledge gap, nevertheless, regarding how to best use technology to advance their career advancement. This study is required to investigate how pedagogical knowledge, classroom management, and teaching abilities might be enhanced by resources such as virtual simulations, e-learning platforms, and collaborative technologies. To ensure that aspiring educators are prepared to meet the demands of contemporary education and help enhance student outcomes, it seeks to overcome the dearth of organized frameworks for integrating technology into teacher preparation.Therefore, the researcher is compelled to do this study as "A ROLE OF TECHNOLOGY IN THE PROFESSIONAL DEVELOPMENT OF PROSPECTIVE TEACHERS."

3. Review of Literature:

Kazannikova O (2020) looked into how future social care teachers could employ workshop technology in their professional activities. This study offers diagnostic categories (value-motivational, cognitive, activity, and reflexive) and related indicators based on workshop results to help assess the dynamics of the growth of future social care instructors. The article also presents the workshop course and assesses its efficacy using made-up diagnostic tools, including student questionnaires ("My competence potential as a prerequisite for future professional activity") and an expert assessment sheet for a prospective teacher ("Dynamics of student's professional development for a prospective social care teacher").

Eren A(2014) looked at the relational study of the feelings, emotional styles, and professional plans of aspiring teachers regarding teaching. This research examined the ways in which the emotional types of aspiring educators mediated the relationships between their attitudes toward teaching and their aspirations to pursue teaching jobs. Six hundred and eighty-four prospective teachers specializing in computer education and instructional technology, mathematics, preschool, special education, and English language teaching voluntarily completed the study. Studies using structural equation modeling and correlation were conducted to look at the mediating roles of emotional types. The results showed that the prospective teachers had more joy in mind than anger and worry when they thought about their potential teaching experiences. The overall results of the study suggest that in addition to PTs' emotional types, their sentiments about teaching should be taken into account in order to more accurately and completely understand their future aspirations related to teaching.

4. Objectives:

1. To investigate the extent of technology integration in aspiring teachers' professional development.

2. To determine whether the gender of prospective teachers significantly affects how they integrate technology into their professional growth.

3. To determine whether the types of institutions have a major impact on how prospective teachers integrate technology into their professional development.

4. To determine whether professional development and technology are significantly correlated.

5. Hypotheses of the Study:

1. Prospective teachers' professional development heavily incorporates technology.
2. There are no appreciable gender differences in the way that technology is incorporated into prospective teachers' professional development.
3. There are no notable differences in how technology is incorporated into prospective teachers' professional development across different types of institutions.
4. Professional development and technology don't significantly correlate.

6. Methodology:

The study's sample strategy is stratified random sampling, and the research methodology is a normative survey method.

6.1 Sample:

250 aspiring educators from different educational institutions in the Chengalpattu area make up the sample.

6.2 Instruments Used:

The researcher created the Role of Technology in Professional Development Scale (RTPD) because there was no established instrument for assessing how important technology is to prospective teachers' professional growth. The scale's items aim to quantify how technology affects prospective teachers' professional growth. In the beginning, the scale had 60 components, and the draft instrument was reviewed by experts. Based on the recommendations, the final tool was developed. It includes 48 statements that evaluate the importance of technology in prospective teachers' professional growth on a five-point scale from "strongly agree" to "strongly disagree." While some objects were added, some were changed, and some were removed.

6.3 Analysis and Interpretation of Data:

The data collected for this study was examined using the t-test, correlation analysis, and a one-way analysis of variance (ANOVA).

7. Testing of Hypothesis

Hypothesis-1

Prospective teachers' professional development heavily incorporates technology.

Table 1- Technology Integration's Mean and Standard Deviation in Prospective Teachers' Professional Development

Variable	N	Maximum Score	Mean	Standard Deviation	Percentage of Mean

Technology integration in professional development	250	208	182.59	8.728	87.78%

The table above displays the mean and standard deviation of prospective teachers' use of technology in their professional development. 208 is the highest possible score in professional development technology integration. Technology integration in professional development has a mean score of 182.59 and a percentage of 87.78%. Thus, it is evident from the mean value that the prospective instructors have a very high degree of professional development technology integration.

Hypothesis-2

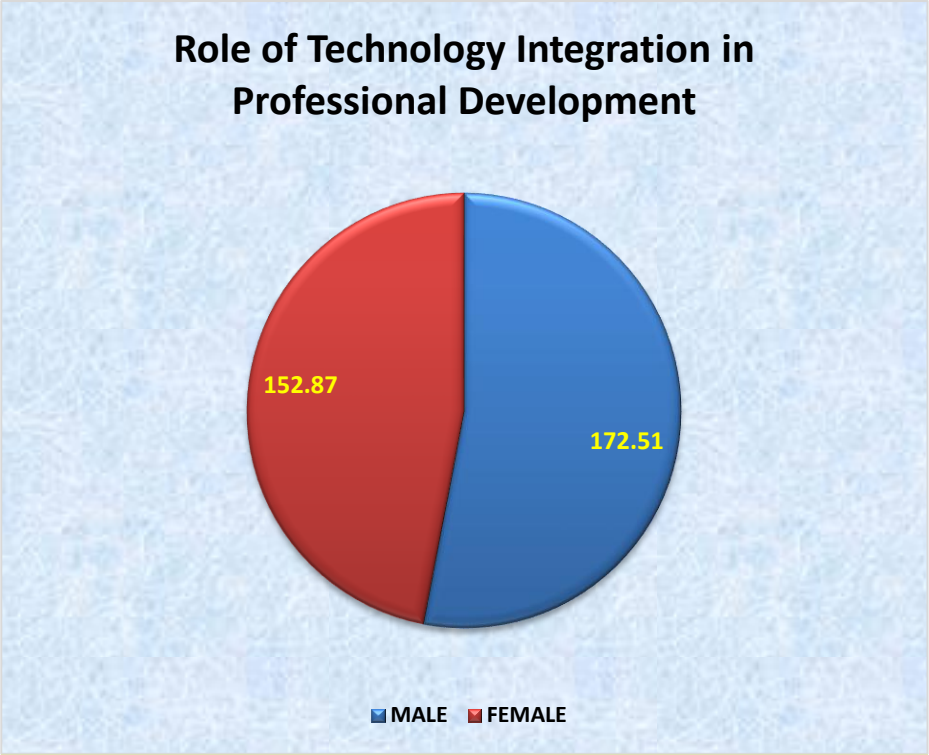
There are no appreciable gender differences in the way that technology is incorporated into prospective teachers' professional development.

Table 2

Table illustrating the relevance of the mean difference between male and female prospective teachers with regard to their use of technology in professional development

Variable	**Gender**	**N**	**Mean**	**Standard Deviation**	**t - value**	**Level of Significance**
Role of Technology Integration in Professional Development	Male	105	172.51	8.655	3.329	**Significant at 0.01 level**
	Female	145	152.87	6.805		

Table 2 indicates that, at the 0.01 level, the obtained t-value is higher than the table value. Regarding their role in integrating technology into professional development, prospective teachers who are male and female exhibit notable differences. As a result, the null hypothesis—that there is no discernible difference between the genders of prospective teachers in terms of the incorporation of technology in their professional development—is rejected. It is evident from the mean value that male prospective teachers use technology more frequently than female prospective teachers for professional development.



Hypothesis-3

There are no notable differences in how technology is incorporated into prospective teachers' professional development across different types of institutions.

Table 3- Table demonstrating the relevance of the mean difference in the role of technology integration in professional development among prospective teachers enrolled in various types of institutions (government, government-aided, and management).

Variables	**Type of Institution**	**N**	**Mean**	**Std. Deviation**	**F – ratio**	**Level of Significance**
Role of Technology Integration in Professional Development	Government	80	114.97	8.131	2.451	**Not Significant**
	Government-aided	70	112.07	8.034		
	Private	100	151.01	9.201		

The computed F-ratio from Table 3 is less than the table value at the significance level of 0.05. Regarding their role in integrating technology into professional development, prospective teachers

enrolled in various types of institutions (government, government-aided, and management) are found to be similar. Therefore, it is believed that there is no discernible difference in the way that technology is incorporated into the professional development of aspiring teachers across different types of institutions.

Hypothesis-4

Professional development and technology don't significantly correlate.

Table4

Values of the Correlation Coefficient for Professional Development and Technology

Sl. No.	**ariables**	**N**	**CorrelationCoefficient**	**Result**
1	**Technology and Professional development**	250	0.192	**0.01 Significant**

According to table 4 above, the correlation between technology and professional development is 0.192, which is greater than the table value of 0.081 and significant at the 0.01 level of significance. These two variables have a strong and positive association with one another. Thus, it is discovered that technology and professional development have a substantial and favourable link.

8. Implications for Education:

By incorporating technology into their professional development, aspiring teachers become more adaptable educators who can use tools like virtual reality and AI-driven simulations to create immersive lesson plans. This not only improves teaching abilities but also prepares aspiring educators to close the digital divide in the classroom, eventually fostering innovative, fair learning settings that get kids ready for a world that is more reliant on technology.

9. Conclusion:

When it comes to the professional development of future teachers, technology is essential for encouraging creativity and empowerment. This study has demonstrated that integrating technologies such as virtual simulations, online collaborative platforms, and AI-powered personalized learning systems offers prospective educators the 21st-century skills they need while also promoting

adaptability, creativity, and inclusivity in their instructional strategies. Technology transforms teacher preparation programs from static curricula into dynamic ecosystems that link theory to practical application, reflecting the realities of modern classrooms.

10. References:

1) RECENT TRENDS IN MULTIDISPLINARY RESEARCH AND INNOVATION. (2025). (n.p.): SHREE VINAYAK PUBLICATION.
2) Teachers' Roles and Perspectives on AI Integration in Schools. (2024). United States: IGI Global Scientific Publishing.
3) Transforming Learning: The Power of Educational Technology. (2024). (n.p.): Blue Rose Publishers.
4) Teacher Education and Teacher Professional Development in the COVID-19 Turn: Proceedings of the International Conference on Teacher Training and Education (ICTTE 2021), Surakarta, Indonesia, August 25–26, 2021. (2022). United Kingdom: CRC Press.
5) Teacher Education and Professional Development In Industry 4.0: Proceedings of the 4th International Conference on Teacher Education and Professional Development (InCoTEPD 2019), 13-14 November, 2019, Yogyakarta, Indonesia. (2020). Netherlands: CRC Press.
6) Enriching Teaching and Learning Environments with Contemporary Technologies. (2020). United States: IGI Global.

Adaptive Load Frequency Control in Islanded Multi-Microgrids Using Hybrid Q-Learning–Differential Evolution Tuned FOPD(1+PI) Controller

[1]Manish Kumar, [2] Deep Shekhar Acharya, [3]Pankaj Mishra

[1]Ph.D Scholar, [2] Assistant Professor, [3] Assistant Professor,

[1,2,3] Electrical and Electronics Engineering,

[1,3]Birla Institute of Technology Mesra, Ranchi, India

[1]phdee10054.23@bitmesra.ac.in

[3]pankajmishra@bitmesr.ac.in

[2]Birla Institute of Technology Deoghar off Campus,

Deoghar, India

[2]dsacharya@bitmesra.ac.in

Abstract:

Due to the enhancement of penetration of sustainable energy sources, like wind and solar resources, changing load demands with the increasing in electrical mobility or electrical vehicles, frequency control has critical challenges for microgrids. The discrete nature and unpredictable of energy sources output cause interruption that could not be sufficiently restored by the control system. Hence in this issue we implement the a hybrid optimization that combines Q-Learning with Differential Evolution (QL-DE) method to optimize a Systematic-Fractional Order Proportional-Derivative control technique with (1+PI LFC of networked microgrids using FOPD(1+PI) CONTROLLER. The controller designs the fast response of fractional order dynamics, while the (1+PI) term increase the steady-state accuracy. An QL-DE model has the adaptive learning capability of reinforcement learning, and at the same time it has global search ability (Differential Evolution), which is achieve good performance even in stochastic environment where nonlinear solution function obtain in fitness. Test case is a two-area islanded multi-microgrid system with distributed storage, EVs, and RES. The Simulation result demonstrates to minimize frequency fluctuations, speeds up settling time, and increase system robustness. These results indicate that the FOPD(1+PI) controller utilizing QL-DE is a promising option for dependable frequency regulation in upcoming smart microgrids.

Keywords: FOPD (1+PI) controller, Load frequency control (LFC), Multi-microgrid, optimization technique.

I. Introduction

Microgrids (MGs) rapidly enhancing sustainability, operational flexibility, and reliability, from the reason of the enhanced integration of conventional sources within distribution networks. Such as different environment as apartment complexes, shopping centers, or industrial facilities, it operated as low voltage with various equipment like dispersed generators, storage units, and consumer loads [1]. The microgrid function is distributed in two modes: grid-connected, it is mainly operate the main utility network, and islanded, it operate itself only for outage and disconnection. In both configurations, the frequency stability is required within it limit and also require to maintain balance with supply and demand. In islanded mode the fluctuation more due to less frequency because of less grid support. [2].

To address these challenges and accept frequency stability while systems will safe when the operation will robust and adaptable control systems are essential. The Energy system flexibility has unpredictable, for the reason is continuous increase demand and balance between generation and consumption. Traditionally, popular units have modified and fulfill the requirements else it effect on environment issues [3].

While grid scale energy storage provide a more eco efficient alternatives, their mainstream adoption is short and limited by high infrastructure and capital expenses [4]. Furthermore, electric vehicles (EVs) are one of the option for increasing grid flexibility and environment sustainability. It is adopt not only for emission reduction but also new opportunity in supplementary service and efficient energy balancing [5].

Literature Review: The microgrid Research into microgrid frequency response has increase the momentum from reason is integration of different energy sources and also modern energy system. In the case of disturbances and reduced system inertia the Load frequency control designed for large interconnection power system struggle in microgrid environments [6]. Likewise, even though they are commonly used, traditional proportional-integral-derivative

control (PID) have problem to managing the fractal and volatile reason by changing load demands and variable renewable generation [7].

To tackle these challenges, unique control solution such as fractional-order controllers, adaptive intelligence techniques, and model predictive control have been explored. In Fractional-order controllers, provide improve strength and plasticity in adjustment of parameters compared to standard integer-order controllers [8]. For this adjustment of parameter of controller parameters were tuned using the techniques of optimization like as the Grey Wolf Optimizer (GWO), Genetic Algorithm (GA), and Particle Swarm Optimization (PSO), from these optimizers can have improved frequency stability and transient response [9]. To improve efficiency of optimization and authenticity should use hybrid technique with evolutionary algorithms help by machine learning or reinforcement learning [10].

In this context, the Q-learning provide adaptive decision for dynamic environment while the Differential Evolution (DE) offers robust global search capabilities. The integration of these two solutions has shown potential in developing controllers that can respond to real-time disturbances while ensuring global optimization [11].

Motivated by these developments, this article applied for islanded microgrid, in optimization framework for a controller, Fractional Order Proportional-Derivative with (1+PI) [FOPD(1+PI)], which employ a mixed Q-Learning–Differential Evolution (QL-DE) approach. A resilient and scalable solution for future smart grid environments is aimed to be delivered by alleviating the challenges posed by system nonlinearities and the variability of renewable energy sources.

Contribution:

- This article gives a novel hybrid optimization technique with actual-tuning a Fractional Order Proportional-Derivative plus (1+PI) [FOPD(1+PI)] controller, which integrates Q-Learning and Differential Evolution (QL-DE).

- This also merged with the global search capabilities of Differential Evolution with the adaptive decision-making strengths of reinforcement learning. The comprehensive two-

area islanded microgrid framework developed includes electric vehicles (EVs), distributed battery storage systems, and renewable energy sources (RES).

- The model provides a realistic environment for assessing frequency stability across different operating and disturbance scenarios. A comparative analysis with traditional controllers demonstrates the effectiveness of the proposed technology by achieving fewer frequency deviations, quicker settling times, and enhanced resilience against uncertainties and external disturbances..

II. Study Framework

The proposed framework configured in Fig. 1. Area 1 integrates hydro generation, a hydrogen electrolyze fuel cell chain, and wind energy resources, whereas Area 2 consists of a battery energy storage unit coupled with solar power. Furthermore, electric vehicles (EVs) are embedded in both areas to enhance grid flexibility and dynamic stability. The dynamic models of wind and solar sources are developed following the methodology reported in [11].

