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MINISTRY OF EDUCATION

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VOLUME II

ACCELERATING SOCIETAL CHANGE THROUGH DIGITAL TRANSFORMATION

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NSBM Green University
Colombo, Sri Lanka
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CONFERENCE AGENDA

08.30 AM	Registrations and Welcome
09.30 AM	Lighting of the Traditional Oil lamp
09.40 AM	Welcome Dance
09.45 AM	Welcome Speech: Ms. Thilini De Silva, Dean – Faculty of Business
09.50 AM	Conference Profile Video
10.10 AM	Keynote Speech 1, Professor Archie Clements, Deputy Vice-Chancellor, Research & Innovation University of Plymouth, UK
11.00 AM	Entertainment Act
11.15 AM	Keynote Speech 2, Professor Roshan Gabriel Ragel, Head - Department of Computer Engineering, University of Peradeniya, Sri Lanka
12. 05 PM	Concluding Remarks
12.15 PM	Lunch
13.00 PM onwards	Commencements of the Conference Parallel Sessions and Poster Presentations

PREFACE

We are delighted to present the proceedings of ICOBI 2023, and it is with great pleasure that we extend a warm welcome to all the authors and delegates of this esteemed event. We trust that the contents within will prove to be not only insightful but also transformative.

For the sixth consecutive year, NSBM Green University proudly hosts the International Conference on Business Innovation (ICOBI), pushing the boundaries of academic discourse. In the landscape of higher education, NSBM continues to pave the way, fostering innovation and scholarly exchange. ICOBI 2023 signifies our commitment to exploring the intersection of business and technology.

This year, under the theme "Accelerating Societal Change Through Digital Transformation," ICOBI takes a bold step into the realm of cutting-edge technologies that are reshaping the fabric of our societies. In an era marked by rapid digital advancements, this conference aims to be a catalyst for discussions on leveraging technology to drive positive and impactful societal changes.

Digital transformation has become an imperative for organizations and nations alike. The fusion of business and technology offers unprecedented opportunities and challenges. ICOBI 2023 serves as a vital platform to bring together local and international researchers, academics, and industry experts to deliberate on the profound impact of digital transformation on society. Our theme aligns with the contemporary need to harness digital innovation for social good. The conference will delve into how businesses, governments, and communities can collaboratively accelerate positive societal changes through the strategic implementation of digital technologies.

As we embark on this intellectual journey, we would like to express our deepest gratitude to Prof. E. A. Weerasinghe, the Vice-Chancellor of NSBM Green University, and Prof. Chaminda Rathnayaka, the Deputy Vice-Chancellor, for their unwavering support and visionary leadership. Special thanks also go to Prof. J. Baratha Dodankotuwa, the Head of Academic Development and Quality Assurance, for his expert input.

We extend our sincere appreciation to all local and international presenters and participants whose contributions enrich the conference. The success of ICOBI 2023 would not be possible without the dedication of our reviewers and the diligent work of the Conference Organizing Committee.

In conclusion, we anticipate that ICOBI 2023 will not only foster meaningful academic discussions but also pave the way for innovative solutions that will contribute to a digitally transformed and socially progressive future. We extend our best wishes to all attendees, confident that your experience with us will be both enriching and enduring.

The Conference Organizing Committee
ICOBI 2023

MESSAGE FROM VICE-CHANCELLOR

PROF. E.A. WEERASINGHE

It is with great pleasure and pride that I extend a warm welcome to the International Conference on Business Innovation (ICOBI) 2023, organized by NSBM Green University. As we embark on the sixth edition of this prestigious conference, we find ourselves at the nexus of academia, innovation, and the transformative power of digital technologies.

Our theme for ICOBI 2023, "Accelerating Societal Change Through Digital Transformation," echoes the evolving landscape of research and innovation. In the context of today's dynamic global environment, the fusion of digital technology with business practices becomes not only relevant but imperative for societal progress.

Building on the success of our previous conferences, ICOBI 2023 serves as a beacon for scholars, researchers, and industry experts to collectively explore the profound impacts of digital transformation on societal change. We stand at the forefront of a new era where the integration of technology into our social fabric has the potential to shape a future that is not only sustainable but also inclusive.

Universities play a pivotal role as catalysts for research and innovation, influencing societal and economic growth. ICOBI 2023, as a testament to this commitment, seeks to create a platform for multidisciplinary scholars to present their research, fostering a productive discourse on the transformative power of digital technologies in the pursuit of societal advancement.

I extend my heartfelt congratulations to the organizing committee for their dedication in curating a conference that promises to be a reservoir of knowledge, ideas, and innovative solutions. The high-quality papers and expert insights gathered for this event are a testament to the commitment of our academic community to push the boundaries of knowledge.

My sincere appreciation goes to all presenters and delegates who contribute to the richness of our annual conferences with their insightful presentations and meaningful discussions. Your efforts are instrumental in enhancing our university's research culture and, more importantly, in contributing to the broader development of our nation.

I look forward to witnessing the informative and fruitful discussions that will unfold at ICOBI 2023. May this conference be a source of inspiration, collaboration, and transformative ideas that will propel us toward a future where digital transformation accelerates positive societal change.

Thank You.

MESSAGE FROM DEPUTY VICE-CHANCELLOR

PROF. CHAMINDA RATHNAYAKE

It is with great pleasure that I extend my warmest greetings to the sixth International Conference on Business Innovation (ICOBI 2023) organized by NSBM Green university. As the Deputy Vice Chancellor of NSBM Green University, it is an honor to welcome you to this prestigious event focused on the theme, "Accelerating Societal Change Through Digital Transformation."

In an era marked by unprecedented technological advancements, the impact of digital transformation on various facets of society is profound and far-reaching. ICOBI 2023 serves as a crucial platform for the exchange of ideas, insights, and research findings that contribute to our collective understanding of the transformative power of digital innovation.

NSBM Green University is committed to fostering an environment of academic excellence, innovation, and collaboration. The ICOBI conference series aligns seamlessly with our mission to promote cutting-edge research and facilitate discussions that pave the way for advancements in business practices and societal well-being.

As we delve into discussions on accelerating societal change through digital transformation, I encourage you to engage actively, share your expertise, and explore collaborative opportunities. The diverse perspectives gathered here will undoubtedly enrich our understanding of the challenges and opportunities presented by the digital era.

I would like to express my gratitude to the organizing committee, sponsors, and all participants for their dedication and efforts in making ICOBI 2023 a reality. Your commitment to advancing knowledge and driving positive change is commendable, and I am confident that this conference will serve as a catalyst for meaningful developments in the field of business innovation.

May your interactions during ICOBI 2023 be both intellectually stimulating and personally enriching. I wish you a productive and inspiring conference experience.

Thank you.

MESSAGE FROM THE HEAD OF ACADEMIC DEVELOPMENT AND QUALITY ASSURANCE

PROF. J. BARATHA DODANKOTUWA

It is my distinct pleasure to extend a warm welcome to all participants, researchers, and scholars who have gathered for the sixth International Conference on Business Innovation (ICOBI 2023), hosted by NSBM Green University. As the Head of Academic Development and Quality Assurance, I am delighted to see the convergence of brilliant minds and innovative ideas around the central theme, "Accelerating Societal Change Through Digital Transformation."

The landscape of academia and industry is undergoing a profound shift, driven by the rapid evolution of digital technologies. ICOBI 2023 provides a unique opportunity for us to collectively explore the myriad ways in which digital transformation is reshaping the business landscape and, by extension, accelerating societal change.

NSBM Green University is dedicated to maintaining the highest standards of academic excellence, and events like ICOBI are instrumental in fostering a culture of inquiry, collaboration, and continuous improvement. As we embark on this intellectual journey, I encourage you to actively participate in the various sessions, share your research findings, and engage in stimulating discussions with your peers.

The theme of this conference underscores the imperative for businesses and societies to adapt to the digital age. It is our hope that the insights shared and collaborations formed during ICOBI 2023 will contribute to a deeper understanding of the challenges and opportunities presented by this transformative era.

I extend my sincere appreciation to the organizing committee, sponsors, and all contributors for their dedicated efforts in making ICOBI 2023 a reality. Your commitment to advancing knowledge and fostering innovation is crucial for the continued success of conferences like ICOBI.

May your experiences during this conference be intellectually rewarding, and may the connections you forge here lead to lasting collaborations that further the frontiers of business innovation and societal progress.

Thank you.

MESSAGE FROM THE CONFERENCE CHAIR

DR. MOHAMED SHAFRAZ
CONFERENCE CHAIR

I am humbled and honoured to pen down this message for the International Conference on Business Innovation (ICOBI), 2023 to be held on 24 November at the NSBM Green University. The journey of the ICOBI continues for the 6th consecutive year, and each year, the conference addresses timely and pressing local and global issues and concerns. Being South Asia's first green university, we always strive to contribute our best to the nation and world through research and development as a part of our pivotal role in academic endeavours.

This year's conference theme is "Accelerating Societal Change Through Digital Transformation". With the exponential growth of technology, it is imperative to recognize the vital role that digital transformation plays in reshaping our societies. The intersection of technology and societal progress is the focal point of our discussions, reflecting the dynamic landscape in which we find ourselves. This conference aims to enhance the impact of digital transformation on societal change, exploring its multifaceted contributions and the potential it holds for accelerating positive transformations. Digital transformation, once confined to business and technology, has evolved into a powerful force shaping our societies. In our interconnected world, the rapid adoption of digital technologies influences how we communicate, learn, work, and address societal challenges. This conference serves as a platform to delve into the transformative potential of digital innovations across various sectors.

In making this conference a success, many individuals contributed to all the phases in the process. I am particularly thankful to the ICOBI 2023 organizing committee and staff members. They have given me tremendous support without any hesitation in organizing the conference. Their contribution to making this conference a success is truly commendable. All these would have been impossible without the guidance and leadership of our visionary leader Prof. E.A. Weerasinghe, Vice-Chancellor. We are always indebted to him for his guidance and encouragement. Further, I would like to especially mention Prof. Chaminda Rathnayake, Deputy Vice-Chancellor and Prof. Baratha Dodankotuwa, Head of Academic Development and Quality Assurance, for their immense support and dedication to enhancing the research culture at the university.

On behalf of the Organizing Committee, a special note of gratitude is extended to all the local and international speakers, authors, reviewers, researchers and presenters for their time and efforts toward the success of this ICOBI 2023. As the Conference Chair, I encourage participants to actively engage in discussions, share insights, and forge collaborations. The collective expertise gathered here has the potential to drive meaningful change. Let us seize this opportunity to shape the digital transformation narrative, ensuring that it aligns with our shared values and forces us toward a future where technology accelerates positive societal change.

Thank you.

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KEYNOTE SPEECH 1

PROF. ARCHIE CLEMENTS
DEPUTY VICE-CHANCELLOR, RESEARCH & INNOVATION UNIVERSITY OF PLYMOUTH, UK

INFECTIOUS DISEASE DATA VISUALISATION PLATFORMS FOR PUBLIC CONSUMPTION: ADVANCES IN THE ERA OF COVID-19

The COVID-19 pandemic is the first major pandemic of the digital age and has been characterised by unprecedented public consumption of disease data via online data visualisation platforms. A variety of state and non-state actors, and collaborative initiatives between them, collated and presented maps, charts, and plots of data related to the pandemic in both static and dynamic formats. In particular, there was a proliferation of online COVID-19 dashboards. The sources and types of information displayed evolved rapidly during the pandemic, with a general trend towards providing more specialised information pertinent to specific aspects of epidemiology or disease control, as opposed simply to disease and death notifications. Limited evaluation of the quality of COVID-19 data visualisation platforms has been conducted and significant effort now needs to be spent on standardisation and quality improvement of national and international data visualisation systems including developing common indicators, data quality assurance mechanisms and visualisation approaches, and building compatible electronic systems for data collection and sharing. The increasing availability of disease data for public consumption presents challenges and opportunities for government, media organisations, academic research institutions, and the general public. Public access to disease data can enable greater transparency and accountability of governments to the public for their public health decisions, but capitalising on opportunities for greater government accountability for public health decision-making, and more effective mobilisation of public health interventions, is predicated on the provision oaccurate and timely information and the COVID-19 pandemic demonstrated many of the challenges that impact on accuracy and timeliness. Additionally, online data platforms created by non-state actors can disseminate information that doesn't have official endorsement and can be inconsistent with officially endorsed information and public health messaging. Information consistency underpins the ability to mount a coordinated response and generate public trust in intervention strategies. Governments should acknowledge and accept the future role of non-state actors in disseminating data and information to the public during pandemics and seek to work with non-state entities to ensure the public need for accurate and timely information is met. This will not only enhance public trust in government decisions, but also leverage the technological capabilities and innovativeness of non-state actors, which can often be mobilised in the short timeframes required for effective pandemic responses.