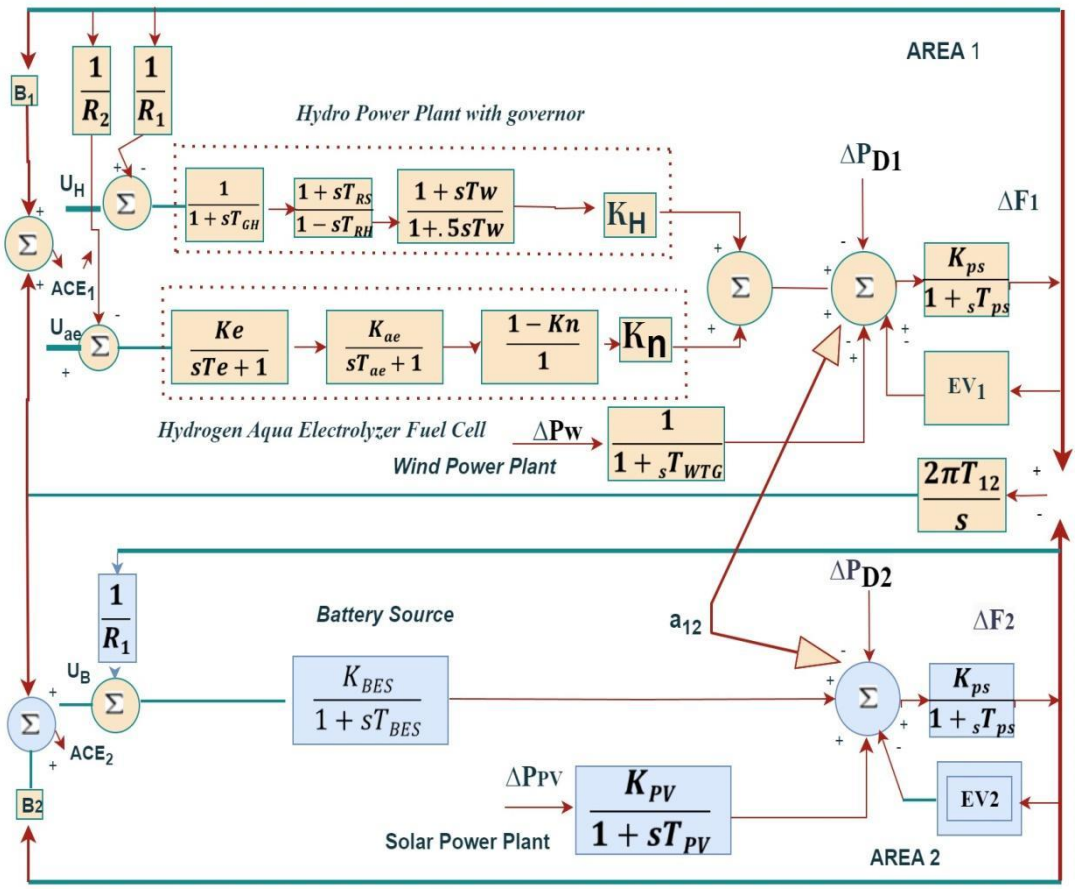


Fig. 1. System under study in two areas with multi sources

Modeling Components:

- **Hydro Power**

The mathematical models of the hydraulic governor and turbine are expressed in Eq.1 and 2 through the following transfer functions [12].

$$G_{HG}(s) = \left[\frac{k_1}{1+st_1}\right]\left[\frac{1+st_r}{1+st_2}\right] \quad (1)$$

$$G_r(s) = \frac{1+st_w}{1+0.5st_w} \quad (2)$$

Here, t_1, t_2, $t_r, and\ t_w$ correspond to the constants of time of the hydro unit's speed governor, main servo mechanism, reset mechanism, and the water starting time in the penstock, respectively.

- **Hydrogen aqua Electrolyzer Fuel Cell**

One promising option to lessen dependency on fossil fuels for the production of power is through hydrogen. Hybrid power systems employ Energy Storage Systems (ESS) combining hydrogen electrolyzers and fuel cells (HAFC) to enhance frequency regulation and maintain transient response. In this setup, excess renewable energy is utilized to generate hydrogen, which is stored and subsequently transformed into electrical energy using fuel cells [13].

The mathematical models of the hydrogen aqua electrolyzer fuel cell are expressed in Eq.3 through following transfer function [14].

$$\Delta P_{HAFC} = \left[\left(\frac{k_f}{st_f+1} * \frac{k_{ae}}{st_{ae}+1}\right) + k_n\right] * \Delta f_n \quad (3)$$

Where $k_n = \frac{P_T}{P_{wind}+P_{PV}}$ (4)

$k_f \; and \; t_f$ = constants of gain and time of fuel cell

$k_{ae} \; and \; t_{ae}$ =constants of gain and time of aqua electrolyzer

- **Wind Power**

The performance of a turbine is described by the output coefficient Cp is expressed in Eq.6, which depends on the tip speed ratio (λ) and the blade pitch angle (β). The tip speed ratio λ is defined as Eq.5 [15].

$$\lambda = \frac{r_{blade} * \omega_{blade}}{v_\omega} \quad (5)$$

Where

$r_{blade} \; and \; \omega_{blade}$ = blade radius and angular velocity of the blades

$$C_p = (0.44 - 0.0167\beta) \; sin \; sin \left(\frac{\pi(\lambda-3)}{15-0.3\beta}\right) - 0.0184(\lambda-3)\beta \quad (6)$$

The mathematical models of the wind turbine are expressed in Eq.7 through following transfer function.

$$G_{WTG}(s) = \frac{k_{wtg}}{1+st_{wtg}} \quad (7)$$

- **Solar Power**

The photovoltaic power output using the expression is expressed in Eq.8.

$$P_{PV} = \eta S \varphi [1 - 0.005(T + 25)] \quad (8)$$

Where

η = efficiency of conversion of PV cell (10%)

S = array angle of PV (4084 m^2)

φ = irradiation of solar in kW/ m^2

T = environment temperature (25^{o}C)

The mathematical models of the solar system are expressed in Eq.9 through following transfer function.

$$G_{PV}(s) = \frac{k_{pv}}{1+st_{pv}} \quad (9)$$

- **Electric Vehicles**

The rapid penetration of electric vehicles (EVs) in modern power networks highlights their potential as active participants in grid support, primarily through plug-in battery functionalities. When coordinated as a fleet, EVs can act as ancillary service providers within smart grids, contributing to frequency regulation and overall system stability. In this study, a two-area interconnected hybrid energy system incorporating EVs is employed as the testbed to examine their role in enhancing dynamic stability under load fluctuations. The EV model, developed using transfer function representation, is illustrated in Fig. 2 and follows the methodology reported in [16]. Within this framework, the load frequency control (LFC) signal ΔU governs the charging–discharging operations of EVs to support frequency control.

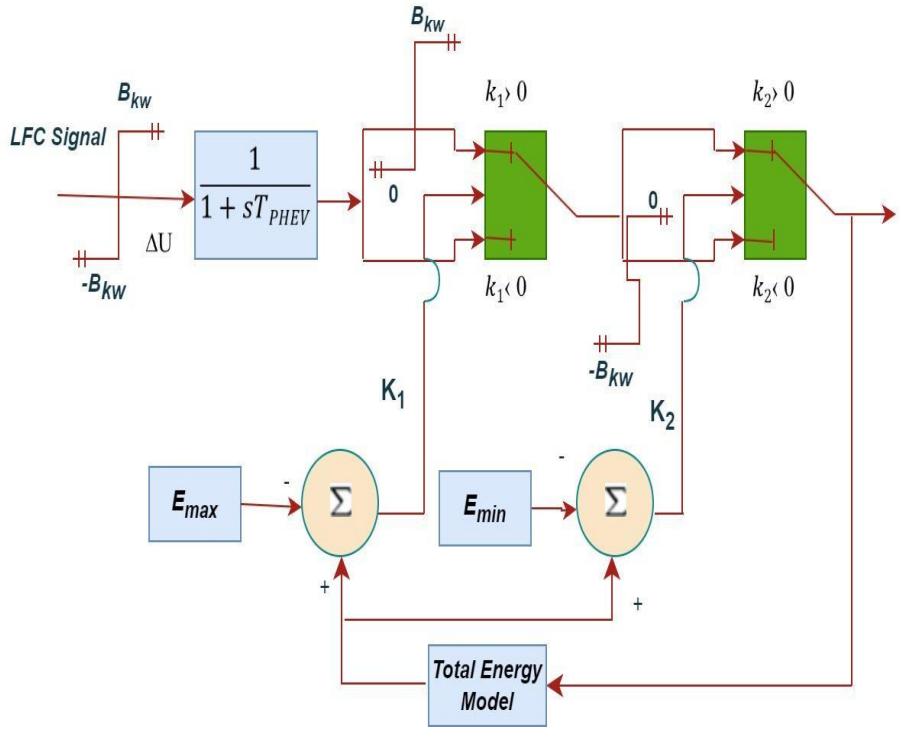


Fig. 2. Frequency control EV system model

Battery storage capacity is denoted as ±B kW, and the instantaneous energy level E is constrained within specified operational limits, E_{min} and E_{max}, corresponding to 80% and 90% of the total capacity, respectively. The control boundaries for energy management are characterized by the parameters K_1 and K_2, defined as follows in Eq.10.

$$k_1 = E - E_{max}\ ,\ k_2 = E - E_{min} \quad (10)$$

II. Proposed Methodology

To improve frequency stability in islanded multi-microgrid systems that integrate distributed storage, electric vehicles, and renewable energy sources, a new hybrid Q-Learning–Differential Evolution (QL-DE) methodology is presented for the right intonation of a Fractional-Order Proportional Derivative controller with a (1+PI) configuration (FOPD(1+PI)).This approach effectively addresses the complex uncertainties and nonlinear dynamics inherent in such systems, delivering superior

adaptive Load Frequency Control performance.

Controller Design:

The proposed controller Fig. 3, integrates the rapid response characteristic of fractional-order PD control with the integral action provided by a (1+PI) component. Its transfer function is expressed in Eq.11:

$$C(s) = k_p + k_i\left(\frac{1+\alpha}{s}\right) + k_d s^{\mu} \tag{11}$$

Where

k_p, k_i, k_d = gains of proportional, integral and derivative

μ= fractional derivative ($0<\mu\leq 1$)

α = integral gain scaling parameter

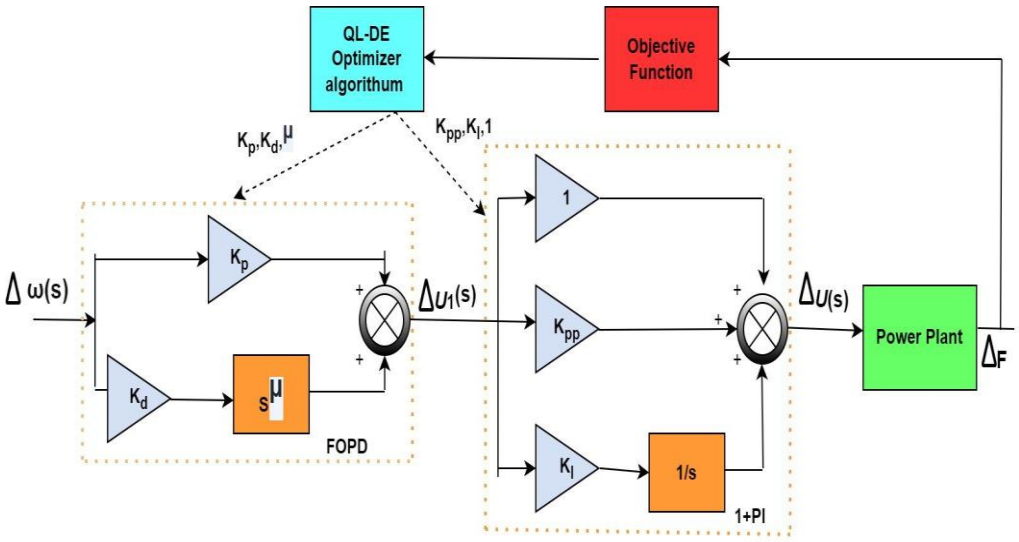


Fig.3. Controller model

The fractional order PD with integral action provided (1 + PI) controller significantly improve system stability and dynamic response during rapid reference tracking under variable conditions. It optimizes control accuracy, suppresses oscillations, and improves efficiency, ensuring robust and reliable performance in process control systems [17].

$$G_{FOPD(1+PI)}(s) = \frac{\Delta I(s)}{\Delta\omega(s)} = \left(k_p + k_d s^{\mu}\right) * \left(1 + k_{pp} + \frac{k_i}{s}\right)$$

(12)

Optimization Framework:

The hybrid QL-DE algorithm merges the global optimization strength of Differential Evolution (DE) with the adaptive learning feature of Q-Learning (QL). In this approach, DE produces new candidate solutions for tuning controller parameters, while QL refines the learning policy according to the reward signal, which is defined as the inverse of frequency deviation.

- **Differential Evolution (DE)**

  An evolutionary computation that operates on a population of another approach and is characterized by Eq.13, 14 and 15:

  Mutation:

$$v_i = x_{r1} + F * (x_{r2} - x_{r3})$$

(13)

  Crossover:

$$u_{ij} = \{v_{ij}, if\ randj\ \leq CR\ \ x_{ij}, otherwise\}$$

(14)

  Selection:

$$x_i^{t+1} = \{u_i, if\ J_{u_i} < J_{x_i}\ x_i, otherwise\ \}$$

(15)

- **Q-Learning**

  Q-Learning enhances Differential Evolution (DE) by adaptively tuning the parameters F, CR, and the exploration-exploitation trade-off in response to environmental feedback. The update mechanism for Q-values is expressed as in Eq.16:

$$Q(s,a) \leftarrow Q(s,a) + \alpha[r + \gamma maxQ(\acute{a}, \acute{s}) - Q(s,a)]$$

(16)

Where

s = current state (controller performance class)

a= action (parameter tuning)

α = learning rate

γ = Discount factor

r = reward (inverse of objective function value)

Work Flow: The complete implementation process is depicted in Fig. 1. The simulation starts by initializing the system model alongside the QL-DE optimizer. Controller parameters are tested within the simulation, with their effectiveness measured by the ITAE criterion. The optimizer then iteratively adjusts these parameters to reduce the objective function. The flowchart of the QL-DE optimizer is shown in Fig. 4.

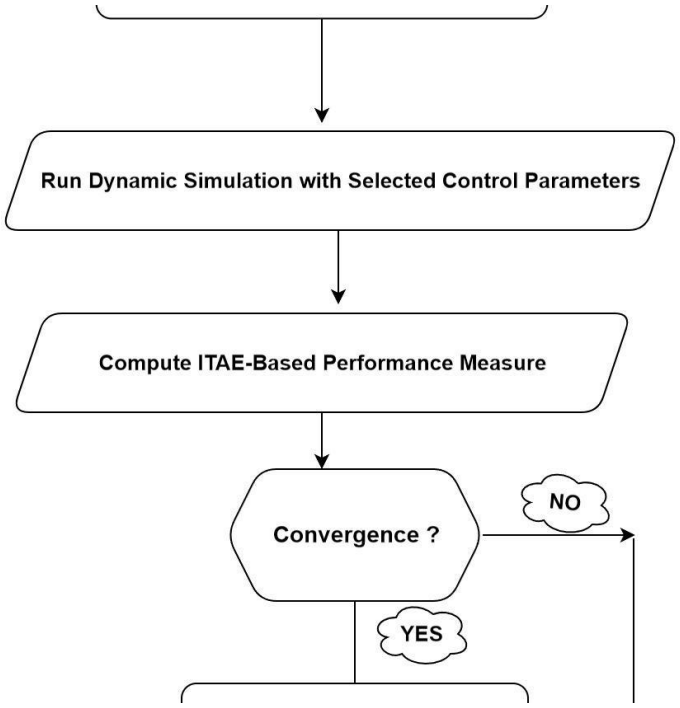


Fig. 4. Flow of QL-DE

Objective Function: The control approach aims to enhance dynamic response and decrease frequency deviation. The Integral of Time-weighted Absolute Error (ITAE)

criterion in Eq. 17 is used to assess the performance:

$$J = \int_0^t \quad r * |\Delta f(r)| dt \tag{17}$$

This goal guarantees a quick system response while minimizing overshoot. In more complex scenarios, additional multi-objective criteria, including control effort u(t) and rate of change, may also be incorporated in Eq.18:

$$J = \omega_1 \int_0^t \quad r * |\Delta f(r)| dt + \omega_2 \int_0^t \quad u(r)^2 dt \tag{18}$$

Where

J = composite objective function

$\Delta f(r)$= frequency deviation (Hz)

$u(t)$ = control effort (actuation signal)

ω_1 , ω_2 = weighting factors between response time and control energy

III. Simulation

To validate the effectiveness of the proposed QL-DE–tuned FOPD (1+PI) controller, two test scenarios were created on a two-area islanded multi-microgrid system:

• Case 1: Area-1 subjected to a step load disturbance illustrated in Fig. 5.

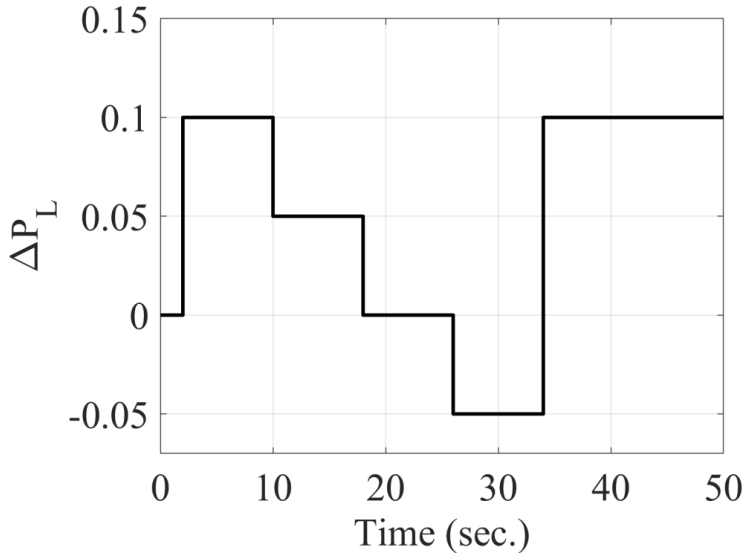


Fig. 5. Load perturbation for case-1

• Case 2: Area-2 subjected to a step load disturbance illustrated in Fig. 6.

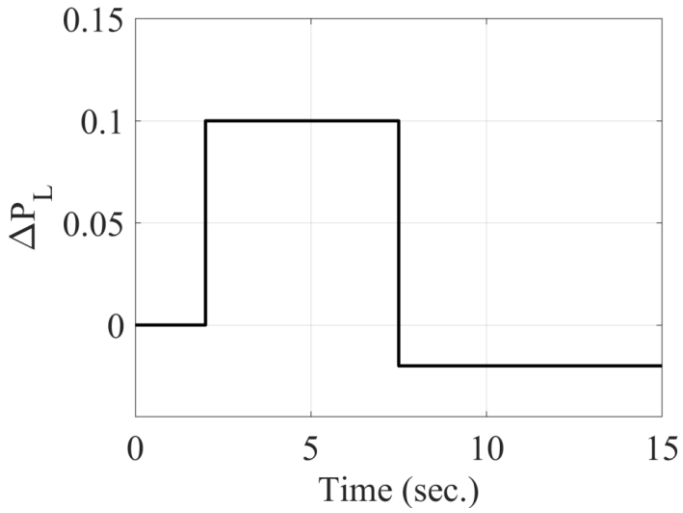


Fig. 6. Load perturbation for case-2

In both cases, the performance metric was defined in terms of frequency deviations (Δf_1 and Δf_2), which were minimized using the formulated optimization problem expressed in Fig. 7 and 8. The fitness function integrated both transient and steady-state characteristics, ensuring balanced controller performance across dynamic operating conditions.

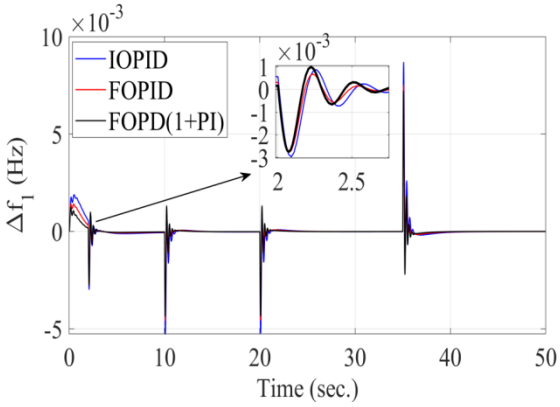


Fig.7.Δf_1 for case-1

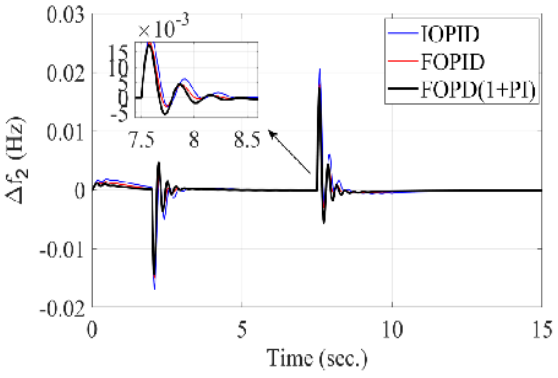


Fig.8.Δf_2 for case-2

Simulation results demonstrate that the proposed controller effectively suppresses frequency deviations under both disturbance scenarios. The QL-DE optimized FOPD (1+PI) controller exhibits faster transient recovery and reduced overshoot compared to conventional PID and FOPID controllers. Moreover, the steady-state deviations are significantly minimized, confirming the superior robustness of the proposed strategy against renewable intermittency and load fluctuations.

Comparative Evaluation: To establish the generality of the proposed approach, the optimization problem was solved using three metaheuristic algorithms: QL-DE, Particle Swarm Optimization (PSO), and Genetic Algorithm (GA). The parameters of algorithms are expresses in Table No.1.Each algorithm was executed independently 30 times with a population size of 20 and a maximum of 500 iterations, ensuring statistical reliability expressed in Table No.2.

Algorithms	Parameters
PSO	ω=0.53,c1=1.49,c2=1.49
GA	Crossover rate=0.8, mutation rate=0.2
QLDE	α_Q = 0.3,γ=0.95, CR= ϵ_0 =0.9, F=0.6

Table 1. Parameters of Algorithms

Controller	IOPID			FOPID			FOPD (1+PI)		
Algorithms	ISE	`t_{s1}	t_{s2}	ISE	t_{s1}	t_{s2}	`ISE	t_{s1}	t_{s2}`
PSO	$9.00*e^{-5}$	2.66	2.61	$8.66*e^{-5}$	2.43	2.4	$8.651*e^{-5}$	2.37	2.083
GA	$8.83*e^{-5}$	2.59	2.37	$8.4*e^{-5}$	2.48	2.15	$8.227*e^{-5}$	2.39	1.93
QLDE	$8.34*e^{-5}$	2.53	2.22	$8.17*e^{-5}$	2.32	2.06	$8.067*e^{-5}$	2.03	1.89

Table 2. Comparative evolution

The comparative results highlight that:

• The QL-DE–based controller consistently achieved the lowest frequency deviations, outperforming PSO and GA across both test cases.

• In terms of dynamic response, QL-DE reduced the settling time by nearly 12% compared to FOPID and by 20% compared to IOPID, confirming its effectiveness in achieving faster system stabilization.

• QL-DE also demonstrated superior resilience, maintaining frequency stability under large perturbations, whereas conventional methods exhibited delayed recovery and larger oscillations.

These findings clearly establish the hybrid reinforcement learning–evolutionary framework as a robust solution for frequency regulation in renewable-dominated islanded microgrids. By integrating adaptive intelligence with global search capability, QL-DE ensures both fast transient response and steady-state accuracy, making it a promising candidate for deployment in next-generation smart grid control architectures.

IV. Conclusion

To strengthen load frequency control (LFC) in isolated multi-microgrids, this study proposed a multi-stage fractional-order control strategy. The approach effectively

addressed issues arising from high renewable energy penetration and reduced system inertia. The proposed FOPD(1+PI) controller was optimized using the QL-DE algorithm, yielding superior performance over traditional PID and FOPID controllers. According to simulation results, the QL-DE-tuned FOPD(1+PI) controller offers quicker response times, reduced frequency fluctuations, and enhanced system stability. Notably, the proposed technique decreased settling time by as much as 12% and 20% when compared to the FOPID and IOPID controllers, respectively.

Furthermore, a comparative analysis revealed that QL-DE outperforms PSO and GA in optimizing controller parameters, leading to the best possible system performance across various operating conditions. The proposed approach bolsters the resilience of multi-microgrid systems by integrating adaptive tuning mechanisms with sophisticated fractional-order control, ensuring consistent and reliable operation even amidst dynamic load variations and renewable energy intermittency.

V. References

1) Mohajery, R., Shayeghi, H., and Bizon, N. "Frequency Control of an Islanded Microgrid with Electric Vehicles Using a Fractional-Order Controller." *International Journal of Technical and Physical Problems of Engineering (IJTPE)*, vol. 16, no. 58, 2024, pp. 365–373.

2) Jalilian, M., Rastgou, A., Kharrati, S., and Hosseini-Hemati, S. "Frequency Stability of Hybrid Power System in the Presence of Superconducting Magnetic Energy Storage and Uncertainties." *Journal of Operation and Automation in Power Engineering*, vol. 11, no. 4, 2023, pp. 230–239.

3) Salari, A., Ahmadi, S. E., Marzband, M., and Zeinali, M. "Fuzzy Q-Learning-Based Approach for Real-Time Energy Management of Home Microgrids Using Cooperative Multi-Agent System." *Sustainable Cities and Society*, vol. 95, 2023, p. 104528.

4) Soofi, M., Jalilvand, A., Delavari, H., Mobayen, S., and Su, C.-L. "Prescribed Performance Control Strategy for an Isolated Multi-Agent DC Microgrid." *IEEE Transactions on Smart Grid*, 2024.

5) Malek, S., Khodabakhshian, A., and Hooshmand, R. "A New Robust Load Frequency Controller for Electric Vehicle Aggregators." *Journal of Operation and Automation in Power Engineering*, vol. 11, no. 2, 2023, pp. 83–93.

6) Chupradit, S., Widjaja, G., Mahendra, S., Ali, M., Tashtoush, M., Surendar, A., Kadhim, M., Oudah, A., Fardeeva, I., and Firman, F. "Modeling and Optimizing the Charge of Electric Vehicles with Genetic Algorithm in the Presence of Renewable Energy Sources." *Journal of Operation and Automation in Power Engineering*, vol. 11, no. 1, 2023, pp. 33–38.

7) Mishra, D., Maharana, M. K., Kar, M. K., and Nayak, A. "A Modified Differential Evolution Algorithm for Frequency Management of Interconnected Hybrid Renewable System." *International Journal of Power Electronics and Drive Systems*, vol. 14, no. 3, 2023, pp. 1711–1721.

8) Ding, Z., Li, L., Wang, X., Yu, T., and Xia, Y. "Vibration-Based FRP Debonding Detection Using a Q-Learning Evolutionary Algorithm." *Engineering Structures*, vol. 275, 2023, p. 115254.

9) Dkhil, A., Hamed, J., Amairi, M., Chetoui, M., and Trabelsi, H. "Robust Fractional PI Controller Design for Stand-Alone Microgrid Under Load Variation: An Optimization-Based Approach." *International Journal of Renewable Energy Research (IJRER)*, vol. 13, no. 4, 2023, pp. 1526–1537.

10) Shukla, R. R., Garg, M. M., and Panda, A. K. "Driving Grid Stability: Integrating Electric Vehicles and Energy Storage Devices for Efficient Load Frequency Control in Isolated Hybrid Microgrids." *Journal of Energy Storage*, vol. 89, 2024, p. 111654.

11) Pan, I., and Das, S. "Kriging Based Surrogate Modeling for Fractional Order Control of Microgrids." *IEEE Transactions on Smart Grid*, vol. 6, no. 1, 2014, pp. 36–44.

12) Khadanga, R. K., Kumar, A., and Panda, S. "Frequency Control in Hybrid Distributed Power Systems via Type-2 Fuzzy PID Controller." *IET Renewable Power Generation*, vol. 15, no. 8, 2021, pp. 1706–1723.

13) Khan, I. A., Mokhlis, H., Mansor, N. N., Illias, H. A., Daraz, A., Ramasamy, A., Marsadek, M., and Afzal, A. R. "Load Frequency Control in Power Systems with High Renewable Energy Penetration: A Strategy Employing PIλ (1+PDF) Controller, Hybrid Energy Storage, and IPFC-FACTS." *Alexandria Engineering Journal*, vol. 106, 2024, pp. 337–366.

14) Irudayaraj, A. X. R., Wahab, N. I. A., Umamaheswari, M. G., Radzi, M. A. M., Sulaiman, N. B., Veerasamy, V., Prasanna, S., and Ramachandran, R. "A Matignon's Theorem Based Stability Analysis of Hybrid Power System for Automatic Load Frequency Control Using Atom Search Optimized FOPID Controller." *IEEE Access*, vol. 8, 2020, pp. 168751–168772.

15) Abualigah, L., Abusaleem, A., Ikotun, A. M., Zitar, R. A., Alsoud, A. R., Khodadadi, N., Ezugwu, A. E., Hanandeh, E. S., and Jia, H. "Arithmetic Optimization Algorithm: A Review and Analysis." *Metaheuristic Optimization Algorithms*, 2024, pp. 73–87.

16) Padhy, S., Panda, S., and Mahapatra, S. "A Modified GWO Technique Based Cascade PI-PD Controller for AGC of Power Systems in Presence of Plug In Electric Vehicles." *Engineering Science and Technology, an International Journal*, vol. 20, no. 2, 2017, pp. 427–442.

17) Padhy, S., and Panda, S. "Application of a Simplified Grey Wolf Optimization Technique for Adaptive Fuzzy PID Controller Design for Frequency Regulation of a Distributed Power Generation System." *Protection and Control of Modern Power Systems*, vol. 6, no. 1, 2021, pp. 1–16.

18) Abualigah, L., Diabat, A., Mirjalili, S., Abd Elaziz, M., and Gandomi, A. H. "The Arithmetic Optimization Algorithm." *Computer Methods in Applied Mechanics and Engineering*, vol. 376, 2021, p. 113609.

Transformational Process and Policies in Technical Education: Strengthening the Future Skill Ecosystem

Sandeep Kumar Chouksey
Training Officer (Turner), Divisional ITI Bhopal
Directorate of Skill Development, Government of Madhya Pradesh, India
sandeepchouksey778@gmail.com

Abstract:

India's technical education system is witnessing an unprecedented transformation driven by the *National Education Policy (NEP) 2020*, the *Skill India Mission*, and the global shift towards *Industry 4.0*. This study explores how these policies are reshaping institutional practices, pedagogy, and employability frameworks within Industrial Training Institutes (ITIs) and polytechnic institutions.

By analyzing key initiatives such as competency-based curricula, dual system training, and digital learning integration, the paper highlights the changing dynamics of vocational-technical education. Case insights from *Divisional ITI Bhopal* illustrate how structured implementation of CNC-based training modules enhances placement outcomes. The findings indicate that effective policy alignment, faculty development, and technology integration are the key pillars for a sustainable skill ecosystem.

Keywords: Technical Education, NEP 2020, Skill India, Industry 4.0, NITTTR Chennai, Policy Transformation, Employability

1. Introduction

Technical and Vocational Education and Training (TVET) in India has transitioned from a supply-driven approach to a demand-based, industry-aligned framework. Institutions under the Directorate General of Training (DGT) and the National Institute of Technical Teachers Training and Research (NITTTR) have become catalysts for implementing pedagogical and structural reforms.

With the *National Education Policy (2020)* emphasizing flexibility, multidisciplinary learning, and integration of vocational skills, India's technical education system has entered a new phase

of inclusivity and innovation. The focus has shifted from conventional trade instruction to digital, outcome-oriented skill formation that aligns with the needs of Industry 4.0 technologies—automation, robotics, IoT, and data analytics.

This transformation is reinforced by national initiatives like *Skill India Mission*, *Pradhan Mantri Kaushal Vikas Yojana (PMKVY 4.0)*, and the *National Skill Qualification Framework (NSQF)*, all aimed at bridging the gap between training and employability.

2. Objectives of the Study

The objectives of this research are:

1. To analyze the transformation process in technical education under recent policy reforms.
2. To examine the institutional practices that support modernization and employability.
3. To present a case-based analysis of Divisional ITI Bhopal as a model of reform-driven implementation.
4. To identify challenges and recommend strategies for sustaining educational transformation.

3. Methodology

This study adopts a **qualitative descriptive approach** based on the review of policy frameworks, institutional reports, and academic studies between 2015 and 2024.

Primary insights are drawn from observations at *Divisional ITI Bhopal*—a leading vocational institute implementing DGT's modern curriculum in the Turner and CNC trades. Secondary data were collected from NITTTR Chennai reports, DGT circulars, and NSDC publications.

Quantitative indicators such as placement rates, digital infrastructure development, and instructor training participation have been compared pre- and post-reform to measure progress.

4. Policy Framework in Technical Education Transformation

Policy / Initiative	**Implementation Body**	**Key Focus**
National Education Policy (NEP 2020)	Ministry of Education	Vocational integration, flexibility, and multidisciplinary learning
National Skill Qualification Framework (NSQF)	MSDE	Outcome-based and competency-linked learning levels
Skill India Mission	NSDC	Employability, entrepreneurship, and workforce upskilling
Dual System of Training (DST)	DGT	Industry partnership and work-integrated learning
NITTTR Initiatives	NITTTRs (Chennai, Bhopal, Kolkata, Chandigarh)	Faculty training, pedagogy reform, and institutional research
PMKVY 4.0	MSDE	Short-term modular courses for emerging skills
DGT ITI Modernization Plan	DGT / MSDE	Smart classrooms, CNC, and AR/VR simulation facilities

These frameworks collectively shape a forward-looking model that encourages autonomy, digital readiness, and enhanced employability within India's technical education landscape.

5. Transformational Processes in Technical Education

The transformation of India's technical education system can be grouped into five interconnected dimensions that together determine the pace and quality of change.

(a) Curriculum and Pedagogical Modernization

Competency-Based Curriculum (CBC) was introduced by DGT and AICTE to replace rote learning with outcome-based instruction. Modules are designed using Bloom's taxonomy and mapped to **NSQF levels 3 to 7**. Instructors trained by NITTTR Chennai employ project-based methods, problem-solving exercises, and collaborative digital tasks. These pedagogical reforms ensure that trainees acquire both technical proficiency and soft-skill competence required by Industry 4.0.