KEYNOTE SPEECH 2

PROFESSOR ROSHAN GABRIEL RAGEL
HEAD - DEPARTMENT OF COMPUTER ENGINEERING, UNIVERSITY OF PERADENIYA, SRI LANKA

GENERATIVE AI IN EDUCATION: CATALYZING DIGITAL TRANSFORMATION FOR SOCIETAL ADVANCEMENT

INTRODUCTION

The education landscape has been significantly transformed, catalyzed by rapid advancements in digital technologies. Generative Artificial Intelligence (GenAI) emerges as a particularly transformative force, poised to redefine the educational paradigm. This article delves into the potential of GenAI in revolutionizing the approach to learning and teaching, particularly in mastery learning and addressing the historical challenges identified in Bloom's 2-sigma problem.

Benjamin Bloom, a renowned educational psychologist, first introduced the concept of mastery learning in 1968. This approach, predicated on the belief that students must attain a particular understanding of prerequisite knowledge before progressing, has been substantiated by numerous studies for its effectiveness in enhancing student outcomes (Kulik, Kulik, & Bangert-Drowns, 1990). However, the practical implementation of mastery learning on a large scale has been historically impeded by significant resource constraints, particularly in providing the individualized attention integral to this method (Clary, L. 1986).

In 1984, Bloom articulated what is now known as the "2-sigma problem." Based on the dissertation research of his graduate students, Joanne Anania and Joseph Arthur Burke, this observation revealed that average students who received one-to-one tutoring using mastery learning techniques outperformed 98% of students in a conventional classroom setting (Bloom, 1984). While this finding underscored the potential of personalized educational support, it also highlighted the impracticality of such an intensive approach, given the resource limitations of most educational systems.

This article proposes that the advent of GenAI presents a viable solution to these historical challenges. GenAI's capability to generate personalized educational content and experiences aligns with mastery learning and one-to-one tutoring requirements, potentially at a scale and cost that traditional methods cannot match. By exploring the intersection of GenAI with established educational theories and practices, this article aims to illuminate how technological advancements can bridge gaps in education, contributing to societal progress in line with the theme of the conference, "Accelerating Societal Change Through Digital Transformation."

HISTORICAL CONTEXT OF MASTERY LEARNING

a. The Origins of Mastery Learning

Mastery learning, an educational philosophy that has profoundly influenced modern educational practices, was first proposed by Benjamin Bloom in 1968. At its core, mastery learning challenges the traditional pace-based approach to education. Instead of moving students through an educational program based on a set timetable, mastery learning insists that students master prerequisite knowledge before learning subsequent information (Bloom, 1968). This approach is predicated on the belief that with sufficient time and appropriate instructional methods, nearly all students can achieve a high level of understanding.

b. Empirical Support for Mastery Learning

The effectiveness of mastery learning has been substantiated by extensive research. A seminal meta-analysis by Kulik, Kulik, and Bangert-Drowns (1990) examined the impact of mastery learning programs and found significant positive effects on student achievement. These researchers analyzed 108 studies and concluded that students in mastery learning classes frequently outperformed those in control groups regarding academic achievement.

Further supporting evidence comes from Clary, L. (1986), who noted that students engaged in mastery learning often exhibit more satisfaction with their instruction and develop more positive attitudes towards the content they are taught. This approach improves students' academic performance, enhances their academic self-concept, and instils aspects of a growth mindset.

c. Challenges in Mastery Learning Implementation

Despite its proven effectiveness, implementing mastery learning on a large scale has been challenging. One of the primary hurdles has been the resource-intensive nature of this approach. Mastery learning requires frequent and timely assessments, individualized feedback, and often additional instructional time and resources to ensure all students achieve mastery. These requirements pose significant logistical and financial challenges, especially in larger educational systems with limited resources.

d. Summary

Mastery learning represents a shift from the traditional educational model, focusing on student mastery rather than time-based progression. While research has consistently demonstrated its effectiveness in enhancing student learning outcomes, the practical challenges of implementing this approach on a large scale have remained a significant barrier. This historical context sets the stage for exploring how modern technological advancements, specifically GenAI, can address these implementation challenges.

BLOOM'S 2-SIGMA PROBLEM

a. Introduction to the 2-Sigma Problem

In education, Benjamin Bloom's 2-Sigma problem, articulated in 1984, is a pivotal observation that has guided much of the discourse on educational efficacy and personalized learning. Bloom's research stemmed from a simple yet profound observation: the average student tutored one-to-one using mastery learning techniques performed two standard deviations better than students taught via conventional classroom methods. This finding, reported in Bloom's seminal paper in The Educational Researcher, illuminated the remarkable poten-

tial of personalized instruction (Bloom, 1984).
b. The Implications of the 2-Sigma Problem
Bloom's observation, often called the 2-Sigma problem, has profound implications. It suggests that if educators could effectively replicate the conditions of one-to-one tutoring on a larger scale, they could significantly enhance students' educational attainment. Bloom's paper analyzed the dissertation results of his graduate students, Joanne Anania and Joseph Arthur Burke, who quantified this improvement: "The average tutored student was above 98% of the students in the control class" (Bloom, 1984). This stark contrast highlighted the effectiveness of individualized instruction and mastery learning in fostering academic success.

c. The Challenge Posed by the 2-Sigma Problem

However, the 2-Sigma problem also underscored a significant challenge: achieving the benefits of one-to-one tutoring within the constraints of conventional educational systems. Given its intensive resource requirements, Bloom recognized the impracticality of one-to-one tutoring as a widespread educational approach. In his paper, Bloom challenged educators and researchers to find methods of group instruction that could be as effective as one-to-one tutoring, a task that has proven daunting over the years.

d. Summary

The 2-sigma problem, therefore, encapsulates the quest within the educational field to bridge the gap between the ideal (personalized instruction) and the feasible (group instruction). It highlights the necessity of innovative approaches to achieve the level of educational efficacy that one-to-one tutoring offers, but within the practical constraints of educational institutions. This historical challenge sets the context for exploring how GenAI might offer solutions to the constraints posed by the 2-sigma problem.

The Unresolved Challenge of Resource Limitations

a. The Core Issue of Resource Constraints

One of the most significant barriers to the widespread implementation of personalized education approaches, such as those highlighted by Bloom's 2-Sigma problem, is the issue of resource limitations. While the benefits of one-to-one tutoring and mastery learning are well-documented, the practicality of these methods in typical educational settings has been persistently hampered by resource constraints.

b. Historical Perspective on Resource Limitations

Historically, educational systems have grappled with various limitations, including inadequate teacher-to-student ratios, limited time for individualized instruction, and insufficient financial resources to support personalized learning initiatives. Bloom acknowledged these challenges in his discussion of the 2-sigma problem, noting that, while highly effective, one-to-one tutoring is "too costly for most societies to bear on a large scale" (Bloom, 1984). The need for individualized attention, frequent assessments, and additional teaching materials substantially strains educational resources.

c. Empirical Evidence of Resource Challenges

Research has consistently highlighted these resource challenges. In a study examining the feasibility of implementing mastery learning in public schools, Guskey and Pigott (1988) found that while teachers recognized the effectiveness of the approach, they were often unable to implement it fully due to a lack of time and support. Similarly, a report by Slavin (1987) on cooperative learning models, which sought to address some aspects of the 2-sigma problem, also identified resource limitations as a significant barrier to effective implementation.

d. The Persistence of the Problem

Despite educational technological advancements, resource limitations have persisted. The challenge is not merely one of financial investment but also involves structural and systemic factors that hinder the adaptation of educational systems to more personalized approaches. A study by Terhart, E. (2011) reiterated the ongoing struggle of educational systems to balance resource constraints with the need for effective instructional strategies.

e. Summary

The unresolved challenge of resource limitations thus remains a central issue in the quest to improve educational outcomes. It underscores the need for innovative solutions to circumvent these constraints, potentially through emerging technologies such as GenAI. Understanding these historical and ongoing challenges is crucial for appreciating the potential impact of GenAI in transforming educational practices.

THE ROLE OF DIGITAL TRANSFORMATION IN EDUCATION

a. Introduction to Digital Transformation

The concept of digital transformation in education encapsulates a broad range of technological integrations and pedagogical shifts that redefine the educational landscape. This transformation is characterized by the adopting of digital tools and a fundamental change in how education is delivered, experienced, and managed.

b. The Shift to Digital Pedagogies

Digital transformation has ushered in new pedagogical approaches, such as flipped classrooms and blended learning, which have been shown to enhance student engagement and learning outcomes. A study by Abeysekera and Dawson (2015) found that the flipped classroom approach, which integrates digital technologies for out-of-classroom content delivery and in-class interactive learning, significantly improves student learning experience and performance. Similarly, Aronoff, et al. (2017) reported in their meta-analysis that blended learning environments, combining online and face-to-face instruction, often result in stronger learning outcomes than traditional classroom settings.

c. The Impact on Mastery Learning

Digital technologies has also made it more feasible to implement mastery learning principles. With online platforms and learning management systems, educators can now provide personalized learning experiences, track student progress in real time, and offer tailored feedback and support. In a study by Steen-Utheim and Foldnes (2018), using digital tools in a mastery learning framework significantly improved student engagement and academic performance.

d. Technological Advancements and Resource Optimization

One of the critical contributions of digital transformation is the optimization of resources. Technologies such as AI and machine learning offer potential solutions to the resource constraints previously hindering personalized education. For instance, Chen, L., Chen, P., & Lin, Z. (2020) and Crompton, H., & Song, D. (2021) discussed how AI in education can streamline the learning process, facilitate personalized learning paths, and optimize the allocation of educational resources.

e. Summary

Digital transformation in education is not merely about incorporating technology into teaching and learning; it represents a paradigm shift in educational delivery and design. This transformation, emphasising personalized

learning and resource optimization, provides a fertile ground for integrating GenAI, offering new possibilities for addressing historical challenges such as those posed by Bloom's 2-sigma problem.

GENERATIVE AI AS A SOLUTION

a. Introduction to Generative AI in Education

Generative AI (GenAI) represents a significant leap in artificial intelligence, particularly in its application to education. GenAI refers to AI systems capable of generating new content, including textual materials, learning resources, and interactive experiences, based on extensive data analysis and pattern recognition. The potential of GenAI in education is vast, from creating personalized learning materials to offering adaptive learning experiences.

b. Personalized Learning Through GenAI

One of the most compelling applications of GenAI in education is its ability to facilitate personalized learning. GenAI can analyze student performance, learning styles, and preferences and generate customized content and learning paths. Research by Nagao, K. (2019) demonstrated that AI-powered personalized learning systems significantly improve student engagement and learning outcomes. These systems adapt to each learner's needs, providing personalization akin to one-to-one tutoring, thereby addressing a key aspect of Bloom's 2-sigma problem.

c. Overcoming Resource Limitations

GenAI also offers a solution to the resource limitations that have traditionally hindered the implementation of personalized education approaches. By automating content generation and adapting to individual learner needs, GenAI reduces the need for extensive human resources. A study by Johnson, Adams Becker, Estrada, and Freeman (2015) highlighted the potential of AI in reducing the time and effort required by educators in creating and tailoring learning materials, thus optimizing educational resources.

d. Enhancing Mastery Learning

In the context of mastery learning, GenAI can play a crucial role. It allows for the frequent assessment and feedback that mastery learning requires but at a scale and efficiency unattainable through traditional methods. Han, S. (2022) explored the integration of AI in mastery learning environments and found that AI systems could effectively support mastery learning principles, providing timely feedback and adaptive learning pathways to students.

e. Challenges and Future Prospects

While GenAI presents immense opportunities, it also challenges ensuring equitable access and addressing ethical concerns related to data privacy and AI biases. The future of GenAI in education hinges on addressing these challenges while harnessing its potential to revolutionize how education is delivered and experienced.

f. Summary

Generative AI stands at the forefront of educational innovation, offering scalable and efficient solutions to longstanding educational challenges. Its capacity for personalization, resource optimization, and support for mastery learning principles makes it a promising tool for transforming the educational landscape and addressing the historical challenges outlined by Bloom's 2-sigma problem.

CONCLUSION

a. Summarizing the Argument

This article has explored the transformative potential of Generative AI (GenAI) in education, particularly in addressing the longstanding

challenges outlined in Bloom's 2-sigma problem. Beginning with a historical overview of mastery learning and the empirical evidence supporting its effectiveness, we delved into the persistent challenge of resource limitations that have traditionally impeded the implementation of personalized education methods. The discussion then transitioned to the role of digital transformation in education, highlighting how technological advancements have begun to reshape pedagogical approaches and offer solutions to these historical challenges.
The focus shifted to GenAI, a groundbreaking development in AI, and its capacity to facilitate personalized learning at an unprecedented scale and efficiency. GenAI's ability to generate customized learning materials and experiences, adapt to individual learner needs, and optimize educational resources addresses key aspects of Bloom's 2-sigma problem. This technology promises to overcome the previously faced resource constraints and enhance mastery learning principles, paving the way for a more effective and personalized educational experience.

b. Vision for the Future

Looking forward, GenAI holds immense potential to contribute to societal advancement through transformative changes in education. As GenAI continues to evolve, its integration into educational systems worldwide could mark a new era of personalized, efficient, and equitable education. This evolution could significantly narrow the educational achievement gaps and democratize access to high-quality, individualized learning experiences.

The future of education, empowered by GenAI, envisions a world where the barriers to personalized learning are dismantled, and every student can achieve their full potential. This augurs well for educational outcomes and broader societal impacts, as a well-educated populace is crucial for addressing the complex challenges of the 21st century.

In conclusion, integrating GenAI into education represents a beacon of hope and a path forward in overcoming historical educational challenges. It invites educators, policymakers, and technologists to collaborate in harnessing its potential, ensuring ethical considerations are met, and laying the groundwork for an educational revolution that promises far-reaching positive impacts on society.

REFERENCES

Abeysekera, L., & Dawson, P. (2015). Motivation and cognitive load in the flipped classroom: Definition, rationale and a call for research. Higher Education Research & Development, 34(1), 1-14.

Aronoff, N., Stellrecht, E., Lyons, A. G., Zafron, M. L., Glogowski, M., Grabowski, J., & Ohtake, P. J. (2017). Teaching evidence-based practice principles to prepare health professions students for an interprofessional learning experience. Journal of the Medical Library Association : JMLA, 105(4), 376–384. https://-doi.org/10.5195/jmla.2017.179

Bloom, B. S. (1984). The 2 sigma problem: The search for methods of group instruction as effective as one-to-one tutoring. Educational Researcher, 13(6), 4-16.

Clary, L. (1986) Twelve "Musts" for Improved Reading Comprehension.. Reading Horizons, 26, 99-104.

Chen, L., Chen, P., & Lin, Z. (2020). Artificial Intelligence in Education: A Review. IEEE Access, 8, 75264-75278. https://-doi.org/10.1109/ACCESS.2020.2988510.

Crompton, H., & Song, D. (2021). The Potential of Artificial Intelligence in Higher Education. Revista Virtual Universidad Católica del Norte. https://doi.org/10.35575/RVUCN.N62A1.

Guskey, T. R., & Pigott, T. D. (1988). Research on group-based mastery learning programs: A

meta-analysis. Journal of Educational Research, 81(4), 197-216.

Han, S. (2022). Flipped classroom: Challenges and benefits of using social media in English language teaching and learning. Frontiers in Psychology, 13. https://doi.org/10.3389/fpsyg.2022.996294.
Johnson, L., Adams Becker, S., Estrada, V., & Freeman, A. (2015). NMC Horizon Report: 2015 Higher Education Edition. The New Media Consortium.

Kulik, J. A., Kulik, C. C., & Bangert-Drowns, R. L. (1990). Effectiveness of mastery learning programs: A meta-analysis. Review of Educational Research, 60(2), 265-299.
Nagao, K. (2019). Artificial Intelligence Accelerates Human Learning. . https://doi.org/10.1007/978-981-13-6175-3.

Oliver, M., & Conole, G. (2003). Evidence-based practice and e-learning in Higher Education: can we and should we?. Research Papers in Education, 18, 385 - 397. https://doi.org/10.1080/0267152032000176873.

Slavin, R. E. (1987). Ability grouping and student achievement in elementary schools: A best-evidence synthesis. Review of Educational Research, 57(3), 293-336.

Steen-Utheim, A. T., & Foldnes, N. (2018). A qualitative investigation of student engagement in a flipped classroom. Teaching in Higher Education, 23(3), 307-324.

Terhart, E. (2011). Has John Hattie really found the holy grail of research on teaching? An extended review of Visible Learning. Journal of Curriculum Studies, 43, 425 - 438. https://doi.org/10.1080/00220272.2011.576774.

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A Novel Encryption Algorithm using Skolem Graceful Labeling

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ABSTRACT

Throughout generations, Graph Theory and Cryptography have gone hand-in-hand as intriguing subject areas with many real-world applications in diverse disciplines; Computer Science, Engineering, Biology, etc. A graph G is defined as a union of a finite non-empty set of elements called vertices $V(G)$, which are associated by a set of lines called edges, $E(G)$. In the present study, Graph Labeling is used to implement a new Cryptography algorithm by generating a key from a constructed polyalphabetic table which is denoted by (G, l, k), where $G, l,$ and k represent the Skolem graceful labeled graph, the size of a block, and the shifting value, respectively. The Polyalphabetic table was constructed using the Skolem graph labeling of Lobster graph $L_3(2,4)$. Cryptography is the science of securing information by converting readable format to unreadable format. The process of converting a given format is called encryption while the reverse process is called decryption. We encrypt a given message into the ciphertext using the polyalphabetic table with the help of the Skolem graceful labeling, and is converted into the plaintext by using the decryption algorithm. As a future study, we are planning to extend this idea to an encryption and decryption algorithm by using graph factorizations and different graph labeling methods.

Keywords - **Cryptography, Encryption algorithm, Decryption algorithm, and Skolem graceful labeling**.

1. INTRODUCTION

Graph Theory is used to solve many real-world phenomena. In this study, finite simple graphs are considered to build an encryption and decryption algorithm. A simple graph G is defined by $V(G)$ which is a non-empty finite set of elements called vertices and $E(G)$, which is a set of unordered pair of distinct elements of $V(G)$

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called edges. Graph labeling is a notable technique (Ni at el., 2021) because it is helpful to solve many applications such as the radio labeling method can be used to find best places to establish signal towers. The *Skolem* graceful labeling is a prominent labeling method which was introduced by S.M. Lee and S.C. Shee following the idea of Skolem sequence (Lee at el., 1991). A graph is said to be Skolem graceful graph, if there exists a function f called a Skolem graceful labeling such that there is a bijective function $f: V \longrightarrow \{1,2, \dots, |V|\}$ and the induced labeling $g: E \longrightarrow \{1,2, \dots, |E|\}$ defined by $g(uv) = |f(u) - f(v)|, \forall\, uv \in E$ is also bijective (Lee at el., 1987).

Cryptology is the art that protects the confidentiality of messages by creating codes and solving them. It has two main areas known as Cryptography and Cryptanalysis. Cryptography is the method of protecting information by converting to unreadable format called ciphertext and this process is known as encryption. On the other hand, Cryptoanalysis is an art how to recover encrypted messages to readable format by doing complex study. The original message called as plaintext and the method to obtain plaintext from ciphertext is called decryption. Cryptosystems can be divided into two main sections; symmetric and asymmetric or private and public, to maintain consistency. Most of the symmetric-key algorithms are classical cryptosystems, in which the sender and the receiver use the same key to encrypt and decrypt a message. The cryptography polyalphabetic method is a famous method based on substitution of many variables for the characters in plaintext (Ni at el., 2021). But in public-key cryptography, the sender encrypts the message using a key which is called the public key and when the receiver receives the encrypted message, it can be decrypted using a secret key called the private key.

In this study, we encrypt the message into ciphertext by introducing cryptography polyalphabetic method by using the knowledge in graph theory. This method is developed using Skolem graceful graph labeling which is a modified version of graceful labeling method. Here we have used a special graph Lobster graph $L_3(2,4)$ which have a Skolem graceful labeling (Urnika at el.,2021). In the next section we explain the method of algorithm in detail and discuss it using a simple example.

2. MATERIALS AND METHODS

2.1 Preliminaries

In this section we provide some fundamental definitions that are used to the proposed encryption technique.

2.1.1 A Lobster graph

A regular lobster graph $L_n(q, r)$ is lobster graph with n vertices on backbone path, each of which is connected to q hand vertices, and each hand vertex is connected to r finger vertices, $n \geq 2$. Figure 1 shows the lobster graph of $L_3(2,4)$.

2.1.2 Graceful labeling

A graceful labeling of a graph G is a vertex labeling $f: V \longrightarrow \{0,1,2, \dots, |E|\}$ such that f is injective and the edge labeling $g: E \longrightarrow \{1,2, \dots, |E|\}$ defined by $g(uv) = |f(u) - f(v)|, \forall\, uv \in E$ is also injective.

2.1.3 Skolem graceful labeling

The Skolem graceful labeling of a graph G is a modified version of the graceful labeling such that there exists a vertex labeling $f: V \longrightarrow \{1,2, \dots, |V|\}$ such that f is injective and the edge labeling $g: E \longrightarrow \{1,2, \dots, |E|\}$ defined by $g(uv) = |f(u) - f(v)|, \forall\, uv \in E$ is also bijective.

2.1.4 Encryption and Decryption

The process of encoding an original message (plaintext) into ciphertext is called encryption and the reverse process known as decryption.

2.2 Methodology

In this section we discuss encryption, decryption algorithms and key generation of these algorithms using polyalphabetic cipher. This cipher is constructed from the Skolem graceful labeling of Lobster graph $L_3(2,4)$.

2.2.1 Encryption Algorithm

The following steps illustrated the algorithm and the construction of the polyalphabetic table.

Step 1:

Label the Lobster graph $L_3(2,4)$ using the Skolem graceful labeling. This graph consists of 33 vertices and 32 edges. The Skolem graceful labeling of the Lobster graph $L_3(2,4)$ is shown in the Figure 1.

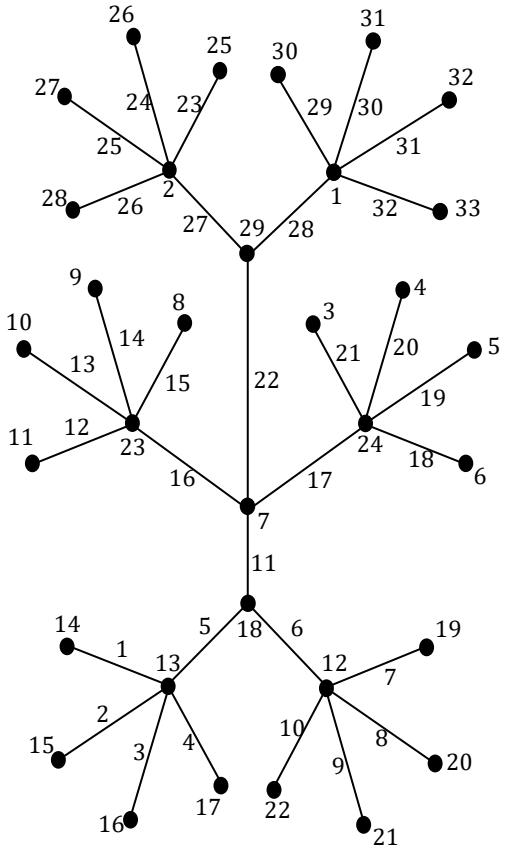

Figure 1. The Skolem graceful labeling method for Lobster graph $L_3(2,4)$.

Urnika, D. A., and Purwanto, (2021). Skolem Graceful Labeling of Lobster Graph $L_n(2,r)$. *The 4th International Conference on Mathematics and Science Education (ICoMSE) 2020, AIP conference Proceeding 2330, 070014.*

Step 2:

Assign letters in the English alphabet to the numbers on the vertices starting from 1 to 26 in the Lobster graph. After that, remain vertices numbers transformed to special characters. Here we have assigned ".", "–", ",", "(", ")", "/" and "?" to the vertex's

numbers $27, 28, 29, 30, 31, 32,$ and 33. Similarly, assign letters and special characters to the edges in the graph. Note that, since the number of vertices is larger than the number of edges by one, assign the last two assignments of special characters to the last edge. The symbol "–" represent the space between any two words.

The following diagram shows the English and special character assignment to the Lobster graph $L_3(2,4)$.

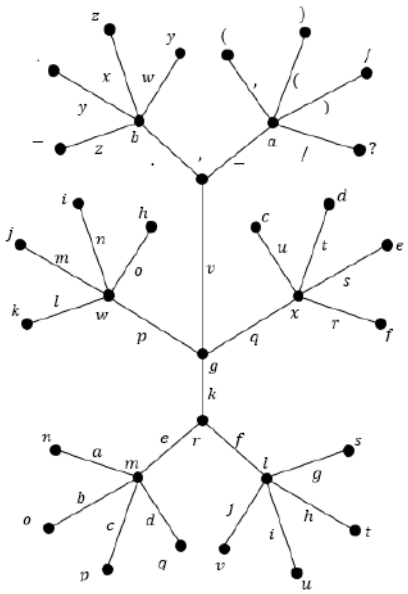

Figure 2. The English letters and special characters labeling method for Lobster graph $L_3(2,4)$.

Step 3:
Using Figure 2, we construct a table to obtain the ciphertext. The letters in the first column in the table is considered as the letters of the plaintext that obtain from vertex characters of the graph. Then the message is divided into equal number of blocks of the same size (l). If the size of the block is less than l, then add "/" to complete the required size of the block. The number of encoding columns in the polyalphabetic table are equal to the number l. The first encoding column is obtained from the letters that are in the adjacent edges related to each vertex. Next, use a shifting key say k to shift the letters in each column vertically.

Step 4:
Finally, using the polyalphabetic table, convert the original message into the ciphertext. Then, send the ciphertext to the receiver with the key (G, l, k). Here, $G, l,$ and k represent the Skolem graceful labeled graph, the number of sizes of the block, and the shifting value respectively.