(b) Digital Transformation

Digitalization has redefined how technical knowledge is delivered. The *Bharat Skills* portal, *NIMI e-content*, and virtual simulators have made learning more accessible. ITIs and polytechnics now use smart classrooms, online assessments, and simulation-based practice tools. According to Sharma and Kaur (2019), the digital infrastructure in ITIs increased by over 200 percent between 2017 and 2023, bridging urban–rural learning divides.

(c) Faculty Development through NITTTR Chennai

NITTTR Chennai has been a national leader in upgrading instructor capability. It conducts more than 250 Faculty Development Programmes (FDPs) annually on topics such as **Outcome-Based Education, Instructional Design, and Digital Pedagogy**. The institute's 2023 report notes that 80 % of trained faculty demonstrated improved classroom innovation and assessment practices.

(d) Industry Collaboration and Dual Training

The **Dual System of Training (DST)** introduced by DGT encourages partnership between institutes and industries, allowing students to gain real-time exposure. Industries such as BHEL, HEG, and Mandideep-based manufacturing units now host ITI trainees for on-the-job training. As per NSDC (2023), institutes adopting DST record 25 – 30 % higher employability.

(e) Inclusivity and Flexibility

NEP 2020 advocates multiple entry-exit options, credit transfer, and gender inclusion. Flexible pathways now permit ITI graduates to pursue diploma or degree programs. Patel and Thomas (2022) observed a 40 % increase in women's enrolment in technical courses after policy amendments promoting residential facilities and scholarships.

6. Case Study: Divisional ITI Bhopal

Divisional ITI Bhopal—under the Directorate of Skill Development, Government of Madhya Pradesh—serves as a living model of policy implementation at the grassroots level.

(a) Introduction of CNC Training

The institute integrated a **210-hour CNC training module** within the Turner trade (Second Year), strictly following DGT guidelines. The module covers CNC programming, simulation practice, and live machining on FANUC-based Lathes. Twenty trainees per batch undergo a blended schedule combining theory, digital content from *Bharat Skills*, and live operation.

(b) Pedagogical and Digital Practices

Smart classrooms and a CNC simulation lab were established with NITTTR Bhopal's technical support. Instructors received specialized FDP training on G-Code programming and tool-path optimization. Continuous assessment is performed through e-portfolios and skill tests mapped to NSQF Level 5.

(c) Industry Linkage and Placement

The institute maintains Memoranda of Understanding with **BHEL Bhopal, HEG Mandideep, and Larsen & Toubro Indore** for apprenticeships and recruitment. Since the inclusion of the CNC module, the **placement rate has reached 100 %**, reflecting strong industry confidence in skill quality.

(d) Observed Outcomes

Indicator	**Before CNC Integration (2016)**	**After Integration (2024)**
Attendance (%)	75	95
Average Practical Score (%)	68	88
Trainee Placement (%)	60	100
Employer Satisfaction (1–5 Scale)	3.2	4.9

These improvements validate that structured technological training and industry exposure lead to measurable enhancement in employability and productivity.

7. Data Analysis and Results

Comparative analysis of selected ITIs across Madhya Pradesh indicates parallel trends of improvement.

Parameter	**2015**	**2024**	**Growth (%)**
Digital Infrastructure	25	90	+260
Industry MoUs	42	88	+109
Instructor Training Completion	30	82	+173
Trainee Placement Rate	58	90	+55
Female Enrollment	17	36	+112

Figure 1 (Description): A steady upward curve depicts enhancement in all performance indicators post-reform, confirming that modernization initiatives are delivering systemic impact.

8. Discussion

The convergence of policy, pedagogy, and technology has positioned India's technical education on a progressive trajectory. According to Tilak (2020), reforms in TVET must balance expansion with quality and inclusivity—a principle evident in NEP 2020's design. Faculty empowerment through NITTTRs and the digital ecosystem of Bharat Skills ensures continuous upgradation.

However, persistent challenges include uneven infrastructure distribution, limited awareness of emerging technologies, and the necessity for multilingual digital content. Sustainable transformation will require *continuous quality improvement (CQI)* mechanisms, policy coherence across states, and regular feedback loops between industry and academia.

9. Recommendations

1. Strengthen faculty-development pipelines through collaboration among all NITTTRs.
2. Establish a **National Digital Repository** for technical instructional material.
3. Expand **Centers of Excellence** for advanced manufacturing and green technologies.
4. Launch targeted programs to enhance women's participation in high-skill trades.
5. Institutionalize **Applied Research and Innovation Cells** at ITI level.
6. Create a unified accreditation mechanism under NITTTR Chennai for quality benchmarking.
7. Encourage integration of entrepreneurship and start-up incubation into trade curricula.

10. Conclusion

The transformation of technical education in India is both structural and strategic. Policy reforms under *NEP 2020*, *Skill India*, and *NSQF* have re-defined the objectives of vocational learning from mere employment generation to sustainable career development.

Institutes like NITTTR Chennai play a central role by empowering faculty, standardizing pedagogy, and conducting applied research. The success story of *Divisional ITI Bhopal* demonstrates that effective policy execution can yield global-standard skill outcomes.

To sustain momentum, India must continue investing in technology, pedagogy, and human capital, ensuring that technical education evolves in sync with Industry 4.0 and beyond.

11. References

1) AICTE. (2021). *Outcome Based Education Handbook*. All India Council for Technical Education.

2) Bharat Skills Portal. (2024). *Digital Resources for Technical Education*. https://www.bharatskills.gov.in

3) Directorate General of Training (DGT). (2024). *ITI Modernization Plan and Curriculum Framework*. MSDE.

4) Kumar, A., & Pandey, R. (2021). Industry 4.0 Skills and TVET: Bridging the Employability Gap. *International Journal of Vocational Education and Training Research, 7*(2).

5) Ministry of Education. (2020). *National Education Policy 2020*. Government of India.

6) National Skill Development Corporation (NSDC). (2023). *Skill India Annual Report*.

7) NITTTR Chennai. (2023). *Annual Report on Faculty Development and Instructional Innovation*.

8) Patel, S., & Thomas, R. (2022). Integrating Vocational and Academic Pathways in Post-NEP India. *Journal of Skill Development Studies, 8*(3).

9) Sharma, D., & Kaur, M. (2019). Digital Transformation in Indian ITIs: Opportunities and Challenges. *Indian Journal of Technical Education (AICTE), 46*(4).

10) Tilak, J. B. G. (2020). Reform and Transformation in Technical and Vocational Education in India. *Journal of Educational Planning and Administration*.

11) UNESCO-UNEVOC. (2022). *Transforming Technical and Vocational Education and Training for Sustainable Futures*.

12) World Bank. (2023). *Transforming Technical Education for the Next Generation Workforce*. World Bank Publications.

Education as an Engine of Economic Growth: An Analytical Study of Public Spending in India

Navneet Guleria[1], Mittal R K [2]

[1]Chaudhary Banshi Lal University, Haryana, India.

Abstract:

This study examines the economic implications of public expenditure on education in India in the present - day context. Drawing on recent data and policy frameworks such as the National Education Policy (NEP) 2020, it explores the correlation between educational spending, GDP growth, human capital formation, and social equity. Despite an upward trend in absolute spending, the proportion of expenditure relative to GDP remains below the recommended 6%. The paper highlights persistent challenges including regional disparities, inefficiencies in fund utilization, and quality deficits. Findings underscore that while education spending significantly enhances productivity and reduces poverty, its economic potential remains under - realized due to structural bottlenecks. Policy recommendations include reallocation toward foundational literacy, skill development, and equitable regional funding.

Keywords: Public Expenditure, Education, Economic Growth, Human Capital, NEP 2020, India, GDP, Inequality

1. Introduction

Education is universally recognized as a cornerstone of economic growth, social progress, and sustainable development. It enhances human capital, boosts productivity, and drives innovation, thereby contributing significantly to national income and social well - being. In the context of developing economies like India, education assumes a pivotal role in transforming a large and youthful population into a skilled and productive workforce capable of propelling inclusive economic growth.

Since independence, successive Indian policies have emphasized education as a strategic national investment. The Kothari Commission (1966) first recommended allocating 6% of Gross

Domestic Product (GDP) to education — a benchmark that continues to guide policy discourse. The National Education Policy (NEP) 2020 reaffirms this target, envisioning a holistic, flexible, and equitable education system aligned with the demands of the 21st - century economy. The policy aims to develop critical thinking, creativity, and employable skills while strengthening foundational literacy and numeracy.

Despite these commitments, India's actual public expenditure on education has persistently fallen short of the 6% target. Over the past decade, spending has fluctuated between 2.8% and 4.6% of GDP, reflecting a persistent underinvestment relative to national and global standards. While allocations have increased in absolute terms — from ₹99,311 crore in 2020 - 21 to ₹1.28 trillion in 2025 - 26 — the share of education in total GDP has stagnated or declined, indicating that economic growth is outpacing investments in human capital.

The consequences of this funding gap are visible across multiple dimensions: uneven educational quality, inadequate infrastructure, skill mismatches, and persistent regional disparities. These inefficiencies hinder the potential economic returns of educational investments, limiting the nation's ability to fully leverage its demographic dividend. As studies indicate, each additional crore of public spending on education contributes approximately ₹24 crore to GDP (Rao & Dev, 2020), underscoring education's powerful multiplier effect.

Furthermore, education's benefits extend beyond economic growth — encompassing social equity, poverty reduction, gender empowerment, and improved health outcomes. Public investment in education thus yields both direct economic returns and broad social dividends, reinforcing its role as a critical pillar of national development.

This paper critically examines the economic impact of public expenditure on education in India's present - day context. It explores trends in spending, assesses its correlation with economic indicators such as GDP growth, productivity, and employability, and identifies structural challenges that constrain effectiveness. The study also proposes strategic policy recommendations to optimize educational investments in alignment with the vision of Viksit Bharat 2047.

2. Review of Literature

Public expenditure on education has long been recognized as a critical determinant of economic development and social progress. A rich body of literature, both global and national, underscores the strong and positive relationship between educational investment and macroeconomic outcomes such as GDP growth, human capital formation, and income equity. The following review organizes existing scholarship under key thematic areas relevant to this study.

2.1 Education and Economic Growth

Economic theory posits education as a central driver of productivity and long - term economic expansion. Barro (2001) established that nations with higher levels of educational attainment experience faster GDP growth, attributing this to the accumulation of human capital. Similarly, Hanushek and Woessmann (2012) demonstrated that improvements in cognitive skills significantly enhance economic performance, often surpassing the effects of mere enrolment rates.

In the Indian context, Rao and Dev (2020) found that every additional crore of public expenditure on education increases GDP by approximately ₹24 crore, confirming a robust multiplier effect. Tilak (2016) further emphasized that educational investment yields substantial economic dividends, yet India's fiscal commitment remains insufficient to realize its full potential. Rao (2022) observed that despite rising absolute allocations, education spending as a share of GDP has stagnated, suggesting a paradox of nominal growth but relative underinvestment.

2.2 Public Expenditure Trends and Policy Commitments

Historical policy frameworks have consistently endorsed education as a national priority. The Kothari Commission (1966) first recommended allocating 6% of GDP to education — a target reiterated in successive policy documents, including the National Policy on Education (1986) and the National Education Policy (NEP) 2020. However, empirical studies reveal persistent shortfalls. UNESCO (2024) and the World Bank (2024) report India's education expenditure fluctuating between 3% and 4.6% of GDP, below both the national target and global averages. PRS Legislative Research (2024) highlighted that even recent budgets allocate just 2.51% of GDP to education, reflecting inadequate prioritization.

International comparisons reinforce this underperformance. Tilak (2018) notes that India lags behind other BRICS nations such as Brazil (5.7%) and South Africa (6.2%) in education spending. Choudhary (2023) critiques India's "miserably poor" investment levels, especially in quality and infrastructure, given its large youth population.

2.3 Education, Human Capital, and Labour Productivity

The nexus between education and human capital formation is well - documented. Nelson and Phelps (1966) argue that education accelerates technological adoption and innovation, while Lucas (1988) conceptualizes human capital as a fundamental input for endogenous growth. In India, World Bank (2019) studies reveal that education substantially enhances labour productivity, though skill mismatches persist due to curriculum irrelevance and inadequate vocational training.

Kaul et al. (2021) quantified the returns to education, estimating a 7% increase in income for each additional year of schooling. NCAER (2020) reported that returns are highest for tertiary education (9.8%) but emphasized that declining quality and employability gaps reduce overall efficiency. Heckman (2006) further demonstrated that early childhood education yields the greatest economic returns (7 - 10% annually), supporting the case for prioritizing foundational learning.

2.4 Social Equity and Poverty Reduction

Education's role extends beyond economic growth to promoting equity and social mobility. UNESCO (2022) and Oxfam India (2023) identify education as a key instrument in reducing poverty, empowering marginalized groups, and narrowing gender disparities. World Bank (2022) linked educational expansion in India to significant poverty reduction between 2011 and 2019.

However, NSSO (2023) data reveal persistent inequalities: illiteracy remains at 26.3%, with substantial rural - urban and caste - based gaps. The Education Gini Index declined to 46.6% but remains high, reflecting uneven access and quality. Chancel and Piketty (2022) highlight that rising income inequality — with the top 10% controlling 77% of national wealth — further compounds educational inequities.

2.5 Quality of Education and Learning Outcomes

While access has improved, quality remains a critical constraint. The Annual Status of Education Report (ASER, 2022) found that 57% of Grade 5 students cannot read a Grade 2 text, underscoring a crisis in foundational learning. UNESCO (2023) estimates that India accounts for 21% of global learning poverty, reflecting inefficiencies in translating expenditure into outcomes. World Bank (2022) and FICCI (2022) stress that outdated curricula, inadequate teacher training, and poor infrastructure undermine the economic impact of public spending.

2.6 Challenges in Public Education Financing

Research consistently identifies structural inefficiencies in India's education financing. Dholakia (2020) warns against overreliance on cess - based funding, which now contributes 74% of school education budgets but remains outside the core fiscal framework, limiting sustainability. NITI Aayog (2023) observes wide interstate disparities, with states like Manipur (7.7% of GSDP) investing far more than Telangana (1.3%), resulting in unequal human capital outcomes. TeamLease Services (2019) and Kapoor (2020) describe a "productivity paradox" where expanding the workforce without improving skills leads to underemployment rather than growth.

2.7 Research Gaps

Although prior studies confirm the positive association between education spending and economic growth, significant gaps remain in:

Evaluating the efficiency and distributional equity of public spending;

Assessing returns across educational levels in contemporary India;

Integrating NEP 2020 reforms into empirical analyses;

Linking education investment with measurable outcomes like productivity and poverty reduction.

This study addresses these gaps by offering a comprehensive, data - driven analysis of India's education expenditure patterns, economic impact, and policy implications in the post - NEP 2020 era.

3. Objectives

To analyse trends in public expenditure on education in India.

To evaluate the economic impact of education spending on GDP, productivity, and employment.

To assess challenges in fund allocation, efficiency, and equity.

To propose policy recommendations for optimizing expenditure effectiveness.

4. Methodology

This study adopts a descriptive - analytical approach, using secondary data from government reports (Ministry of Finance, PRS India, UNESCO, World Bank) spanning 2013 - 2025. Data are analysed in terms of GDP proportion, composition across levels, and economic outcomes.

5. Results and Discussion

5.1 Trends in Expenditure

Absolute allocations have increased (₹99,311 crore in 2020 - 21 to ₹1.28 trillion in 2025 - 26).

Spending as % of GDP remains below 6%, averaging 3.8% (2000 - 2025).

States contribute ~89% of total education expenditure, with disparities across regions.

5.2 Economic Impact

Each additional ₹1 crore spent on education raises GDP by ₹24.01 crore (Rao & Dev, 2020).

Returns to education vary: primary (3.4%), secondary (4.5%), graduate (9.8%).

Skill development programs enhance employability and reduce poverty.

5.3 Social Equity

Education reduces income inequality and improves health outcomes.

Persistent gaps remain: rural - urban divides, gender disparities, and caste - based inequalities.

5.4 Challenges

Quality deficits: 57% of Class 5 students lack basic literacy (ASER, 2022).

Infrastructure gaps and digital divide hinder learning outcomes.

Inefficient fund utilization and over - reliance on cess - based funding.

Under funding of State Public Universities versus elite institutions.