Plaintext	Ciphertext					
a	-	o	b	j	?	u
b	.	n	c	p	,	t
c	u	m	d	q	(	s
d	t	l	k	w	)	r
e	s	f	g	x	/	v
f	r	e	h	y	-	o
g	v	a	i	z	.	n
h	o	b	j	?	u	m
i	n	c	p	,	t	l
j	m	d	q	(	s	f
k	l	k	w	)	r	e
l	f	g	x	/	v	a
m	e	h	y	-	o	b
n	a	i	z	.	n	c
o	b	j	?	u	m	d
p	c	p	,	t	l	k
q	d	q	(	s	f	g
r	k	w	)	r	e	h
s	g	x	/	v	a	i
t	h	y	-	o	b	j
u	i	z	.	n	c	p
v	j	?	u	m	d	q
w	p	,	t	l	k	w
x	q	(	s	f	g	x
y	w	)	r	e	h	y
z	x	/	v	a	i	z
.	y	-	o	b	j	?
-	z	.	n	c	p	,
,	?	u	m	d	q	(
(	,	t	l	k	w	)
)	(	s	f	g	x	/
/	)	r	e	h	y	-

?	/	v	a	i	z	.

Table 1. The polyalphabetic ciphertext for the key $(L_3(2,4), 6,7)$.

2.2.2 Decryption Algorithm

Step 1:
According to the key, identify the terms in (G, l, k). Then assign characters according to the second step in the encryption algorithm.

Step 2:
Construct the polyalphabetic table using the values l and k.

Step 3:
Finally, find the suitable letters from the constructed table and then the ciphertext can be converted into the plaintext.

3. RESULT AND DISCUSSION

In this study, a developed encryption algorithm is introduced using the labeling method known as Skolem graceful labeling in Graph Theory. The method is described using the plaintext "The Department of Mathematics. (UOP)".

First, substitute "-" symbol for spaces in your plaintext and divide it into size 6 equal blocks. Then $l = 6$.

The-Department-of-Mathematics.-(UOP)

The-De	partme	nt-of-
Mathem	atics.	-(UOP)

Table 2. 6 equal blocks with size 6 for the plaintext "The Department of Mathematics (UOP)".

Construct a polyalphabetic table according to the first three steps in encryption algorithm considering the Skolem graceful labeling of $L_3(2,4)$. When $k = 7$, the table can be obtained as shown in table 1. Finally convert it into the ciphertext.

hosztf	c-khes	ahzbr.
e-hosh	-hnug	z,ibc(

Table 3. 6 equal blocks with size 6 for the ciphertext.

Therefore, the ciphertext is "hosztfc-khesahzbr.e-hosh-hnugz,ibc(".

4. CONCLUSION

Cryptography is used to transmit data in a secure manner. Encryption algorithms are used to transform any given message from readable format to unreadable format and decryption algorithm is used to recover them. In this study, we have introduced symmetric key encryption and decryption algorithm by using graph labelling concepts with generating a key for the ciphertext. Two different methods were used to construct a polyalphabetic table. First, using the Skolem graceful labeled graph, construct the polyalphabetic table by dividing the plaintext into equal number of blocks of the same size (l). When the table is constructed, identify the terms G, and term k that helps to generate key. Then, convert the plaintext into the cihpertext and send it to the receiver with the key (G, l, k). In future, we are trying to extend the present study for an encryption algorithm by using graph factorizations and different graph labeling methods to obtain the ciphertext.

REFERENCES

Lee, S.M., and Shee,S.C.(1991).On Skolem graceful graphs. Discrete Math. 93, 195-200.

Lee, S.M., and Wui,I.(1987).Skolem gracefulness of 2-stars and 3-stars.Bulletin of Malaysian Math. Society, 10, 15-20.

Ni, B., Qazi, R., Rehman, S. U., and Farid, G. (2021). Some Graph-Based Encryption Schemes.Hindawi Journal of Mathematics, 1-8.

Pasaribu, M., Yundari, and Ilyas, M. (2021). Graceful Labeling and Skolem Graceful Labeling on the U-star Graph and It's Application in Cryptography.Jambura Journal of Mathematics, Jambura J. Math. Vol. 3, pp.103-114.

Sakthivel, S., and Karpagam, T. R. (2017). Prime Labeling of Some New Standard Graphs. Paripex - Indian Journal of Research, Vol. 6, Issue 2, pp. 343-345.

Thennakoon,T. R. D. S. M., Weerarathna, M. D. M. C. P., and Perera,A. A. I., (2020).Prime Labeling of Newly Constructed Graph Using Star Graphs and Complete Bipartite Graphs.Sumerianz Journal of Scientific Research, Vol. 3, No. 2, pp. 10-17.

Urnika, D. A., and Purwanto, (2021). Skolem Graceful Labeling of Lobster Graph $L_n(2,r)$. The 4th International Conference on Mathematics and Science Education (ICoMSE) 2020, AIP conference Proceeding 2330, 070014.

Generalization of Incidence Chromatic Number for Snake Graphs

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ABSTRACT

One of the most important areas of research in graph theory is graph coloring. In this paper, we study the version of graph coloring which is incidence coloring. In 1993, the concept of the incidence chromatic number of a graph was introduced by Brualdi and Massey. In that study, they proved that the every graph G can be incidence colored with $\Delta(G) + 2$ colors, where $\Delta(G)$ denotes the maximum degree of a graph. The incidence chromatic number is a concept in graph theory that deals with coloring the edges of a graph such that no two incident edges have the same color. It is a variant of the chromatic coloring problem that focuses on coloring edges rather than vertices. Then find the minimum number of colors needed for such a coloring, which is known as the incidence chromatic number of the graph which is denoted by $\chi'(G)$ or $inc(G)$. An incidence in a graph G is a pair (v, e) with $v \in V(G)$ and $e \in E(G)$, such that v and e are incident. Two incidences (v, e) and (w, f) are adjacent if $v = w$, or $e = f$, or the

edge vw equals e or f. This paper deals with finite, undirected, simple and loop-less graph $G(V, E)$ called snake graph with vertex set $V(G)$ and edge $E(G)$. Snake graph ($T_{n,m}$) where $n(\geq 1)$ denotes the number of cycles in the graph and where $m(\geq 1)$ denotes the number of vertices in each cycle. In this paper, we determined the incidence chromatic number of the snake graphs and give the incidence chromatic number for any infinite families of snake graphs.

Keywords **- Incidence Chromatic Number, Incidence Colouring, Snake Graph**

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1. INTRODUCTION

The concept of incidence coloring was introduced by Brualdi and Massey in 1993(Brualdi & Quinn Massey, 1993). In that study they proved that every graph G can be incidence colored with $\Delta(G) + 2$ colors. In the paper, the all graphs we considered are finite, simple, undirected, and loop-less graphs. Let $G(V, E)$ be a graph G and $V(G), E(G)$ denote the vertex set and the edge set of the graph respectively. The maximum degree of graph G is denoted by $\Delta(G)$. The order of G and the size of G are represented $|v(G)|\ and\ |E(G)|$ respectively for all the graphs that we considered. An incidence in graph G is a pair (v, e) which is $v \in V(G)$ and $e \in E(G)$, such that v and e are incidence (Xikui & Yan, 2005)t. The set of all incidences in G denoted by $I(G)$. Two incidences (v, e) and (w, f) are adjacent if provided one of the conditions following holds:

$I(G) = \{(v, e) \mid v \in V, e \in E \mid v \text{ is incident with } e\}$

(i). $v = w$

(ii). $e = f$

(iii). The edge $vw = e$ or $= f$.

Pairs of adjacent incidences,

A black dot denotes a vertex and a asterisk (*) on an edge $e \in E(G)$ next to a vertex $v \in V(G)$ denotes the incidence (v, e).

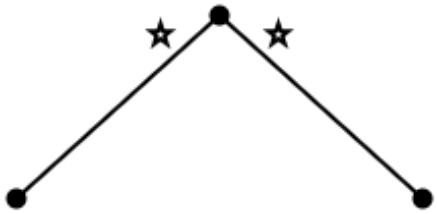

Figure.1.1 shows pairs of adjacent incidences that holds condition (i)

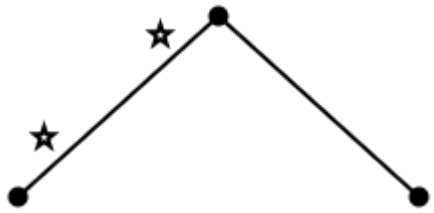

Figure.1.2 shows pairs of adjacent incidences that holds condition (ii)

Figure.1.3 shows pairs of adjacent incidences that holds condition (iii).

Pairs of non-adjacent incidences,

Figure.1.4 shows pairs of non-adjacent incidences

Formally, an incidence coloring is an assignment of colors to the edges such that no two incident edges have the same color such that adjacent incidences are assigned distinct colors. This is different from the traditional vertex coloring problem, an incidence coloring of G is a mapping $I(G)$ to a set S such that no two adjacent incidences of G have the same image. If $I(G) \rightarrow S$ is an incidence coloring of G then |S| = k, k is a positive integer, then say that G is k-incidence colorable(Dolama & Sopena, 2005). The goal is to find the minimum number of colors needed for such a coloring, which is known as the incidence chromatic number of the graph $\chi'(G)$. There are two main types of graphs in graph theory. They are directed graphs, where the edges have a direction and are called arcs and the other one is undirected graphs, where the edges do not have a direction and are simply called edges. This paper focus on undirected, simple, and connected snake graph $T_{n,m}$ (De Silva, 2023).

2. PRELIMINARIES

The concept of incidence chromatic number was developed by Brualdi and Massey in 1993(Brualdi & Quinn Massey, 1993) and In that they proved the incidence coloring conjecture, which states that for every graph G, $\chi'(G) = \Delta(G) + 2$. Also they established the following theorems:

Theorem 1.1

For each $n \geq 2$, $\chi'(K_n) = n$

They proved that by induction on n that there is an incidence coloring of K_n , where K_n be the vertices with the n colors having the property that $C_k = \{1, \ldots, k-1, k+1, \ldots, n\}$ and $(k = 1, \ldots, n)$. If $n = 2$ this is obvious and when $n \geq 3$ it take a coloring for K_{n-1}.

Theorem 1.2

Let T be a tree of order $n \geq 2$ with maximum degree $\Delta(G)$. Then χ'(T) = $\Delta(G) + 1$.

They proved that above theorem by induction on n and Let v be a pendant vertex with pendant edge e and let T' be the tree obtained from T by deleting v. By induction there is an incidence coloring of T' with at most $\Delta(G) + 1$ colors.

Theorem 1.3

For all $m \geq n \geq 2$, $\chi'(K_{m,n}) = m + 2$

Let the vertices of degree n be $W_1, W_2, \ldots W_m$ and vertices of degree m be $U_1, U_2, \ldots U_n$. Then suppose $K_{m,n}$ has an $m + 1$ incidence coloring using the colors $1, \ldots . m + 1$. Then each of the incidences $(W_i, \{W_i, U_1\})$ $(1 \leq i \leq m)$ is colored the same, as are the incidences $(W_i, \{W_i, U_2\})$. This easily gives a contradiction. Hence $\chi'(K_{m,n}) = m + 2$

Theorem 1.4

For each graph G we have $\chi'(G) \leq 2\,\Delta(G)$

Corollary 1.5

Let H be a bipartite graph with hipartition X, Y with no cycles of length 4. Let the maximum degree of a vertex of X be 2 and the maximum degree of a vertex of Y be $\Delta(G)$. Then the strong chromatic index of H satisfies $sq(H) < 2\Delta(G)$.

They proved that there conjecture about strong chromatic index of the bipartite graphs whose cycle lengths are divisible by 4.

Theorem 1.6

Let H be a bipartite graph with bipartition X, Y. Let the maximum degree of a vertex in X be α and that in Y be β. Assume that all cycle lengths are divisible by 4. Then

$$Sq(H) \leq \alpha\beta$$

Theorem 1.7

If H is the bipartite graph associated with a 2-totally unimodular $(0,1)-$matrix with maximum row sum α and maximum column sum β, then $Sq(H) \leq \alpha\beta$

Theorem 1.8

The incidence coloring number of a projective plane of order n is at most $n^2 + 2n$ and of an affine plane of order n is at most $n^2 + n$.

In t 1995, Barry Guiduli(Guiduli, 1997) proved that incidence coloring of a special case of directed star arboricity, that was introduced by I. AIgor and N. Alon in 1989. They considered the Paley graphs and proved that the conjecture false and raises the question as to how big $\chi'(G)$ can be in terms of $\Delta(G)$.

In below we mention the some of the important outcomes they got in there study.

Theorem 1.9

Let D be a directed graph. Let k be the larger of the maximum in-degree and the maximum out-degree $k = max(\Delta(G)_{in}(D), \Delta(G)_{out}(D)$ and let directed star forest $dst(D)$,(Andres, 2009)

$$dst(D) \leq k + 201og(k) + 84$$

Lemma 1.10

lf G is a directed graph (with possible multiple edges) such that every vertex has in-degree at most c, then $dst(D) \leq 3c$.

3. METHODOLOGY

In this section use graph G is a snake graph $T_{n,m}$ is an undirected, finite, simple and loop-less graph where n denotes number of cycles in graph for any $n \geq 1$ and $n = 1, 2, 3, ..$ and where m denotes number of vertices in the each cycle for any $m \geq 1$ and $m = 1,2,3, ..$ such that n and m are fixed for a particular given graph. n, m ϵ N (Natural number set).

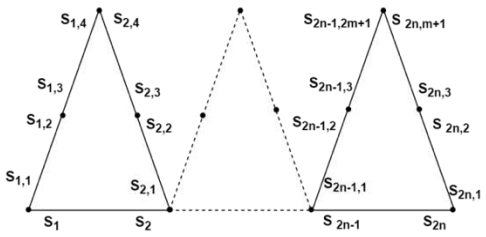

Figure 3.1 Incidence coloring of Snake Graph of $T_{n,m}$

Proof.

Labeling starting with path graph of the snake graph from initial cycle as S_1 to last cycle as S_{2n} in a snake graph. Then by using the labeling technique mentioned below we labeled the cycles of the snake graph. We label the 1st half of the cycles in clockwise order and the 2nd half of the cycles in anticlockwise order. We will label the 2nd half of the nth cycle of graph sequentially from $S_{2n,1}$ to $S_{2n,m+1}$ in anticlockwise order. Given a 2nd half of the nth cycle as S_{2n}, consider the labeling in anticlockwise order as $S_{2n,1}, S_{2n,2}, S_{2n,3}, \ldots, S_{2n,m+1}$. Let m be the number of vertices in the cycle and n be the number of cycles in graph.

Consider the labeling of the nth cycle, first half as $\{S_{2n-1,1}, S_{2n-1,2}, S_{2n-1,3}, \ldots, S_{2n-1,m+1}\}$ in clockwise order and consider the labeling of the nth cycle, second half as $\{S_{2n,1}, S_{2n,2}, S_{2n,3}, \ldots, S_{2n,m+1}\}$ in anticlockwise order respectively.

Then we assign the values for the each label in the snake graph by using following formulas which are satisfy the all conditions that holds incidence coloring. Notation $k, l \geq 1$ is positive integer.

Labeling the S_i values in snake graph,

$$S_i = \begin{cases} 1 \ ; S_{3k-2} \\ 2 \ ; S_{3k-1} \\ 3 \ ; S_{3k} \end{cases} \quad \leftarrow (1)$$

$$k = \{1,2,\ldots,n\}$$

Labeling the $S_{i,j}$ values in snake graph with value 1

$$S_{i,j} = \begin{cases} 1 \ ; S_{3k-2,4l} \\ 1 \ ; S_{6k-4,4l-2} \\ 1 \ ; S_{6k-3,4l-2} \end{cases} \quad \leftarrow (2)$$

$$k = \{1,2,\ldots,n\} \qquad l = \{1,2,\ldots,m\}$$

Labeling the $S_{i,j}$ values in snake graph with value 2.

$$S_{i,j} = \begin{cases} 2 ; \quad S_{3k-1,4l} \\ 2 \ ; S_{6k-5,4l-2} \\ 2 ; \quad S_{6k,4l-2} \end{cases} \quad \leftarrow (3)$$

$$k = \{1,2,\ldots,n\} \qquad l = \{1,2,\ldots,m\}$$

Labeling the $S_{i,j}$ values in snake graph with value 3.

$$S_{i,j} = \begin{cases} 3 ; \quad S_{3k,4l} \\ 3 \ ; S_{6k-2,4l-2} \\ 3 \ ; S_{6k-1,4l-2} \end{cases} \quad \leftarrow (4)$$

$$k = \{1,2,\ldots,n\} \qquad l = \{1,2,\ldots,m\}$$

Labeling the $S_{i,j}$ values in snake graph with value 4.

$$S_{i,j} = \begin{cases} 4 \ ; S_{2k-1,4l-1} \\ 4 ; \quad S_{2k,4l-3} \end{cases} \quad \leftarrow (5)$$

$$k = \{1,2,\ldots,n\} \qquad l = \{1,2,\ldots,m\}$$

Labeling the $S_{i,j}$ values in snake graph with value 5.

$$S_{i,j} = \begin{cases} 5\ ;\ S_{2k-1\ ,4l-3} \\ 5\ ;\quad S_{2k\ ,4l-1} \end{cases} \leftarrow (6)$$

$$k = \{1,2,..,n\} \qquad l = \{1,2,..,m\}$$

Depending on the number of cycles (n) and the number of vertices in each cycle (m) ,the snake graph can be varying. We prove that snake graph can be labeled 5-incidence colorable which means incidence chromatic number, $\chi'(T_{n,m}) = 5$ by using the above formulas for any number of cycles n and any number of vertices in each cycle m. So we prove that, any snake graph is $\chi'(T_{n,m}) = 5$.

4. RESULTS AND DISCUSSION

Example 1

Consider the snake graph, $T_{2,3}$

Here number of cycles (n) = 2 and number of vertices in the each cycle (m) = 3.

Then $n = 2$, $m = 3$, $k = \{1,2\}$, $l = \{1,2,3\}$

Using (1),

$$S_i = \begin{cases} 1\ ;\ S_{3k-2} \\ 2\ ;\ S_{3k-1} \\ 3\ ;\ S_{3k} \end{cases} \qquad k = \{1,2\}$$

Using (2),

$$S_{i,j} = \begin{cases} 1\ ;\ S_{3k-2\ ,4l} \\ 1\ ;\ S_{6k-4\ ,4l-2} \\ 1\ ;\ S_{6k-3\ ,4l-2} \end{cases}$$

$$k = \{1,2\} \qquad l = \{1,2,3\}$$

Using (3),

$$S_{i,j} = \begin{cases} 2\ ;\quad S_{3k-1\ ,4l} \\ 2\ ;\ S_{6k-5\ ,4l-2} \\ 2\ ;\quad S_{6k\ ,4l-2} \end{cases}$$

$$k = \{1,2\} \qquad l = \{1,2,3\}$$

Using (4),

$$S_{i,j} = \begin{cases} 3\ ;\quad S_{3k\ ,4l} \\ 3\ ;\ S_{6k-2\ ,4l-2} \\ 3\ ;\ S_{6k-1\ ,4l-2} \end{cases}$$

$$k = \{1,2\} \qquad l = \{1,2,3\}$$

Using (5),

$$S_{i,j} = \begin{cases} 4\ ;\ S_{2k-1\ ,4l-1} \\ 4\ ;\quad S_{2k\ ,4l-3} \end{cases}$$

$$k = \{1,2\} \qquad l = \{1,2,3\}$$

Using (6),

$$S_{i,j} = \begin{cases} 5\ ;\ S_{2k-1\ ,4l-3} \\ 5\ ;\quad S_{2k\ ,4l-1} \end{cases}$$

$$k = \{1,2\} \qquad l = \{1,2,3\}$$

Results received from (1),(2),(3),(4),(5),(6) when $n = 2$, $m = 3$,

Table 4.1 Labeling list of Snake Graph $T_{2,3}$

		(K,l)					
Formula	Condition	(1,1)	(1,2)	(1,3)	(2,1)	(2,2)	(2,3)
1	(i)	S1			S4		
	(ii)	S2			S5		
	(iii)	S3			S6		
2	(i)	S1,4	S1,8	S1,12	S4,4	S4,8	S4,12
	(ii)	S2,2	S2,6	S1,10	S8,2	S8,6	S8,10
	(iii)	S3,2	S3,6	S3,10	S9,2	S9,6	S9,10
3	(i)	S2,4	S2,8	S2,12	S5,4	S5,8	S5,12
	(ii)	S1,2	S1,6	S1,10	S7,2	S7,6	S7,10
	(iii)	S6,2	S6,6	S6,10	S12,2	S12,6	S12,10
4	(i)	S3,4	S3,8	S312	S6,4	S6,8	S612
	(ii)	S4,2	S4,6	S4,10	S10,2	S10,6	S10,10
	(iii)	S5,2	S5,6	S5,10	S11,2	S11,6	S11,10
5	(i)	S1,3	S1,7	S1,11	S3,3	S3,7	S3,11
	(ii)	S2,1	S2,5	S2,9	S4,1	S4,5	S4,9
6	(i)	S1,1	S1,5	S1,9	S3,1	S3,5	S3,9
	(ii)	S2,3	S2,7	S2,11	S4,3	S4,7	S4,11

Table 4.2 Colors corresponds to each values

Label	Colour
1	
2	
3	
4	
5	

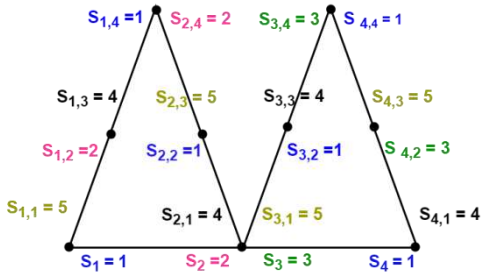

Figure 4.1 Incidence coloring of Snake Graph of $T_{2,3}$

The incidence chromatic number of snake graph $T_{2,3}$ is 5, which is $\chi'(T_{2,3}) = 5$.

Example 2

Consider the snake graph, $T_{3,1}$

Here number of cycles (n) = 3 and number of vertices in the each cycle (m) = 1.

Then $n = 3$, $m = 1$

$k = \{1,2,3\}$, $l = \{1\}$

Using (1),

$$S_i = \begin{cases} 1 \ ; S_{3k-2} \\ 2 \ ; S_{3k-1} \\ 3 \ ; S_{3k} \end{cases}$$

		(K,l)		
Formula	Condition	(1,1)	(2,1)	(3,1)
1	(i)	S1	S2	S3
	(ii)	S4	S5	S6
	(iii)	S7	S8	S9
2	(i)	S1,4	S4,4	S7,4
	(ii)	S2,2	S8,2	S14,2
	(iii)	S3,2	S9,2	S15,2
3	(i)	S2,4	S5,4	S8,4
	(ii)	S1,2	S7,2	S13,2
	(iii)	S6,2	S12,2	S18,2
4	(i)	S3,4	S6,4	S9,4
	(ii)	S4,2	S10,2	S16,2
	(iii)	S5,2	S11,2	S17,2
5	(i)	S1,3	S3,3	S5,3
	(ii)	S2,1	S4,1	S6,1
6	(i)	S1,1	S3,1	S5,1
	(ii)	S2,3	S4,3	S6,3

$k = \{1,2,3\}$

Using (2),

$$S_{i,j} = \begin{cases} 1 \ ; S_{3k-2,4l} \\ 1 \ ; S_{6k-4,4l-2} \\ 1 \ ; S_{6k-3,4l-2} \end{cases}$$

$k = \{1,2,3\}$ $l = \{1\}$

Using (3),

$$S_{i,j} = \begin{cases} 2\,; & S_{3k-1,4l} \\ 2\,; & S_{6k-5,4l-2} \\ 2\,; & S_{6k,4l-2} \end{cases}$$

$k = \{1,2,3\} \quad l = \{1\}$

Using (4),

$$S_{i,j} = \begin{cases} 3\,; & S_{3k,4l} \\ 3\,; & S_{6k-2,4l-2} \\ 3\,; & S_{6k-1,4l-2} \end{cases}$$

$k = \{1,2,3\} \quad l = \{1\}$

Using (5),

$$S_{i,j} = \begin{cases} 4\,; & S_{2k-1,4l-1} \\ 4\,; & S_{2k,4l-3} \end{cases}$$

$k = \{1,2,3\} \quad l = \{1\}$

Using (6),

$$S_{i,j} = \begin{cases} 5\,; & S_{2k-1,4l-3} \\ 5\,; & S_{2k,4l-1} \end{cases}$$

$k = \{1,2,3\} \quad l = \{1\}$

Results received from (1),(2),(3),(4),(5),(6) when $n = 3$, $m = 1$

Table 4.3 Labeling list of Snake Graph $T_{3,1}$

Label	Colour
1	
2	
3	
4	
5	

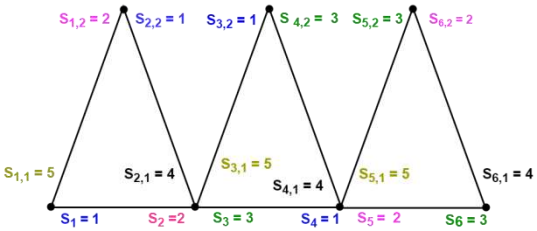

Figure 4.2 Incidence coloring of Snake Graph of $T_{3,1}$.

The incidence chromatic number of snake graph $T_{3,1}$ is 5, which is $\chi'(T_{3,1}) = 5$.

5. CONCLUSION

Incidence coloring is a graph coloring concept that involves assigning colors to the edges of a graph such that no two incident edges have the same color. The snake graph can vary depending on the number of cycles (n) and the number of vertices in each cycle (m). In this paper, we prove that a snake graph can be colorable by using five color labels (1, 2, 3, 4, 5) for any number of cycles $n(\geq 1)$ and any number of vertices in each cycle $m(\geq 1)$. Then calculate the incidence chromatic number of the snake graphs and give the incidence chromatic number $\chi'(T_{n,m}) = 5$.