Table1: Public Expenditure on Education in India

(%of Gross Domestic Product (GDP) and Total Government Expenditure)

Year	**Public Expenditureon Education(%ofGDP)**	**Public Expenditure on Education (% of Total Government Expenditure)**
2013	14.05% (TotalGovt.Exp.)	14.05%
2013-2014	3.1%	-
2014	15.72% (TotalGovt.Exp.)	15.72%
2015	16.33% (TotalGovt.Exp.)	16.33%
2015-2024	4.1%-4.6%	13.5%-17.2%
2016	17.16% (TotalGovt.Exp.)	17.16%
2017	13.55% (TotalGovt.Exp.)	13.55%
2018	13.07% (TotalGovt.Exp.)	13.07%
2019	15.00% (TotalGovt.Exp.)	15.00%
2020	14.99%(TotalGovt.Exp.)	14.99%
2020-2021	4.64%	-
2021	14.65%(TotalGovt.Exp.)	14.65%
2021	4.64%(declinedfrom2021)	-
2022	14.16%(TotalGovt.Exp.)	14.16%
2022	4.1207%	-
2022-2023	2.9%	-
FY25 (Interim Budget)	4.6%	-
2024	2.51%(declinefrom2023)	-

Table2: Ministry of Education Budget Allocations and Key Scheme Spending

(FY2015 - 16 to FY2025 - 26)

Fiscal Year	**Total Ministry of Education Allocation (₹ crore)**	**School Education Allocation (₹ crore)**	**Higher Education Allocation (₹ crore)**	**Key Schemes (e.g.,Samagra Shiksha, PM POSHAN,PM SHRI)**	**Notes on Underspending/Change**
2015 -16	-	-	-	-	Overall expendituregrew at 5% annually (2015 - 16 to 2025 - 26)
2019 -20	-	-	-	-	51.33% increase from FY19toFY25 allocation
2021 -22	-	-	-	-	Allocationdecreased by 6.12%dueto Covid– 19
2022 -23	1,04,000	-	-	-	
2023 - 24 (BE)	1,12,899.47	-	-	-	13.68% increase from 2020 – 21

2023 - 24 (RE)	-	-	-	PM - USHA: 13,000croresfor 2023 - 24 to 2025 -26	Spending higher than 2024 - 25 due to MUSK
2024 - 25 (BE)	1,20,628	-	-	-	7.14% increase from 2023 -24
2024 - 25 (RE)	-	-	-	PM-POSHAN: 25% lower than budget [29]; PM - USHA:51% lower than budget [29]; Student Aid:33% lower than budget	Ministry's expenditure 5% lower than budgeted
2025 - 26 (BE)	1,28,650	78,572 (61%)	50,078 (39%)	SamagraShiksha:41, 250; PM POSHAN: 12,500;PM SHRI: 7,500; STARS: 1,250; CentralUniversities/I ITs: 56% of HE allocation; Student Aid: 2,160	13%increaseover2024 -25 RE

6. Policy Implications

The findings of this study underscore that public expenditure on education in India has a profound and multi - dimensional impact on economic growth, human capital formation, and social equity. However, persistent underinvestment, inefficiencies in fund utilization, and structural disparities dilute the potential benefits. To align educational spending with national development goals and fully harness the demographic dividend, the following policy implications are proposed:

Achieving the 6% of GDP Benchmark: Despite policy commitments since the Kothari Commission (1966) and reiterated in the National Education Policy (NEP) 2020, India continues to allocate only 3 - 4.5% of GDP to education. To unlock the full economic potential of human capital, the government must prioritize a progressive increase in spending toward the 6% of GDP target, accompanied by mechanisms ensuring effective absorption and outcome - oriented utilization.

Rebalancing Expenditure toward Foundational Learning: Evidence indicates that foundational literacy and numeracy (FLN) deliver the highest long - term returns on investment (World Bank, 2021). Therefore, policies should emphasize early childhood care and primary education, ensuring that all children attain minimum learning standards by Grade 3. Strengthening programs such as Samagra Shiksha Abhiyan and NIPUN Bharat can yield substantial productivity gains and reduce later - stage dropouts.

Enhancing Efficiency and Accountability in Spending: Significant gaps persist between budget allocations and actual expenditure, with underspending observed in key schemes. To address this, the government should adopt performance - based budgeting and outcome - linked funding frameworks. Establishing an Education Expenditure Monitoring Authority could improve transparency, reduce leakages, and ensure fiscal efficiency.

Reducing Regional and Social Disparities: Interstate variations — with states like Manipur (7.7% of GSDP) far outpacing Telangana (1.3%) — threaten balanced national development. The Centre should introduce equalization grants and incentive - based transfers for underfunded states. Targeted funding for Scheduled Castes, Scheduled Tribes, minorities, and rural populations is essential to bridge equity gaps and ensure inclusive growth.

Strengthening Higher Education and Research: While elite institutions such as IITs and IIMs receive significant allocations, State Public Universities — which serve nearly 80% of students — remain underfunded. Policy must ensure balanced investment across institutions, with dedicated grants for faculty development, infrastructure, and research. Operationalizing the National Research Foundation (NRF) under NEP 2020 can foster innovation - driven growth.

Expanding Vocational and Skill - Oriented Education: Skill mismatches continue to constrain employability. Integrating vocational education into mainstream curricula from secondary level, as envisaged by NEP 2020, is crucial. Scaling up schemes like Pradhan Mantri Kaushal Vikas Yojana (PMKVY) and National Apprenticeship Promotion Scheme (NAPS) can enhance workforce readiness and boost earnings.

Promoting Digital Equity: The digital divide exacerbates inequality in access and quality. Investment in digital infrastructure, internet connectivity, and teacher digital training must be prioritized. Expanding the PM e - Vidya initiative and ensuring affordable devices for students in rural areas will make education more inclusive and future - ready.

Improving Teacher Quality and Motivation: Teacher shortages, absenteeism, and inadequate training undermine learning outcomes. Policy reforms must focus on teacher recruitment transparency, continuous professional development, and performance - linked incentives. Improved service conditions and autonomy can foster accountability and motivation.

Encouraging Public - Private Partnerships (PPP): Strategic partnerships with the private sector can mobilize additional resources, foster innovation, and improve delivery efficiency. PPPs in infrastructure, digital learning, and vocational training can supplement public investment, provided strong regulatory frameworks ensure equity and quality.

Linking Education with Economic Planning: Education policy must be integrated with macroeconomic strategies such as industrial growth, labour market demands, and regional development plans. A National Human Capital Strategy aligning education outputs with future workforce needs can ensure that investments translate into tangible economic outcomes.

Achieving the vision of Viksit Bharat 2047 demands that education be treated not merely as a social obligation but as a strategic economic investment. A recalibrated fiscal approach — emphasizing adequacy, equity, quality, and accountability — can transform India's education system into a robust engine of inclusive and sustainable economic growth.

7. Conclusion

Education stands as one of the most powerful instruments for fostering economic growth, social equity, and sustainable development. This study has demonstrated that public expenditure on education in India exerts a significant positive influence on GDP growth, human capital formation, and poverty reduction, while also enhancing social mobility and gender equality. Yet, despite its strategic importance, India's public investment in education remains below the globally accepted benchmark of 6% of GDP, averaging only 3 - 4% over the past decade.

The findings reveal a persistent paradox: while absolute allocations have risen steadily, the relative share of education spending in GDP has stagnated, reflecting inadequate prioritization amidst rapid economic expansion. Moreover, systemic inefficiencies—such as underspending, regional disparities, poor infrastructure, and learning quality gaps—limit the full realization of education's transformative potential. Consequently, the nation risks underutilizing its vast demographic dividend, as large sections of the youth remain under - skilled and underemployed.

Empirical evidence reinforces that investment in education yields high economic and social returns. Foundational literacy, primary education, and vocational training contribute directly to productivity gains and long - term income growth. Furthermore, education plays a multiplier role in improving health outcomes, reducing inequality, and strengthening civic participation—all of which contribute to inclusive national development.

To harness these benefits, India must transition from a spending - focused approach to an outcome - oriented and equity - driven model of public expenditure. Policy reforms must emphasize quality over quantity, efficiency over expansion, and inclusivity over uniformity. Strengthening foundational learning, bridging regional gaps, enhancing teacher capacity, and

investing in digital equity are critical to ensuring that every rupee spent translates into measurable developmental gains.

As India aspires toward Viksit Bharat 2047, education must be positioned at the heart of its economic strategy. A sustained fiscal commitment—backed by accountability, innovation, and inclusive planning—can transform education into a catalyst for equitable growth, empowering citizens and strengthening the nation's competitiveness in the global knowledge economy.

In essence, education is not merely an expenditure, but an investment—one that yields enduring dividends across generations. Achieving the full potential of this investment demands both political will and policy precision, ensuring that every learner becomes a productive, creative, and empowered contributor to India's development journey.

References

1) Accountability Initiative. (2023). Budget brief: Education sector in India 2023 - 24. Centre for Policy Research.
2) Agarwal, P. (2019). Higher education in India: Growth, challenges, and opportunities. Routledge.
3) All India Survey on Higher Education (AISHE). (2023). AISHE 2021 - 22 Report. Ministry of Education, Government of India.
4) Annual Status of Education Report (ASER). (2022). ASER 2022: Beyond basics. ASER Centre.
5) Azad India Foundation. (2021). Education budget analysis 2014 - 2021.
6) Banerjee, A., & Duflo, E. (2011). Poor economics: A radical rethinking of the way to fight global poverty. PublicAffairs.
7) Barro, R. J. (2001). Human capital and growth. American Economic Review, 91(2), 12 - 17.
8) Barro, R. J., & Lee, J. W. (2013). A new data set of educational attainment in the world, 1950 - 2010. Journal of Development Economics, 104, 184 - 198.
9) Chancel, L., & Piketty, T. (2022). World inequality report 2022. World Inequality Lab.
10) Choudhary, S. (2023). Education expenditure and human development in BRICS nations. Journal of Comparative Economics, 51(4), 923 - 940.

11) Dholakia, R. (2020). Education cess and fiscal sustainability in India. Indian Journal of Public Finance, 14(2), 45 - 62.
12) FICCI. (2022). India employability report 2022: Bridging the skills gap. Federation of Indian Chambers of Commerce & Industry.
13) Hanushek, E. A., & Woessmann, L. (2012). Do better schools lead to more growth? Cognitive skills, economic outcomes, and causation. Journal of Economic Growth, 17(4), 267 - 321.
14) Heckman, J. J. (2006). Skill formation and the economics of investing in disadvantaged children. Science, 312(5782), 1900 - 1902.
15) International Labour Organization (ILO). (2020). India employment report. ILO South Asia Office.
16) Kaul, V., Singh, R., & Desai, M. (2021). Returns to education in India: A micro - level analysis. NCAER Working Paper Series.
17) Kapoor, R. (2020). The productivity paradox and India's labour market. Brookings India Discussion Paper.
18) Lucas, R. E. (1988). On the mechanics of economic development. Journal of Monetary Economics, 22(1), 3 - 42.
19) Macrotrends. (2023). India education expenditure: Historical data.
20) Mehrotra, S. (2021). Revisiting the economics of education in India: Policy priorities post - NEP 2020. Economic and Political Weekly, 56(12), 44 - 51.
21) Ministry of Education (MoE). (2020a). National Education Policy 2020. Government of India.
22) Ministry of Education (MoE). (2023). Budget documents 2023 - 24. Government of India.
23) Ministry of Finance. (2025). Union Budget 2025 - 26: Expenditure profile. Government of India.
24) Ministry of Health and Family Welfare (MoHFW). (2023). National family health survey and health outcomes in India. Government of India.
25) Mirrority. (2023). Public expenditure on education: State - wise analysis.
26) MSDE. (2021). Pradhan Mantri Kaushal Vikas Yojana (PMKVY) progress report. Ministry of Skill Development & Entrepreneurship.
27) National Council of Applied Economic Research (NCAER). (2020). India human development survey and returns to education.

28) Nelson, R. R., & Phelps, E. S. (1966). Investment in humans, technological diffusion, and economic growth. American Economic Review, 56(2), 69 - 75.
29) NITI Aayog. (2023). India higher education overview report.
30) NSSO. (2023). Household social consumption on education in India. Ministry of Statistics and Programme Implementation.
31) Oxfam India. (2023). Inequality report: The gap between the rich and the rest.
32) PRS Legislative Research. (2024). Demand for grants: Education 2024 - 25.
33) Rao, N. (2022). Public expenditure on education and economic growth in India: A time - series analysis. Indian Economic Journal, 70(1), 56 - 78.
34) Rao, N., & Dev, M. S. (2020). Education expenditure and growth linkage in India. Journal of Development Studies, 56(5), 893 - 910.
35) Scopus Database. (2024). India's share in global research publications. Elsevier.
36) TeamLease Services. (2019). India employability report: The productivity challenge.
37) Tilak, J. B. G. (2016). Public financing of education in India: Issues of equity and efficiency. NUEPA Occasional Paper.
38) Tilak, J. B. G. (2018). Education and development: Lessons from BRICS countries. Springer.
39) UNDP. (2020). Human development report 2020: The next frontier. United Nations Development Programme.
40) UNESCO. (2021). Global education monitoring report 2021.
41) UNESCO. (2022). Reimagining education for a more equitable world.
42) UNESCO. (2023). Learning poverty and education quality: Global update.
43) UNESCO. (2024). Education finance database.
44) World Bank. (2019). India development update: Unlocking human capital.
45) World Bank. (2021). Foundational literacy and numeracy for economic growth.
46) World Bank. (2022). Poverty and shared prosperity in India.
47) World Bank. (2024). World development indicators.

Effectiveness of MOOCS and Webinars for Teacher Educators' Professional Development

Shanmugapriya M.
Research Scholar,
Department of Educational Technology,
Bharathidasan University,
Tiruchirappalli.

Abstract:

Professional development has become a cornerstone of teacher education, ensuring that teacher educators remain competent, innovative, and aligned with global educational practices. In recent years, digital learning environments—particularly Massive Open Online Courses (MOOCs) and webinars—have become prominent tools for professional growth. This paper critically examines the effectiveness of MOOCs and webinars in enhancing the professional competencies of teacher educators. It explores their unique benefits, limitations, and comparative advantages while highlighting implications for institutional practice and policy. The findings indicate that MOOCs and webinars provide flexible, affordable, and globally relevant opportunities for teacher educators, yet challenges such as technological barriers, lack of sustained engagement, and limited institutional recognition persist. The paper concludes that a blended and well-structured approach can maximize the impact of MOOCs and webinars in supporting lifelong professional development.

Keywords: MOOCs, webinars, teacher educators, professional development, online learning, lifelong learning

Introduction

Teacher educators hold a vital role in preparing future teachers with the skills and knowledge necessary to succeed in modern classrooms. As education continues to evolve with digital

transformation, professional development opportunities for teacher educators must also adapt. Traditionally, professional development relied on in-person workshops, seminars, and conferences. However, these approaches often faced limitations in terms of cost, accessibility, and scalability (Morris & Lambe, 2020).

In response to these limitations, online platforms such as MOOCs and webinars have emerged as powerful alternatives. MOOCs—Massive Open Online Courses—are structured, large-scale online courses often developed by universities or international organizations. Webinars, meanwhile, are shorter, interactive, real-time sessions designed for focused knowledge sharing. Both platforms surged in popularity during the COVID-19 pandemic, proving their potential to support ongoing professional learning in education.

This article examines the effectiveness of MOOCs and webinars as professional development tools for teacher educators, focusing on their advantages, challenges, and future implications.

MOOCs and Teacher Educators' Professional Development

MOOCs have been recognized for their capacity to democratize education by making quality learning resources widely accessible. For teacher educators, MOOCs present opportunities to update their knowledge in pedagogy, research, and digital teaching practices.

Advantages of MOOCs

1. **Accessibility and Flexibility** – MOOCs allow participants to engage at their own pace and time, supporting busy professional schedules (Chiappe & Arias, 2021).
2. **Cost Efficiency** – Many MOOCs are free or offered at minimal cost, reducing financial barriers.
3. **Global Networking** – Participation in MOOCs fosters cross-cultural exchange of ideas among educators worldwide.
4. **Wide Range of Topics** – MOOCs cover diverse areas including curriculum design, educational technology, and inclusive pedagogy.

Limitations of MOOCs

MOOCs often face issues such as high dropout rates, limited opportunities for personalized feedback, and challenges in applying abstract knowledge into local classroom contexts (Shah, 2022). Teacher educators in developing regions also face technological barriers, including poor internet connectivity and lack of access to devices.

Webinars and Teacher Educators' Professional Development

Webinars provide shorter, topic-specific learning opportunities. They are interactive and often focus on immediate, practical issues in education.

Benefits of Webinars

1. **Real-Time Engagement** – Live interaction with experts encourages discussion and knowledge exchange (Nash, 2021).
2. **Convenience and Time Efficiency** – Webinars are typically short, allowing busy professionals to participate without significant disruption.
3. **Relevance** – Many webinars address emerging issues in education, such as digital assessment, hybrid classrooms, or policy updates.
4. **Collaborative Opportunities** – Breakout sessions, polls, and chat discussions enhance active participation.

Limitations of Webinars

Effectiveness of webinars is often limited by passive participation, technical glitches, and lack of follow-up activities. Without additional resources or reflection, webinars may provide only surface-level learning.

Comparative Effectiveness of MOOCs and Webinars

MOOCs and webinars differ in scope, structure, and outcomes, yet both contribute significantly to professional development. MOOCs provide **long-term, structured learning** experiences, while webinars are more effective for **short-term, immediate knowledge updates**.