6. REFERENCES

Andres, S. D. (2009). The incidence game chromatic number. *Discrete Applied Mathematics*, *157*(9), 1980–1987. https://doi.org/10.1016/j.dam.2007.10.021

Brualdi, R. A., & Quinn Massey, J. J. (1993). Incidence and strong edge colorings of graphs. *Discrete Mathematics*, *122*(1–3), 51–58. https://doi.org/10.1016/0012-365X(93)90286-3

De Silva, K. (2023). Odd Prime Labeling of Snake Graphs. *SLIIT International Conference On Engineering and Technology*, *2*, 36. https://doi.org/10.54389/LUFM4069

Dolama, M. H., & Sopena, E. (2005). On the maximum average degree and the incidence chromatic number of a graph. *Discrete Mathematics & Theoretical Computer Science*, *Vol. 7*, 349. https://doi.org/10.46298/dmtcs.349

Guiduli, B. (1997). On incidence coloring and star arboricity of graphs. *Discrete Mathematics*, *163*(1–3), 275–278. https://doi.org/10.1016/0012-365X(95)00342-T

Xikui, L., & Yan, L. (2005). The incidence chromatic number of some graph. *International Journal of Mathematics and Mathematical Sciences*, *2005*(5), 803–813. https://doi.org/10.1155/IJMMS.2005.803

Exploring rt Graceful Labeling for Path Graphs and Union of Two Ladder Graphs with One Vertex Common.

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ABSTRACT

Graceful labeling is a concept in graph theory and combinatorics. Let G be a graph with a vertex set [V(G)] and edges set [E(G)]. In a r^t graceful labeling each vertex and edge are assigned a unique label from the set {0, 1, 2, …, $p+r^t-1$} and {r^t, r^t+1, r^t+2, …, $p+r^t-1$} respectively, where p is defined as the number of edges in a graph and both r and t be any positive integer. Let i, j be in V(G) and defined an injective function (f) such that the resulting edges get distinct values when each edge is assigned the absolute difference | f(i) - f(j) |. A path graph is r^t graceful. The objective of this paper is to present every path graph is r^t graceful. Adding rungs one by one to a path graph still admits r^t graceful labeling and at the end a ladder graph appears. A ladder graph is a type of graph theory representation which consists of two parallel paths with rungs connecting them which can be denoted as Ln where n represents the number of rungs. Further rt graceful labelling for union of two ladder graphs with one vertex common was discussed.

Keywords - Gracefullabeling, Laddergraphs,Pathgraphs

1. INTRODUCTION

In the area of graph labeling graceful labeling is an interesting method which was introduced by Alexandar Rosa in 1967 [Smith and Johnson 1967]. The problem involves assigning distinct integers to the vertices of a graph in such a way that the resulting edge labels (absolute differences between vertex labels) are all distinct. The labelled graph resembles a graceful arrangement of integers [Miller and Joe 2011, Joseph and Daphne 2017, Joseph 2019]. The study of graceful labeling continues to be an active research area in graph theory with mathematicians and computer scientists exploring different aspects and properties of graceful graphs.

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Over the years, mathematicians have extended the study of graceful labeling to various other graph classes like trees, grids, and more complex structures. [Chartrand, Egan & Zhang 2019] In this paper we are working on labelling for a path graph and discuss about adding rungs to a path graph. This process finally approaches a ladder graph which can also be labelled as r^t graceful [Velmurugan and Ramachandran 2020]. We are giving general formulas for vertices labelling insch a way that the graph remains graceful. In that case we are introducing a general integer representation (r^t) where we can substitute any positive integer and can get gracefully labelled graphs. We are going to get different labelling and each labelling is graceful. The fundamental definitions of r^t graceful labelling, Ladder graphs and Path graphs are introduced.

Definition 1: (r^t - Graceful Labeling) Let $G = G(V, E)$ be a graph with $p = |E(G)|$, where $V(G)$ and $E(G)$ denote the set of vertices and edges,respectively. A graceful labeling of G isa vertex labelling f: $V \rightarrow [0, p + r^t - 1]$ such that f is injective and the edge labelling $f\gamma$: $E \rightarrow [r^t, p+ r^t - 1]$ defined by $f\gamma:(uv) = |f(u) - f(v)|$ is also injective. Such a graph is called a r^t graceful graph. When $r = t = 1$, it is called ordinary graceful labeling.

Definition 2: (Ladder Graph)

For an integer $n \geq 1$, a ladder Ln is defined by $L_n = P_n \times K_n$, where P_n is a path with n vertices and × denotes the Cartesian product. Clearly, L_n has $2n$ vertices and $3n - 2$ edges.

Definition 3: (Path graph)

A path graph (or linear graph) is a graph which can be listed in the order v_1 v_2 …, v_n such that the edges are $\{v_i, v_{i+1}\}$ where $i = 1, 2, \ldots, n - 1$. Equivalently, a path with at least two vertices is connected and has two terminal vertices (vertices that have degree 1), while all others (if any) have degree 2.

2. METHODOLOGY

Theorem 1:

Every Path graph is r^t graceful.

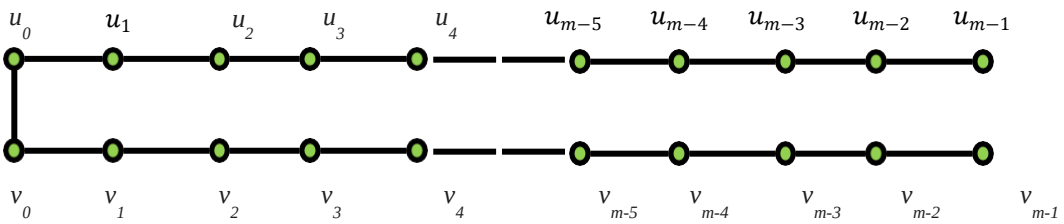

Figure 1: Path graph with $2m$ vertices & $2m - 1$ edges $R_{2(m-1, m)}$

Proof:

Here we consider 2 cases. For both cases, vertex labeling is taken as f and as the above figure the vertices from the 1st and 2nd lines are labelled from u_0 to u_{m-1} and v_0 to v_{m-1} respectively.

Case 1: When m is odd.

$$f(U_i) = \begin{cases} \frac{i}{2} & ; i = 0,2,4,\dots,m-1 \\ r^t + 2m - \left(\frac{i+3}{2}\right) & ; i = 1,3,5,\dots,m-2 \end{cases}$$

$$f(V_i) = \begin{cases} r^t + m - 1 + \frac{i}{2} & ; i = 0,2,4,\dots,m-1 \\ m - \left(\frac{i+1}{2}\right) & ; i = 1,3,5,\dots,m-2 \end{cases}$$

Case 2: When m is even.

$$f(U_i) = \begin{cases} \frac{i}{2} & ; i = 0,2,4,\dots,m-2 \\ r^t + 2m - \left(\frac{i+3}{2}\right) & ; i = 1,3,5,\dots,m-1 \end{cases}$$

$$f(V_i) = \begin{cases} r^t + m - 1 + \frac{i}{2} & ; i = 0,2,4,\dots,m-2 \\ m - \left(\frac{i+1}{2}\right) & ; i = 1,3,5,\dots,m-1 \end{cases}$$

Each graph which we can obtain by adding rungs to a path graph still admits the r^t graceful labeling. This finally approaches a ladder graph.

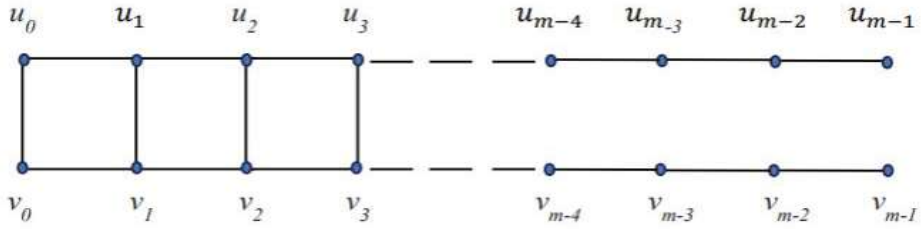

Figure 2: roach graph $R_{2(4,5)}$

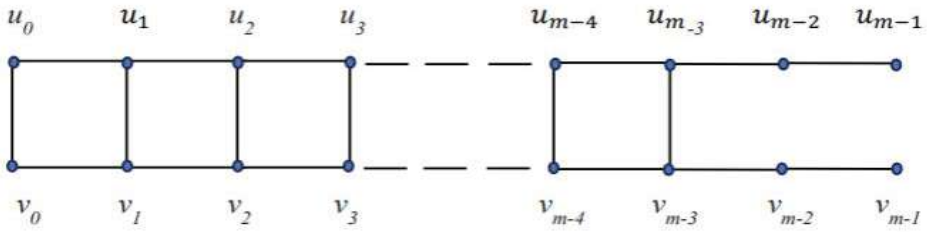

Figure 3: roach graph $R_{2(2,3)}$

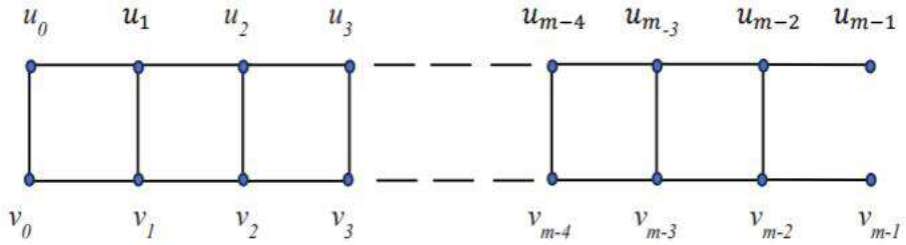

Figure 4: roach graph $R_{2(1,2)}$

Theorem 2:

Every Ladder graph is r^t graceful.

Known. [W.K.M. Indunil (2023)]

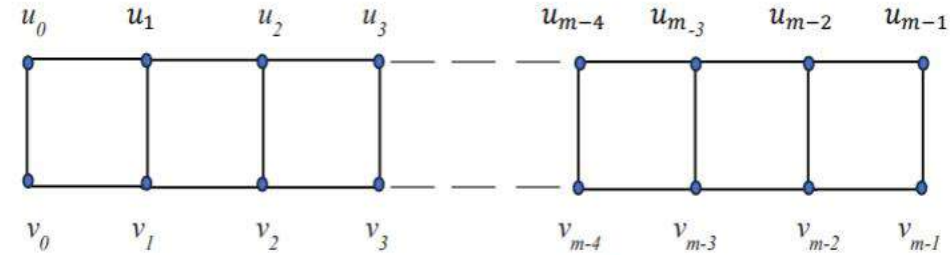

Figure 5: Ladder graph of $P_m \times P_2$

Theorem 3:

Union of two ladder graphs with one vertex common is r^t graceful.

When m is odd

$$f(u_i) = \begin{cases} \frac{3i}{2}; i = 0,2,4,\dots,m-1 \\ r^t + 6m - \frac{3i+9}{2}; i = 1,3,5,\dots,m-2 \end{cases}$$

$$f(v_i) = \begin{cases} r^t + 6m - \frac{3i+10}{2}; i = 0,2,4,\dots,m-1 \\ 2 + \frac{3}{2}(i-1); i = 1,3,5,\dots,m-2 \end{cases}$$

$$f(w_i) = \begin{cases} \frac{3(m+i)-1}{2}; i = 0,2,4,\dots,m-1 \\ r^t + \frac{3}{2}(3m-i) - 4; i = 1,3,5,\dots,m-2 \end{cases}$$

When m is even

$$f(u_i) = \begin{cases} \frac{3i}{2}; i = 0,2,4,\dots,m-2 \\ r^t + 6m - \frac{3i+9}{2}; i = 1,3,5,\dots,m-1 \end{cases}$$

$$f(v_i) = \begin{cases} r^t + 6m - \frac{3i+10}{2}; i = 0,2,4,\dots,m-2 \\ 2 + \frac{3}{2}(i-1); i = 1,3,5,\dots,m-1 \end{cases}$$

$$f(W_i) = \begin{cases} r^t + \frac{3}{2}(3m-i) - 4; i = 0,2,4,\dots,m-2 \\ \frac{3(m+i)-1}{2}; i = 1,3,5,\dots,m-1 \end{cases}$$

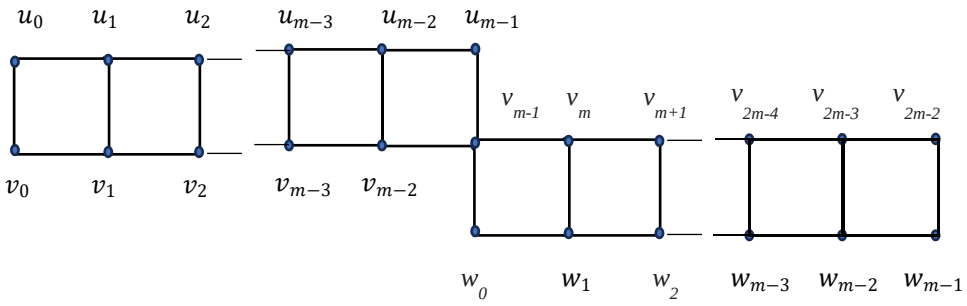

Figure 6: Union of two ladder graphs

By substituting the r, t, m values wherem is the half of the value of number of vertices in a path graph and $r, t \in Z^+$, we can get a path graph which is labelled r^t gracefully. Next, we are heading to adding rungs and discussing some examples for Ladder graphs by using theproof.

3. RESULTS AND DISCUSSION

We'll discuss a couple of examples by illustrating the above two theorems.

Theorem 1:

When $t = 2, m = 3$, and $r = 3$

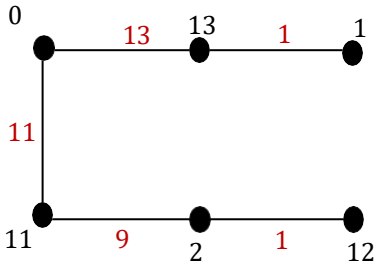

Figure 7

When $t = 1, m = 3$ and $r = 2$

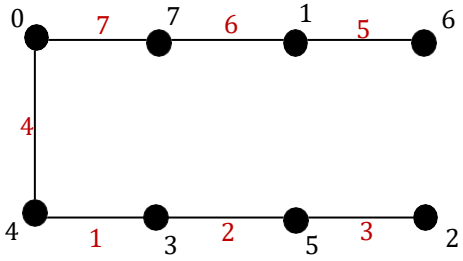

Figure 8

Theorem 3:

When $t = 3, m = 4$ and $r = 2$

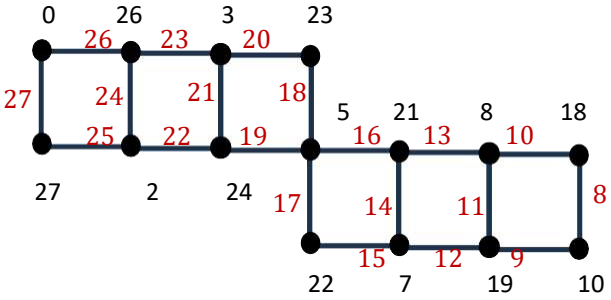

Figure 9

When $t = 2, m = 7$ and $r = 4$

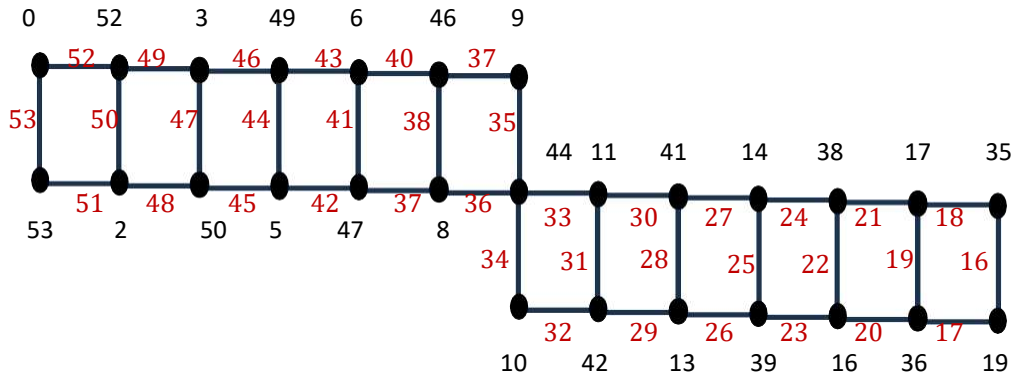

Figure 10

4. CONCLUSION

In conclusion, this research focused on the concept of r^t graceful labeling ingraph theory. The proved that every path graph can be labelled in a r^t graceful manner in Theorem 1, where each vertex and edge is assigned a unique label. We demonstrated that this labeling property extends as rungs are added to a path graph, resulting in the formation of a ladder graph. That is every ladder graph is also r^t graceful. Further we proved that the union of two ladder graphs with one vertex common is also r^t graceful. This research contributes to a deeper understanding of labeling techniques and their implications in graph theory and combinatorics.

5. REFERENCES

Chartrand, G., Egan, C., & Zhang, P. (2019). Graceful Labelings. In How to Label a Graph, SpringerBriefs in Mathematics (pp. 13-38).

Gallian, J. A., & Liu, D. (2017). Graceful, Harmonious and Magic Type Labelings.

Gallian, J. A. (2019). Graceful Labelings. In Graph Labelings, Springer, pp. 9-28.

Indunil, W. K. M. (2023). k-Graceful labeling for the ladder graph and theroach grap

Miller, M., & Ryan, J. (2011). Graceful Labelling: State of the Art, Applications and Future Directions. In Mathematics in Computer Science, 5(2), 101-123.

Smith, J. A., & Johnson, B. C. (1967). "On the Introduction of Graceful Labeling in Graph Theory." Journal of Mathematical Structures, 15(3), 45-62.

Velmurugan, C., & Ramachandran, V. (2020). "Algorithm for M modulo N Graceful Labeling of Ladder and Subdivision of LadderGraps

On the Choice of the Inverse Linear Mapping in the Method of Directly Defining the Inverse Mapping for Nonlinear Partial Differential Equations

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ABSTRACT

Analytical technique for solving nonlinear partial differential equations (PDEs) is a difficult and time-consuming method used in mathematics, physics, and engineering. However, because nonlinear PDEs are so complicated, numerical approaches or approximation procedures may be required. A new technique to obtaining approximate solutions for nonlinear PDEs is the Method of Directly Defining the inverse Mapping (MDDiM). MDDiM was utilized in this work to find approximation solutions for inhomogeneous advection problem, and the Cahn-Hilliard initial value problem (IVP). Although the Cahn-Hilliard equation, and advection problem, have numerical or exact solutions in the literature, the current results are entirely semi-analytical. Different initial conditions are used to properly illustrate the range of possible solutions. We analyzed variety of inverse linear mappings to discover the optimal mapping which allows accuracy after a few numbers of terms have been calculated to provideaccurate approximate solutions using Maple 16.

Keywords **- Cahn-Hilliard initial value problem, convergence control parameter, Inhomogeneous advection problem, Inverse linear mapping, Method of directly defining the inverse mapping**

1. INTRODUCTION

The advection nonlinear PDEs encompasses a specialized area within the broader field of applied mathematics, particularly in fluid dynamics and transport phenomena. The nonlinear advection equation describes the transport of a quantity by a velocity field, where the advection term introduces nonlinearity. This equation is relevant in fluid dynamics and meteorology. Notable literature includes Majda (2002), introduction to PDEs and waves for the atmosphere and ocean. This book introduces PDEs in geophysical fluid dynamics, including

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nonlinear advection equations.

Constantin and Foias (1988), Navier–Stokes Equations. While this book primarily focuses on the Navier-Stokes equations, it also covers nonlinear advection equations and their properties. Exact solution for the considered advection problem available in the book of Partial Differential Equations and Solitary Waves Theory, by Wazwaz (2009). Jaddoa (2020) solved this using Homotopy Perturbation Method.

The Cahn-Hilliard equation is a partial differential equation that describes phase separation in materials. It is often used in the study of materials science, physics, and chemistry to model the evolution of concentration fields in binary mixtures undergoing phase separation. The equation was first introduced by John W. Cahn and John E. Hilliard in 1958 (Cahn and Hilliard, 1958), and there are numerical findings in the literature for this equation. For instance, the equivalent boundary value issue is studied in (Elliott and French, 1987) using the Galerkin finite element method. The asymptotes for the three-dimensional asymptotes have been taken into consideration in (Toral et. Al, 1988). Copetti et al. studies the existence and distinctiveness of numerical solutions derived using the finite element method (Copetti et al., 1992). In (De Melloa et al., 2005), a splitting potential with explicit and implicit time parts and free boundary conditions is used in a conservative finite difference approach.

In this current study, MDDiM was used to obtain approximate solutions to the inhomogeneous advection problem, and the Cahn-Hilliard IVP.

The Method of Directly Defining the inverse Mapping (MDDiM) is a recent approach to getting approximate solutions for complicated linear or nonlinear PDEs without using any kind of transformations. MDDiM was first discovered by Liao in 2016 (Liao, 2016). Dewasurendrea et al. further extended it to solve a system of coupled ordinary differential equations (Dewasurendra et al., 2018), (Baxter et al., 2018). As time went by MDDiM was studied in several perspectives (Karunarathna et al., 2023) and Sahabandu et al. extended it to solve nonlinear PDEs (Sahabandu et al., 2021; 2022).

Calculating the inverse operator L^{-1} of a differential equation $L\,\varphi = f$ in scientific computing is time-consuming, especially when L is a highly nonlinear operator. Without having to calculate any inverse operators, a nonlinear differential equation $L\,\varphi = f$ can be solved by just specifying an inverse mapping, or ℓ. Since "mapping" is a broader term than "differential operator" in this context, it is not even essential to describe the inverse mapping ℓ directly in differential form. Some rules are given to instruct how to directly define an inverse mapping ℓ (Liao, 2016).

ℓ denotes a directly defined mapping from $U \rightarrow V$, with the following rules:

I. ℓ is linear,
   i.e $\forall \alpha, \beta \in \mathbb{R}, \forall x, y \in U,$ $\ell(\alpha x + \beta y) = \alpha \ell(x) + \beta \ell(y)$;
II. ℓ is injective, say, the kernel of ℓ is $\{0\}$,
   i.e $\{x | x \in U, \ell(x) = 0\} = \{0\}$;

III. $\ell[\delta m(x)]$ contains each base function $\varphi_i \in \hat{S}\ (\mu + 1 \leq i < +\infty)$ as $m \to +\infty$;

IV. ℓ is finite,
i.e. there exists such a finite constant K that for any $\varphi \in V$ it holds $\frac{||\ell[N[\varphi]]||}{||\varphi||} \leq K$.

Here, $V, \hat{S}, U$ are defined by respectively,
$V = \{\sum_{k=1}^{+\infty} a_k \varphi_k(x) |\ a_k \in \mathbb{R}\}$,
$\hat{S} = \{\varphi_{\mu+1}(x), \varphi_{\mu+2}(x), \dots\}$,
$U = \{\sum_{m=1}^{+\infty} c_m \varphi_m(x) |\ c_m \in \mathbb{R}\}$.

We explore several inverse linear mappings to determine the optimal inverse linear mapping that allows accuracy after just a few terms are evaluated. Additionally, we optimize the convergence control parameter by constructing an optimum control problem for minimizing the accumulated L^2-norm of the squared residual errors using directed sum. This is because directed sum computations are way simpler than those for square integrals.

2. METHODOLOGY

Consider the n^{th}-order nonlinear differential equation $N[u(x)] = 0$ and the equation of MDDiM given by,

$$u_k = \chi_k\, u_{k-1} + h\, \ell[\delta_{k-1}(x)] + \sum_{n=1}^{\mu} a_{k,n}\varphi_{\mathrm{n}}, \quad \text{for } k \geq 1 \qquad (1)$$

defined as $\chi_k = \begin{cases} 0, & k \leq 1, \\ 1, & k > 1, \end{cases}$

$$\delta_n(x) = \mathcal{D}_n\left\{N\left[u_0(x) + \sum_{j=1}^{+\infty} u_j(x) q^j\right]\right\}$$

$\mathcal{D}_n$ is the so-called n[th] order homotopy derivative defined by,

$\mathcal{D}_n\phi = \frac{1}{\mathrm{n}!}\frac{\partial^n \phi}{\partial q^n}\Big|_{q=0}$ (Liao, 2016).

Here, $\ell$is the directly defined inverse liner mapping, N is the nonlinear differential operator, $a_{k,n}$ is real constant, φ_{n} is the base function, and h is the convergence control parameter, which should be determined.

2.1 Advection Problem

The governing equation inhomogeneous heat and advection problem with the initial condition given in equation (2).

$$u_t + uu_x = x; \qquad u(x,0) = 2 \qquad (2)$$

By applying MDDiM to equation (2) we obtained the equation

$$u_k(x,t) = \chi_k\, u_{k-1}(x,t) + h\, \ell[\delta_{k-1}] + a_{k,0}, \qquad (3)$$ see (Sahabandu, 2021).

By considering $N[u] = u_t + uu_x - x$ with the initial condition, we obtained initial guess as $u_0 = 2$.

In the frame of MDDiM we have great freedom to choose an inverse linear mapping. For this problem, we chose following inverse mappings,

1. $\ell[t^k] = \frac{t^{k+1}}{Ak+1}$, (4)
2. $\ell[t^k] = \frac{t^{k+1}}{Bk^2+Ck+1}$, (5)

here, A, B and C are constants.

2.3 Cahn-Hilliard IVP

The Cahn-Hilliard equation given by,

$$u_t = \Delta(u^3 - u - \Delta u), \qquad (6)$$

held subject to the initial condition, $u(\tilde{x}, 0) = f(\tilde{x})$ is a nonlinear evolution equation that describes the free energy of a binary alloy (Cahn and Hilliard, 1958). Cahn and Hilliard have been succeeded with re-deriving the Van der Waals

argument that a compressible fluid has its free energy at constant temperature dependent density gradient, while obtaining results on the interfacial energy between phases (Carr et al., 1984). As studied in (Elliott and Songmu, 1986) corresponding boundary value problem, where in $0 < x < L,\ t > 0,$ and $n = 1,$ subject to $u_{xxx}(x,0) = u_{xxx}(L,0) = 0$ has its global existence or finite time.