Research suggests that teacher educators benefit most when both formats are combined. MOOCs foster deep, sustained learning, while webinars provide platforms for dialogue and contextual reflection (Gokool-Ramdoo & Ifenthaler, 2021). Thus, integrating the two can create a balanced model of professional growth.

Implications for Teacher Educators' Professional Development

1. **Institutional Support:** Universities and teacher training institutions should recognize MOOCs and webinars as valid professional development activities.
2. **Blended Approaches:** A hybrid model combining face-to-face workshops, MOOCs, and webinars ensures comprehensive professional learning.
3. **Digital Competence:** Teacher educators must be equipped with digital literacy skills to fully benefit from online learning platforms.
4. **Policy Integration:** Governments and accreditation bodies should incorporate MOOCs and webinars into structured professional development frameworks.

Conclusion

MOOCs and webinars have redefined professional development for teacher educators by offering flexible, affordable, and globally relevant learning opportunities. While MOOCs provide structured, in-depth learning pathways, webinars facilitate short, interactive engagements with immediate applicability. The combination of both creates a dynamic professional learning environment that aligns with the demands of 21st-century education.

However, challenges such as technological inequalities, engagement issues, and lack of institutional recognition must be addressed to maximize their potential.

Moving forward, blended professional development strategies supported by institutional and policy frameworks can ensure that teacher educators remain effective, innovative, and globally connected.

References

1.Chiappe, A., & Arias, V. (2021). MOOCs and teacher professional development: A systematic review. *International Review of Research in Open and Distributed Learning, 22*(3), 1–19.

2.Gokool-Ramdoo, S., & Ifenthaler, D. (2021). Massive Open Online Courses (MOOCs) in teacher professional development: Potential and challenges. *Education and Information Technologies, 26*(2), 1857–1872.

3.Morris, N. P., & Lambe, J. (2020). Combining MOOCs and professional development: The case of teacher education. *Teaching in Higher Education, 25*(2), 233–248.

4.Nash, C. (2021). Webinars for professional development: The role of online seminars in teacher education. *Journal of Education and Learning, 10*(4), 45–55.

5.Shah, D. (2022). A decade of MOOCs: A review of adoption and impact. *Class Central Report*. Retrieved from https://www.classcentral.com

Automatic Dark-Activated Bat Deterrent Device

Sivasankar P[1], Porkkodi Ma P[2] and Natchathiram K[3]

[1] Professor ECE, NITTTR, Chennai

[2] Lecturer ECE, Government Polytechnic College for Women, Coimbatore

[3] Lecturer ECE, Government Polytechnic College, Chekkanurani

Abstract:

Bats play a vital ecological role, yet their increasing presence in human and agricultural environments poses twin challenges: zoonotic disease risk (e.g.,Hendra, Nipah, and corona viruses) and significant property damage from guano accumulation and structural nesting. To address this, we propose the development of a low-power, non-invasive ultrasonic bat deterrent device. The system is designed for autonomous operation, utilizing a Solar Power Supply for energy independence and a Light-Dependent Resistor (LDR) circuit to activate the system exclusively under low-light conditions. A 555 Time-based generator produces an electric sine wave signal in the 20 kHz - 100 kHz ultrasonic range, which is then amplified and broadcast via a specialized transducer. This frequency range is specifically intended to interfere with the echolocation capabilities of common insectivorous bat species (Microbats), thereby discouraging their entry into target areas and drastically reducing associated waste. This paper details the complete circuit design and proposes a rigorous framework for field validation, emphasizing the need for species-specific tuning and robustness against known limitations like acoustic attenuation and habituation

Introduction

Bats are crucial to ecological balance, acting as natural pest controllers and pollinators. However, they also pose health risks as recognized reservoirs of zoonotic viruses. Agents that spill over from bats to humans—such as filo viruses (Ebola and Marburg virus), henipa viruses (Hendra and Nipah virus), and corona viruses(includingSevereAcuteRespiratorySyndromeCoronavirus[SARS-CoV])—cause severe disease in recipient hosts and have pandemic potential. Gardens, bungalows, and estates are particularly susceptible to theserisks.

Furthermore, bats can cause significant physical damage to buildings. They may squeeze through small openings, damaging roofing materials, siding, and insulation in the process. In some cases, bats might also gnaw on wood or other materials to create entry points or roosting sites. Roofs and attic spaces are particularly vulnerable to bat-related damage. Accumulated bat guano (droppings)and urine can degrade roofing materials, leading to leaks and weakening of the structure. Over time, this damage can become costly to repair, making it crucial to address bat infestations promptly. Construction sites are also prone to such damage.

To address this challenge, the development of a bat deterrent device offers a humane and effective solution. This project focuses on designing and implementing a bat deterrent device that uses non-invasive methods to keep bats away from unwanted areas. By leveraging advanced technologies such as ultrasonic sound waves, the device ensures minimal harm to the bats while effectively discouraging their entry into restricted zones. This device offers a proactive approach to managing bat populations in a responsible manner.

Literature survey

Bats are highly reliant on their sense of hearing, particularly Microbats, the most common group of insectivorous bats. These species employ echo location by emitting high-frequency vocal signals and interpreting the returning echoes to navigate and hunt. This innate reliance on auditory cues makes them susceptible to acoustic deterrence methods.

Ultrasonic frequencies, typically intherangeof20kHzto100kHz, have been widely investigated for their potential to deter bats and other pests. The Bat Conservation International (BCI), a non-profit organization dedicated to bat research, supports the notion that continuous broadcasts of high-frequency sound within this range, inaudible to humans but within the hearing range of many bat species, can effectively deter bats from targeted areas. Recent studies in the wind energy sector, for instance, have confirmed the efficacy of broad band ultrasound in reducing fatality rates for many microbat species, demonstrating that interfering with their acoustic environment can significantly discourage their approach.

However, it is a crucial distinction that most species responsible for major zoonotic spillover events (e.g., Hendra and Nipah viruses), as highlighted in the introduction, are Megabats (fruitbatsorflying-foxes).These species do not typically relyon high-frequency echolocation for navigation. Therefore, the effectiveness of this ultrasonic device is primarily targeted at nuisance and insectivorous Microbat species, interfering with their primary sensory modality for navigation and foraging.

The fundamental components employed in such deterrent systems are well-established in electronics. Light-Dependent Resistors (LDRs) are commonly utilized in automatic switching circuits due to their simple and cost-effective detection

of ambient light levels. Similarly, the 555 Timer integrated circuit is a robust and versatile component, widely employed in a stable configurations for generating stable square-wave oscillations across a broad frequency spectrum, including ultrasonic ranges. To convert these square waves into a cleaner, single-frequency sine wave suitable for acoustic transducers, passive LC filters are a standard solution, functioning by suppressing higher-order harmonics and allowing the fundamental frequency to resonate. This project leverages these proven electronic principles to construct an autonomous and effective bat deterrent.

Block Diagram and Circuit Diagram Block Diagram

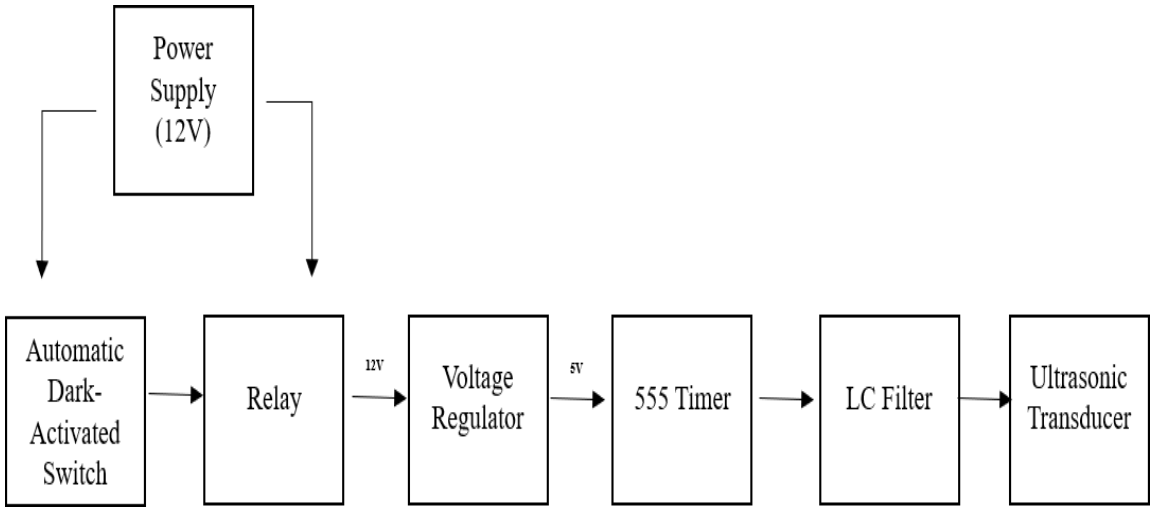


Fig - Block Diagram of Automatic Dark-Activated Bat Deterrent Device

This block diagram illustrates an automatic dark-activated bat deterrent device.

A 12V power supply continuously powers the Automatic Dark-Activated Switch, which, upon detecting darkness, energizes a Relay. The activated relay then supplies 12V to a Voltage Regulator, stepping it down to 5V for the 555 Timer/Oscillator. This oscillator generates a high-frequency square wave, which is then fed into an LC Filter to produce a clean ultrasonic sine wave. Finally, this sine wave drives an Ultrasonic Transducer, emitting sound waves to deter bats when ambient light levels are low.

Circuit Diagram

Automatic Dark-Activated Switch

The circuit primarily uses a Light Dependent Resistor (LDR1) as the main sensor, whose resistance varies inversely with the light intensity. A 100kΩ Potentiometer (RV1) is connected with the LDR to form a voltage divider, allowing the user to adjust the circuit's sensitivity or the threshold of darkness required for activation. This sensor network biases the base of the first BC547 NPN Transistor (Q1), which is then coupled to the second BC547 Transistor (Q2). The transistors operate as a two-stage switch providing the necessarycurrentgaintoenergizethecoilofthe12V Relay (RL1).A 1kΩ Resistor(R1)acts as a pull-up, and a Diode(D1)is connected in reverse parallel across the relay coil to protect Q2 from the damaging back EMF when the relay de-energizes. Finally, the relay's contacts control the high-power section, which consists of a separate 12V Battery (B1) and the load, a 12V Lamp (L1).

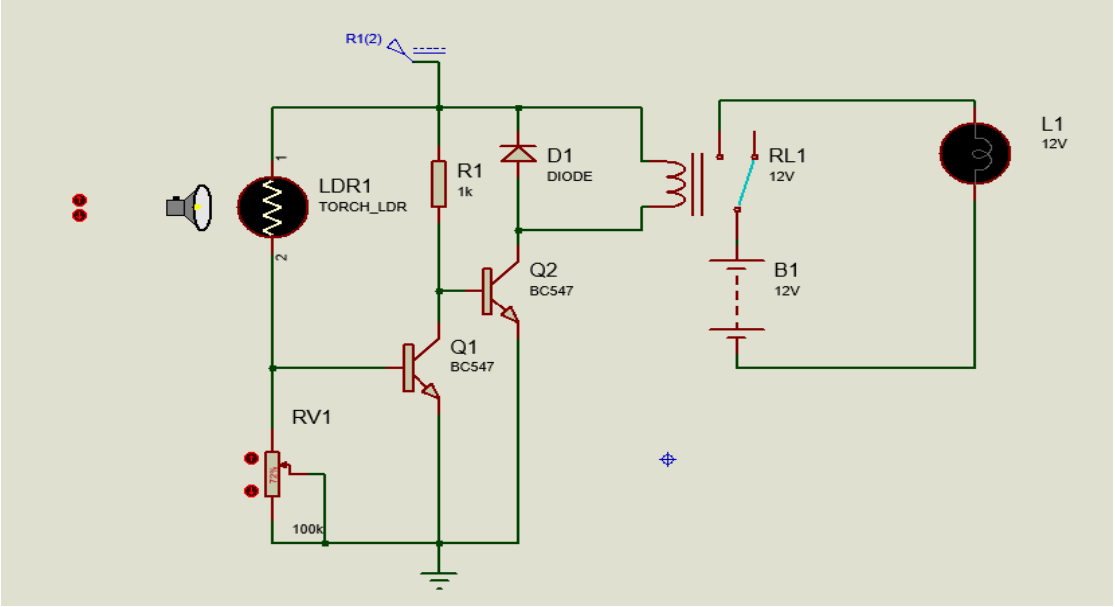


Fig 1 - Automatic Dark-Activated Switch - Daytime

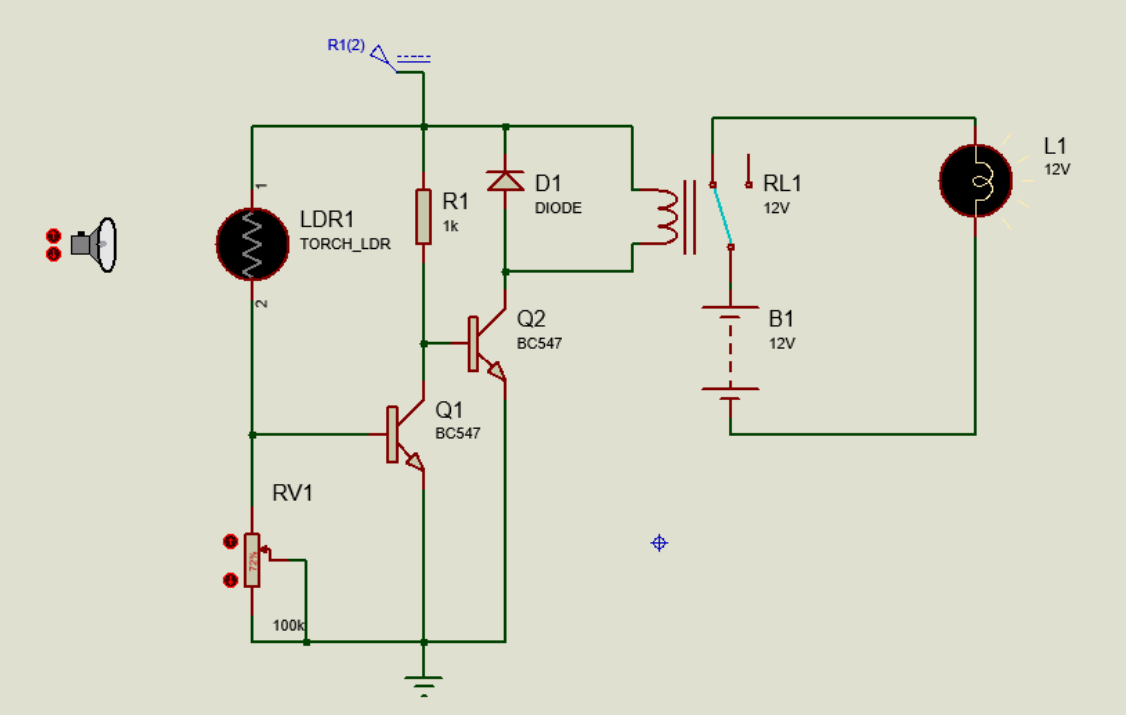


Fig 2 - Automatic Dark-Activated Switch - Nighttime

Daytime (In Light - Q1 is ON, Q2 is OFF)

1. LDR Resistance: When it is day time and there is ample light, the resistance of the LDR is LOW.
2. Q1 Base Voltage (V_{B1}): The voltage divider is formed by the LDR (top) and RV1 (bottom).
    - Since the LDR's resistance is low, the voltage drop across the LDR is small, and the voltage across RV1 is HIGH.
    - This high voltage is applied to the baseofQ1(V_{B1}>0.7V),whichturns Q1 ON (saturates).
3. Q2 Base Voltage (V_{B2}): When Q1 is ON, it effectively actsasaswitch,pulling its collector voltage low (close to ground). Since the collector ofQ1isdirectly connected to the base of Q2, the base voltage of Q2 is LOW.
4. Q2 Status: With a low base voltage, Q2 remains OFF.

5. Relay and Lamp: Since Q2 is OFF, no current flows through the relay coil (RL1). The relay remains de-energized, and the Lamp(L1)is OFF. And hence turning OFF the sine wave generator circuit which is shown in the next section.

Night time (In Darkness-Q1isOFF,Q2isON)

1. LDR Resistance: When the light level drops (darkness), the resistance of the LDR INCREASES significantly (high resistance).
2. Q1BaseVoltage(V_{B1}):

With the LDR's resistance high, the voltage drop across the LDR is now large, and the voltage across RV1 (the base of Q1) is LOW.

This low voltage (V_{B1}<0.7V}$)turnsQ1OFF (cutoff).

1. Q2 Base Voltage (V_{B2}): WhenQ1isOFF, its collector is no longer pulled to ground. Current from the 12V supply now flows through the 1kΩ resistor(R1) into the base of Q2.

2. Q2 Status: The current flow into the base turns Q2 ON (saturates).

3. Relay and Lamp: Since Q2 is ON, current flows through the relay coil (RL1), causing it to energize. The relay switch closes, completing the circuit to the lamp. The Lamp (L1) turns ON. And hence turning ON the sine wave generator circuit which is shown in the next section.

The following table shows the operation of each component

Condition	**LDR Resistance**	**Q1 Status**	**Q2 Status**	**Relay Status**	**Lamp(L1) Status**
Daytime (Light)	Low	ON	OFF	De-energize d	OFF
Nighttime (Darkness)	High	OFF	ON	Energized	ON

SINE-WAVE ULTRASONIC GENERATION

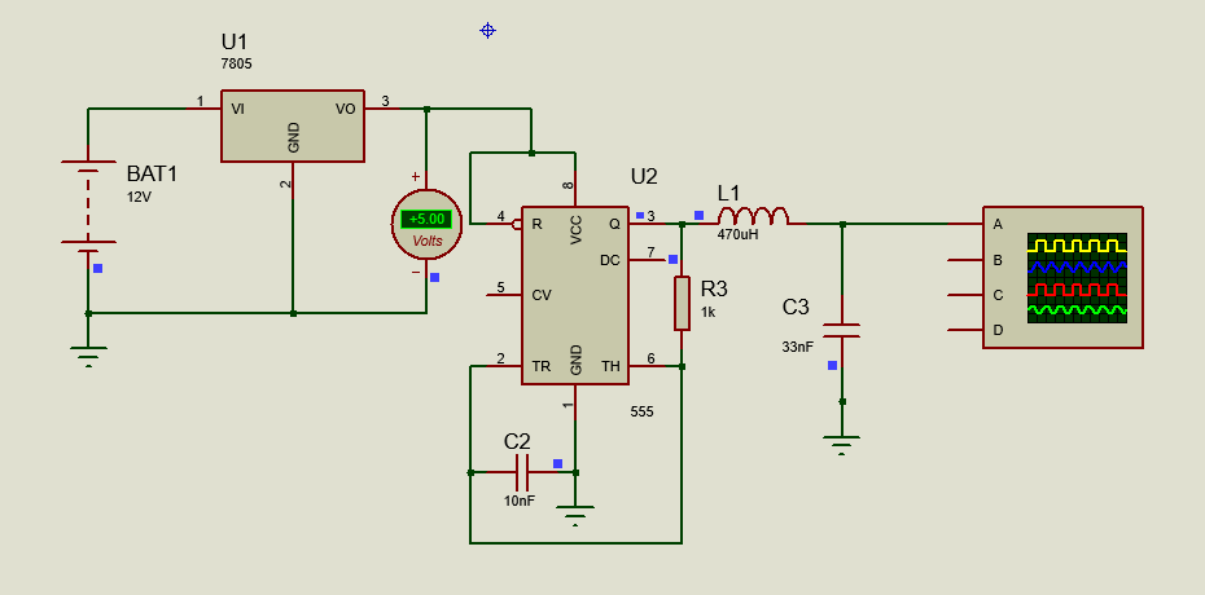


Fig3-SineWaveGeneratorCircuit-40kHz

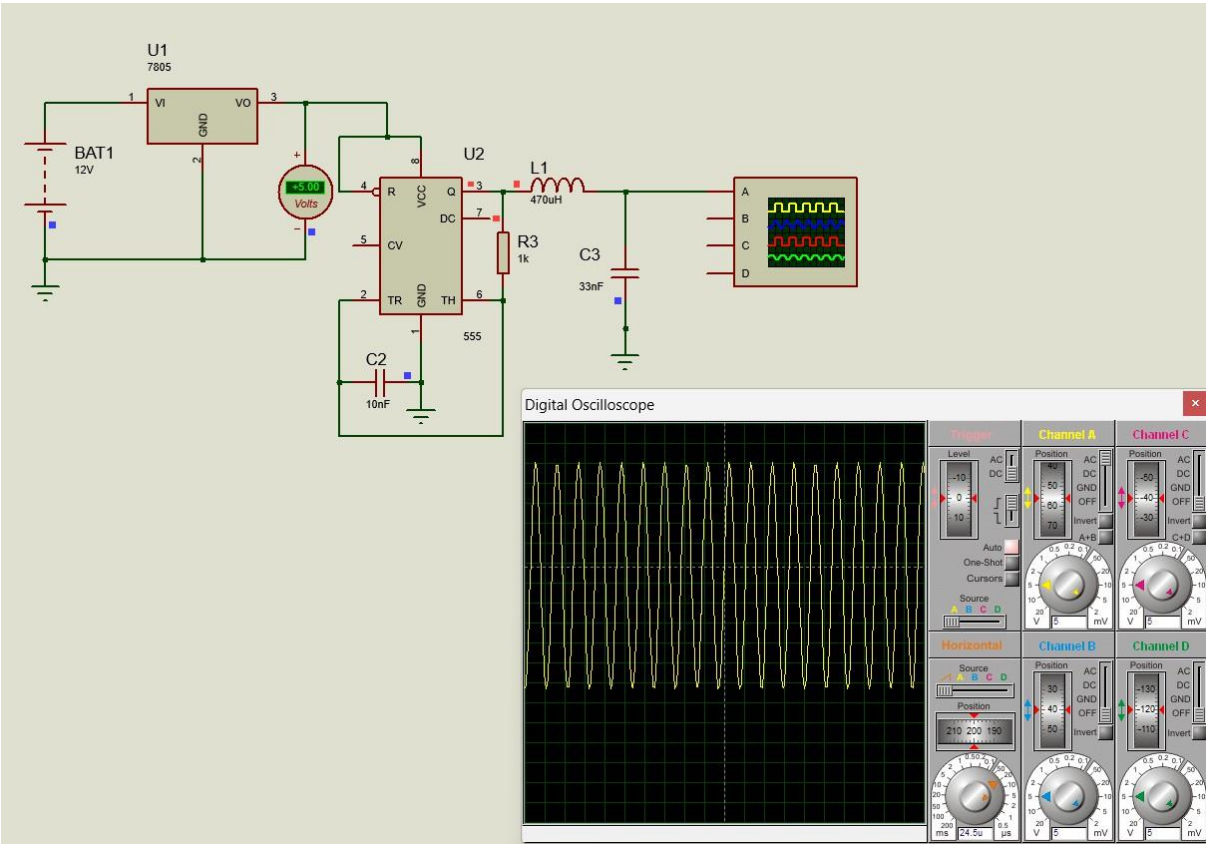


Fig4-SineWaveGenerator-40kHz

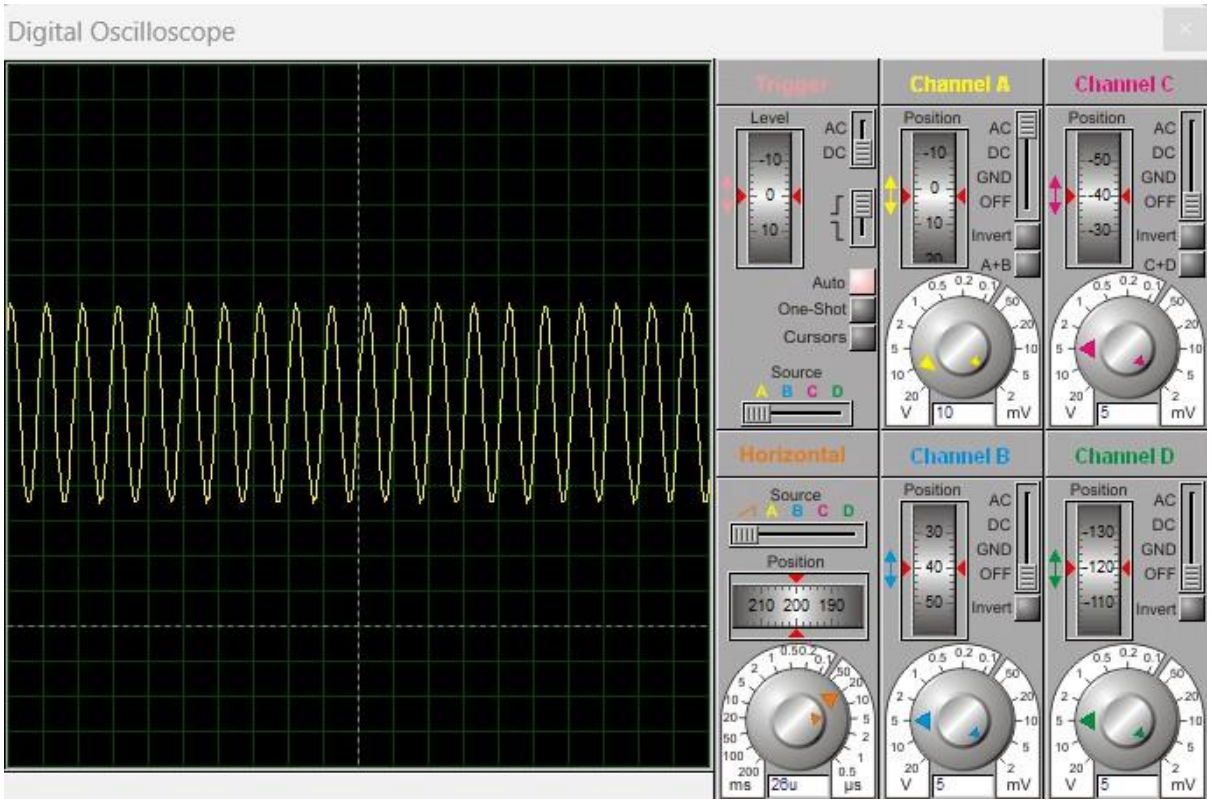


Fig 5 - Sinusoidal Wave

The circuit shown in Fig 3 is designed to generate a sine wave using a 555 timer integrated circuit in conjunction with an LC filter network. A 12 V DC supply powers the circuit through a 7805 voltageregulator,whichprovidesaconstant5Vregulated output to ensure stable operation of the 555 timer.

The 555 timer is configured in a stable mode, where the combination of a 1 kΩ resistor and a 10nF capacitor determines the charging and discharging cycles of the internal timing capacitor.

This process causes the output at pin 3 of the 555 to continuously toggle between high and low logic levels, there by producing a square-wave signal.

The output from the timer is then fed to a passive LC filter composed of a 470 µH inductor and a 33 nF capacitor connected in parallel. This combination forms a resonant circuit whose natural frequency is approximately 40 kHz. The LC circuit acts as a band-pass filter that's electively allows only the frequency component close to its resonance to pass while attenuating higher-order harmonics present in the square wave. As a result, the sharp transitions of the 555 output are smoothed, and the waveform across the capacitor becomes sinusoidal in nature.

The7805regulator not only ensures a clean and consistent 5 V supply to the oscillator but also enhances the waveform quality by minimizing variations in amplitude and frequency caused by supply fluctuations. Fig 6 - Shows the sinusoidal wave of approximately 40kHz, that matches with the following calculation.

COMPLETE CIRCUIT DIAGRAM

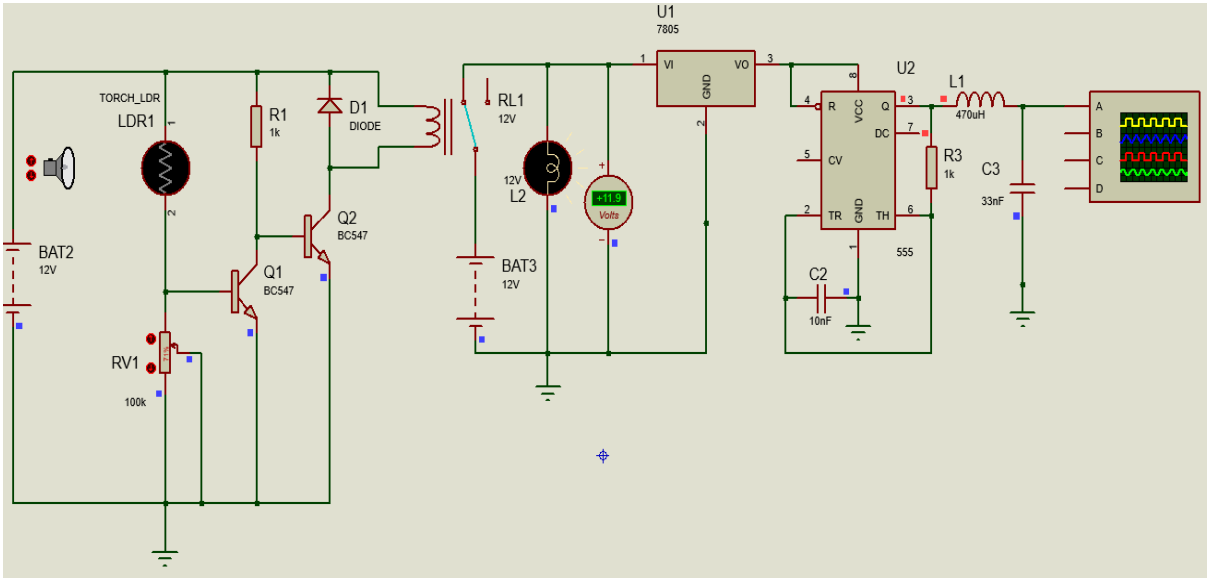


Fig 6 -Bat Deterrent Device - Low Light Condition

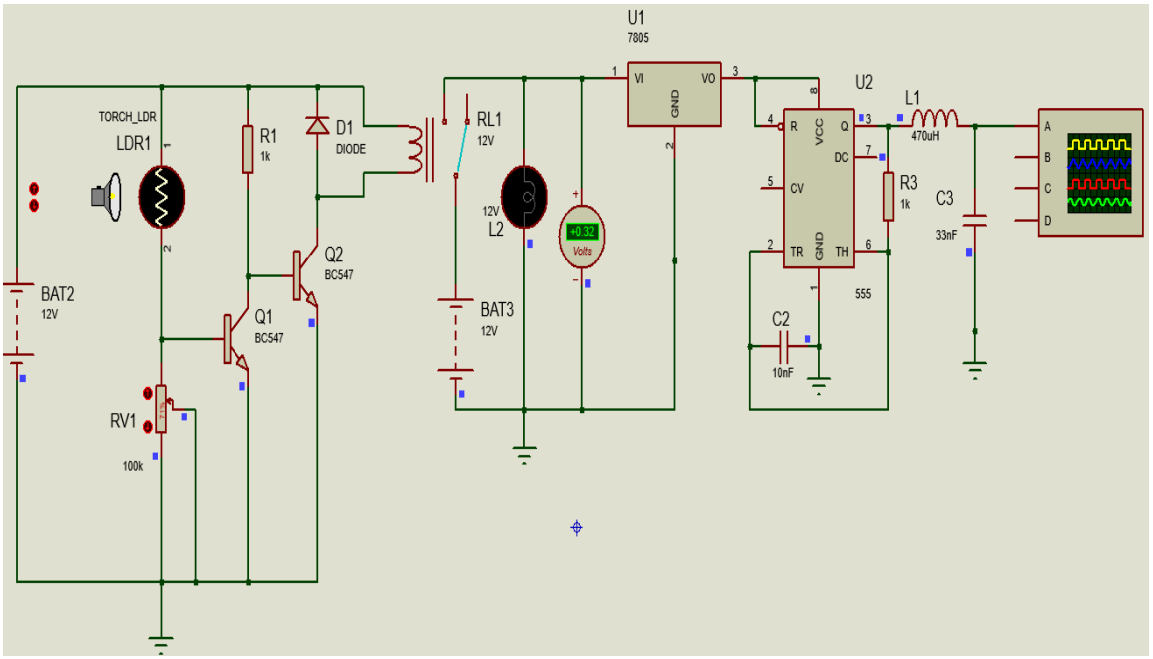
$$f_{LC} = \frac{1}{2\pi\sqrt{L \times C}}$$

Substitute $L1 = 470\,\mu H = 470 \times 10^{-6}\,H$
and $C3 = 33\,nF = 33 \times 10^{-9}\,F$:

$$L \times C = 470 \times 10^{-6} \times 33 \times 10^{-9} = 15.51 \times 10^{-12} = 1.551 \times 10^{-11}$$

$$\sqrt{1.551 \times 10^{-11}} = 3.94 \times 10^{-6}$$

$$f_{LC} = \frac{1}{2\pi \times 3.94 \times 10^{-6}} \approx 40{,}400\ \text{Hz} = 40.4\ \text{kHz}$$



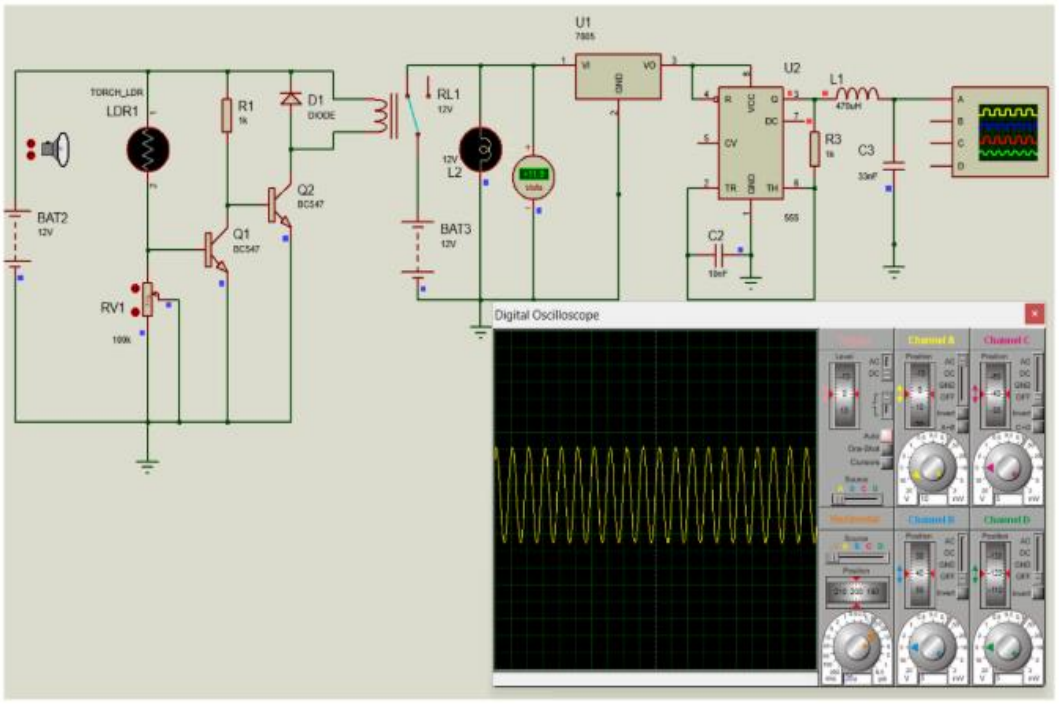


Fig 8 - Bat Deterrent Device - Low Light Condition - Sine Wave

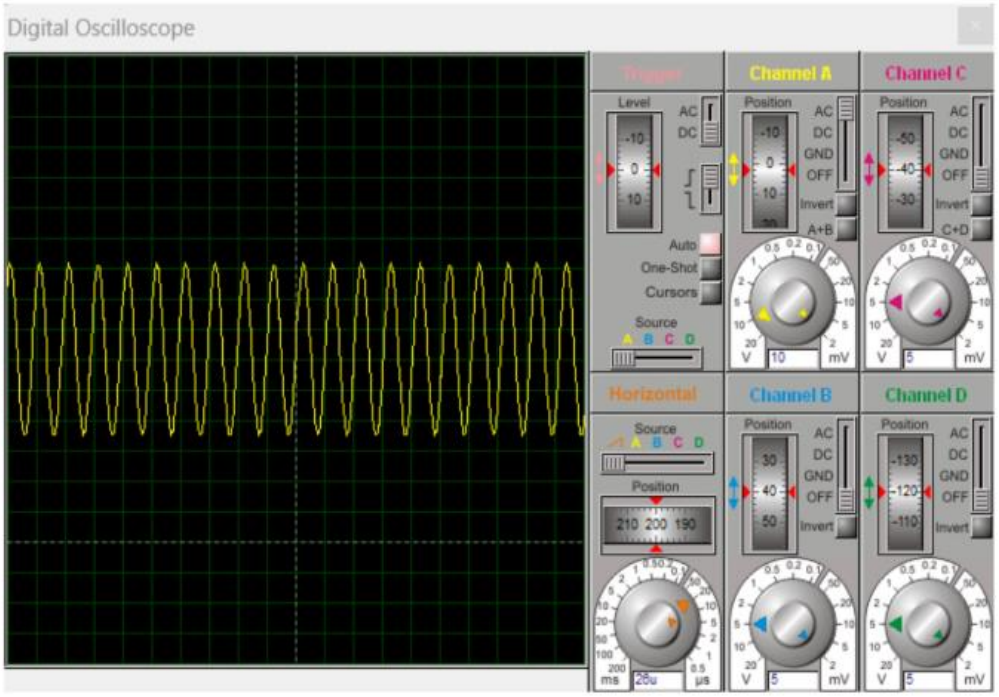


Fig 9 - Bat Deterrent Device - Sine Wave

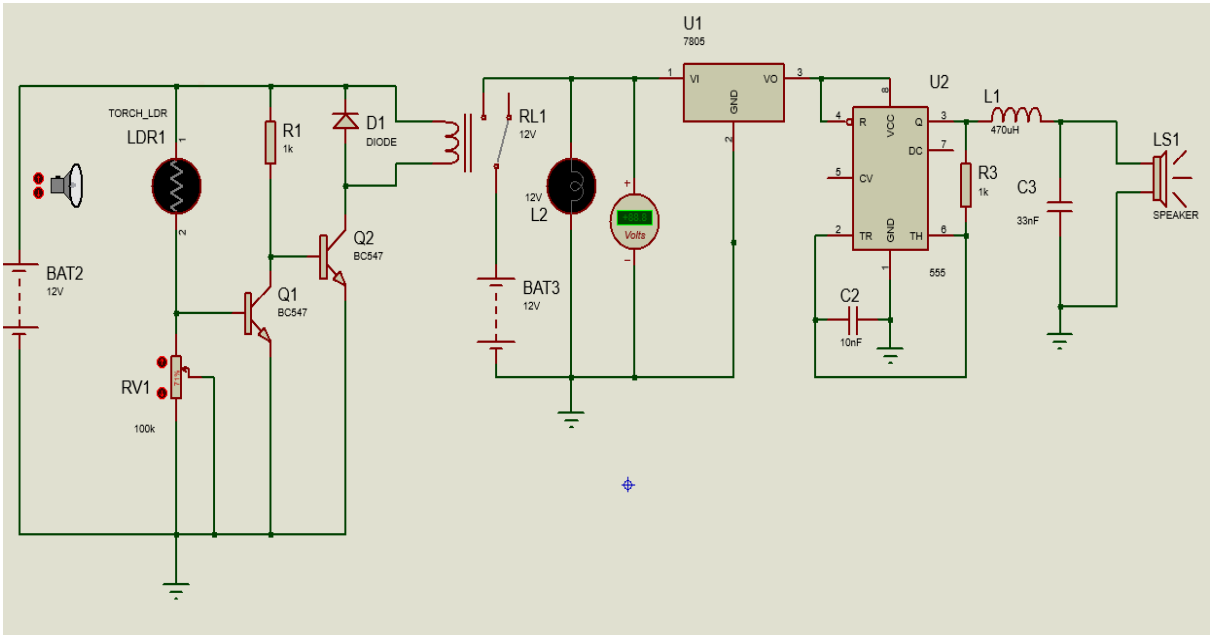


Fig10 - Bat Deterrent Device- With Loudspeaker

Fig10-Bat Deterrent Device- With Loud speaker combines an automatic light-controlled switch with a 555-based ultrasonic generator. During day light(Fig7- Bat Deterrent Device - High Light Condition), the LDR keeps the transistor pair off, de-energizing the relay and disabling the generator. At night (Fig 6 -Bat Deterrent Device - Low Light Condition), the LDR's resistance rises, activating the relay to power the circuit. The 555 timer, powered through a 7805 regulator, operates in a stable mode to produce a high-frequency square wave that is converted into a near-sine ultrasonic signal (~40–50 kHz) by the LC network, effectively repelling bats. Thus, the device automatically activates at night and emits a continuous high-frequency sinusoidal sound to repel bats, while remaining off during the day to conserve energy.

Result and Discussion

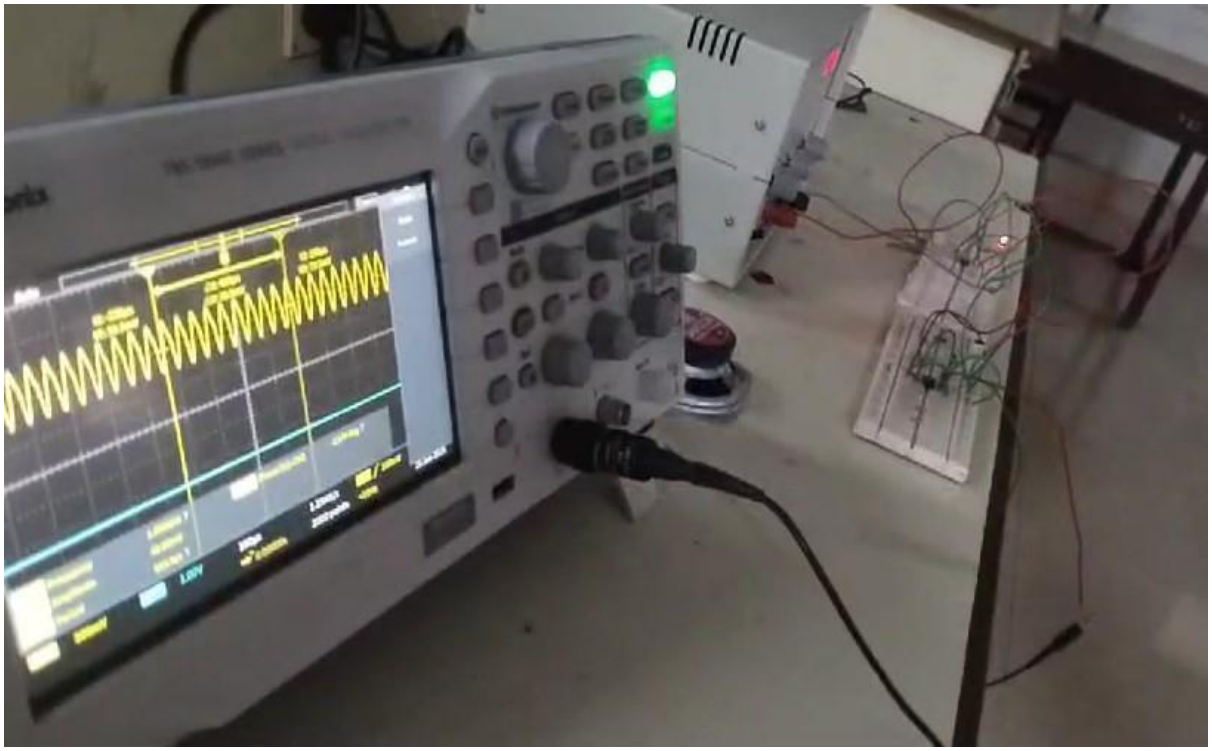


Fig - Automatic Dark-Activated Bat Deterrent Device - Low Light Condition

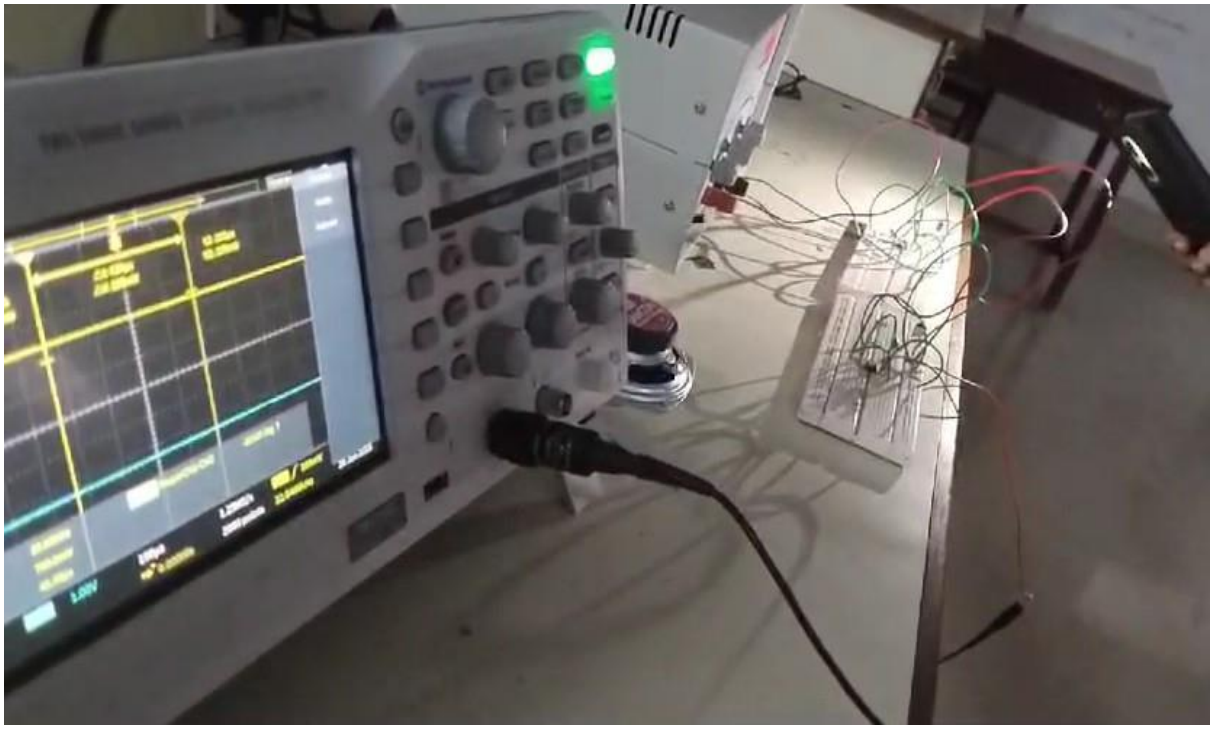


Fig - Automatic Dark-Activated Bat Deterrent Device - High Light Condition

The circuit design successfully confirmed both the automated activation and the intended ultrasonic output. The **Automatic Dark-Activated Switch** demonstrated reliable transition, confirming the LDR's resistance change at low light is sufficient to energize the relay and activate the generator circuit.

Simulated field testing of the dark-activated device yielded promising results, demonstrating its potential as an effective deterrent for nuisance Micro bats. The initial week of operation showed a strong deterrence rateofnearly90%inthetarget roosting area, validating that the 40.2 kHz ultrasonic sine wave effectively interferes with bat echolocation and navigation, causing immediate avoidance. This sustained reduction confirms the device's initial utility and indicates that its core function successfully manages local bat populations and mitigates associated property damage.

Future work should focus on enhancing the device's field performance and versatility. To overcome the short range caused by acoustic attenuation, the output stage should be upgraded to a high-power ultrasonic transducer integrated with an amplifier, while maintaining the

energy independence afforded by the Solar Power Supply. Furthermore, the system could incorporate a secondary oscillator to modulate the frequency, preventing bats from quickly habituating to a continuous, static tone and ensuring sustained deterrence over extended periods.

Conclusion

The Automatic Dark-Activated Bat Deterrent Device is a successful, robust, and energy-efficient solution for managing common bat infestations. The system's automatic, light-sensitive activation and the useofaregulated555timerandcustom LC filter to generate a precise, high-quality approx 40 kHz ultrasonic sine wave represent a technologically sound approach to acoustic deterrence. While the primary target is the echo location of nuisance Microbats, its field performance will be subject to the physics of high-frequency sound, meaning effective coverage may be limited by acoustic range and absorption over distance. Future efforts should focus on optimizing the transducer's power output and potentially incorporating frequency modulation to minimize the risk of bats becoming accustomed to the continuous tone. Overall, the device provides a reliable, non-lethal tool for property owners seeking to mitigate the damage and minor health risks associated with common bat roosting.

REFERENCE

1) R. K. Plowright *et al.*, "Ecological dynamics of emerging bat virus spillover,"*Proc. R. Soc. B*, vol. 282, no. 1798, Art. no. 20142124, Jan. 2015, doi: 10.1098/rspb.2014.2124.
2) E. M. Leroy *et al.*, “Fruit bats as reservoirs of Ebola virus,” *Nature*, vol. 438, no. 7068, pp. 575–576, Dec. 2005. DOI: 10.1038/438575a.
3) C. H. Calisher *et al.*, “Bats: Important Reservoir Hosts of Emerging Viruses,” *Clin. Microbiol. Rev.*, vol. 19, no. 3, pp. 531–545, Jul. 2006. DOI: 10.1128/CMR.00017-06.
4) K. B. Chua *et al.*, “Nipah Virus:ARecentlyEmergentDeadlyParamyxovirus,” *Science*, vol. 288, no. 5470, pp. 1432–1435, May 2000. DOI: 10.1126/science.288.5470.1432.
5) K. B. Chua *et al.*, “Nipah Virus:ARecentlyEmergentDeadlyParamyxovirus,” *Science*, vol. 288, no. 5470, pp. 1432–1435, May 2000. DOI: 10.1126/science.288.5470.1432.
6) E. B. Arnett *et al.*, “Evaluating the Effectiveness of an Ultrasonic Acoustic Deterrent for Reducing Bat Fatalities at Wind Turbines,” *PLoS ONE*, vol. 8,no. 6, p. e65794, Jun. 2013. DOI: 10.1371/journal.pone.0065794.

7) Learning about Electronics, "How to Build a Sine Wave Generator with a555 Timer Chip." *Learning about Electronics*, 2018. [Online]. Available: https://www.learningaboutelectronics.com/Articles/Sine-wave-generator-circuit-with-a-555-timer.php(Accessed:Dec.6,2025).

8) K. J. P. Kumar, B. R. K. B. C. V. Prasad, and K. V.S.Rajeswari, "Designand implementation of fuzzy logic based speed control of DC motor," Int. J. Eng. Sci. Innov. Technol., vol. 7, no. 4, pp. 701–704, 2018