If we consider the case when $n = 1$, then (6) becomes,

$$u_t = 6uu_x^2 + 3u^2u_{xx} - u_{xx} - u_{xxxx}, \quad (7)$$

subject to $u(x,0) = f(x)$. Baxter et al. studies this equation using optimal homotopy analysis method (OHAM) and explained how to choose auxiliary linear operator (Baxter et al., 2013).

To get approximate semi-analytical solutions using MDDiM we considered the nonlinear Cahn-Hilliard PDE and related IVPs described in equation (7).

By applying MDDiM to equation (7) we obtained the equation,

$$u_k(x,t) = \chi_k\, u_{k-1}(x,t) + h\,\ell[\delta_{k-1}] + a_{k,0}, \quad (8)$$

see (Sahabandu, 2021).

We considered three cases when $f(x)$ is equal to $\operatorname{sech} x$, 1 and e^{-x^2}. By considering $N[u] = u_t - 6uu_x^2 - 3u^2u_{xx} + u_{xx} + u_{xxxx}$ with the initial condition, we obtained initial guesses as $u_0 = f(x)e^{-t}$, and chose following inverse mappings for each case,

1. $\ell[t^k] = \frac{t^{k+1}}{Dk+1}, \quad (9)$

$\ell[e^{-t}] = \frac{e^{-kt}}{Ek+1}, \quad (10)$

here D and E are arbitrary constants to be determined, and the following results obtained using Maple 16.

2.3 Error calculation

In MDDiM, we are considering only the nth term approximation, so this leads to an error. To calculate that error $E(h)$, we can use either squared residual error function or the weighted sum. But sometimes integral over an infinite domain is difficult, in that case we can use weighted sum given in (Sahabandu et Al., 2021; 2022),

$$E(h) = \frac{1}{(M+1)\cdot(N+1)} \sum_{i=1}^{M} \sum_{j=1}^{N} \left[N\left(u(x,t;h)\right)\right]^2. \quad (11)$$

3. RESULTS AND DISCUSSIONS

Exact solution for advection problem is,

$$u(x,t) = 2\operatorname{sech} t + x\tanh t \quad (12)$$

(Wazwaz, 2009).

Solving equation (2), we obtained three-term approximate MDDiM solutions for $u(x,t)$. In figure 1, curve 1, 2, 3 represents exact solutions given in (12) (Wazwaz, 2009), (Jaddoa, 2020), MDDiM solution for the inverse linear mapping in (4) when $A = 100$, and MDDiM solution for the inverse linear mapping in (5) when $B = -100, C = -100$) respectively.

In figure 2, you can see relevant values of h when minimum squared residual error occurs. The lower error as well as more accurate solution to the exact solution gives the inverse linear mapping given in (4) (see figure 1 and table 1).

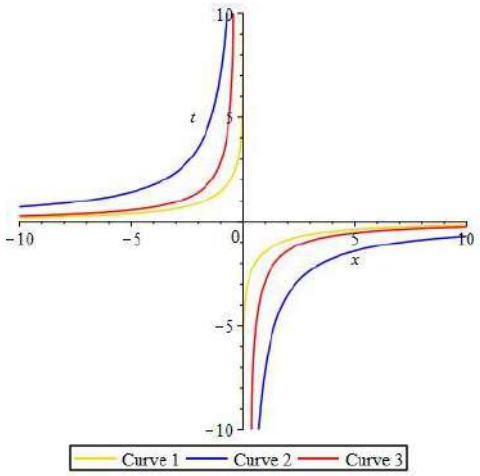

Figure 1: Exact solution (Curve 1) and three-term approximate MDDiM solutions of $u(x,t)$; curve 2 (using (5) for $B = -100, C = -100$), and curve 3 (using (4) for $A = 100$).

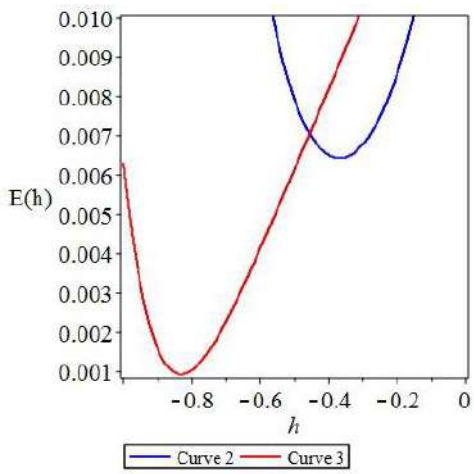

Figure 2: Corresponding error graphs for curves 2 and 3 in figure 1 respectively.

Results of the Cahn-Hilliard IVP with various forms of initial data discussed under three cases. Following results obtained when $D = E = 1$.

Case I: For $f(x) = \operatorname{sech} x$.

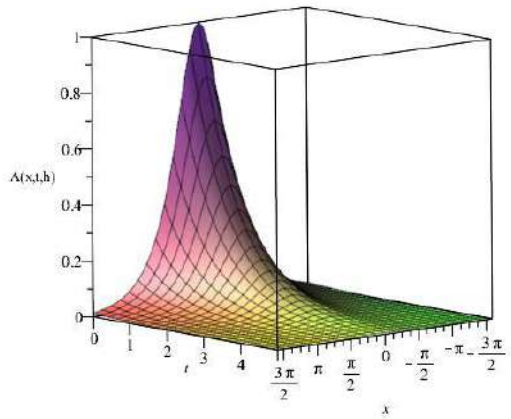

Figure 3: MDDiM solution for inverse linear mapping (9) when $\boldsymbol{f(x) = \operatorname{sech} x}$.

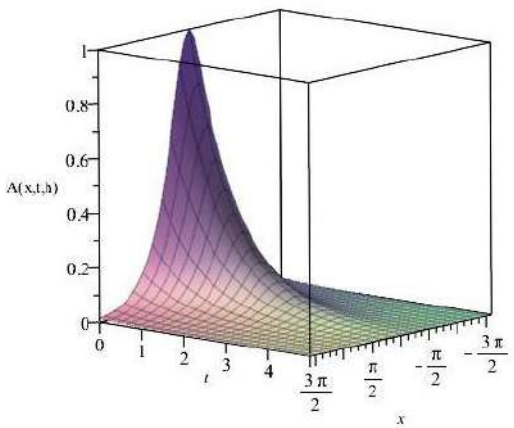

Figure 4: MDDiM solution for inverse linear mapping (10) when $\boldsymbol{f(x) = \operatorname{sech} x}$.

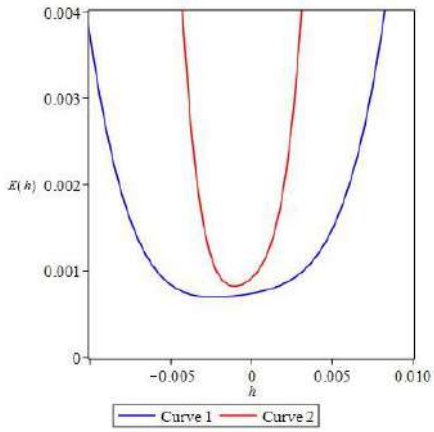

Figure 5: Corresponding error graphs when $\boldsymbol{f(x) = \operatorname{sech} x}$; curve 1 and 2 for figures 3 and 4 respectively.

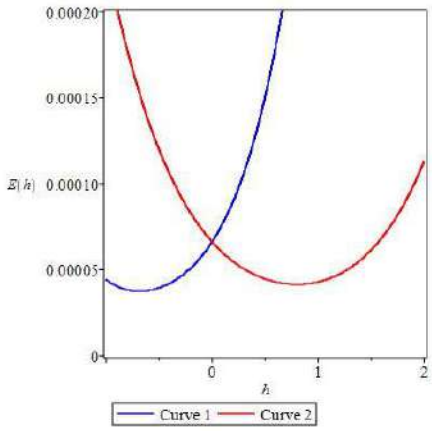

Figure 8: Corresponding error graphs when $\boldsymbol{f(x) = 1}$; curve 1 and 2 for figures 6 and 7 respectively.

Case II: For $\boldsymbol{f(x) = 1}$.

Case III: For $f(x) = e^{-x^2}$.

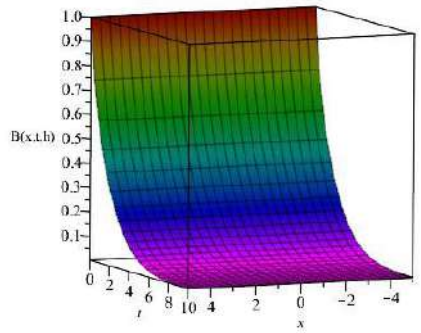

Figure 6: MDDiM solution for inverse linear mapping (9) when $\boldsymbol{f(x) = 1}$.

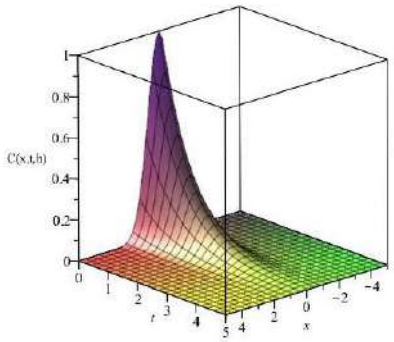

Figure 9: MDDiM solution for inverse linear mapping (9) when $\boldsymbol{f(x) = e^{-x^2}}$.

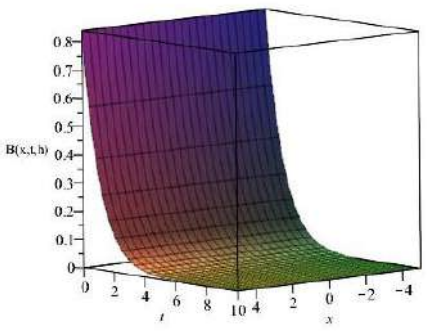

Figure 7: MDDiM solution for inverse linear mapping (10) when $\boldsymbol{f(x) = 1}$.

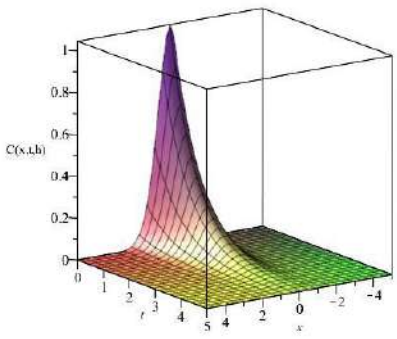

Figure 10: MDDiM solution for inverse linear mapping (10) when $\boldsymbol{f(x) = e^{-x^2}}$.

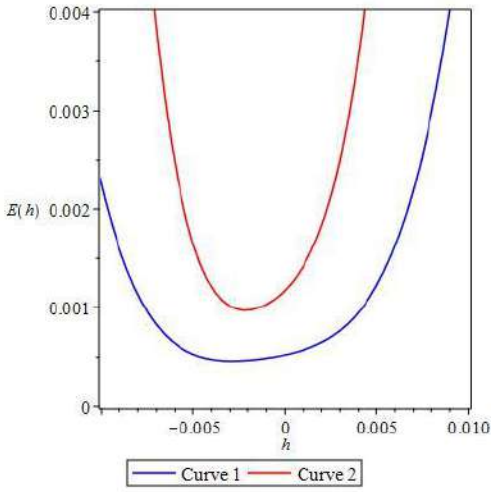

Figure 11: Corresponding error graphs when $f(x) = e^{-x^2}$; curve 1 and 2 for figures 9 and 10 respectively.

inhomogeneous advection problem and Cahn-Hilliard IVP with different initial values, which are nonlinear partial differential equations. MDDiM solutions were compared with the exact solutions available in (Wazwaz, 2009) and (Jaddoa, 2020). In the literature, you can find the relevant OHAM solutions (Baxter et al., 2013) and numerical solutions for the Chan-Hilliard IVP. All the solutions are accurate enough with the squared residual errors given in table 1. We applied different inverse linear mappings without computing the

Table 1: Squared residual errors and values of convergence control parameter.

Problem		Using mapping (4)		Using mapping (5)	
		$E(h)$	h	$E(h)$	h
1. Advection		$9.388\ 10^{-4}$	-0.832	$6.433\ 10^{-3}$	-0.369
	Case	Using mapping (9)		Using mapping (10)	
2. Chan-Hillard	I	$6.977\ 10^{-4}$	-0.002	$9.095\ 10^{-4}$	-0.00003
	II	$3.744\ 10^{-5}$	-0.687	$4.155\ 10^{-5}$	-0.799
	III	$4.603\ 10^{-4}$	-0.003	$9.733\ 10^{-4}$	-0.002

Three-term MDDiM approximate solutions calculated for each case using inverse linear mappings given in (9) and (10) when the minimum error occurs (see figures 3-11 and table 1). For each case whatever the initial data, the lower error gives the inverse linear mapping given in (9). This is the same as the advection problem.

4. CONCLUSION(S)

We computed three-term optimal approximate solutions for the auxiliary operator or inverse operator at all to obtain the above results and chose the better inverse linear mapping out of them. Also, we can see the squared residual error of the better mapping is lower than the other one. We can conclude that choosing an appropriate inverse linear mapping can lead to a more accurate solution in MDDiM, and

the convergence depends on that. To select an appropriate mapping, we must study the solution space of the given problem.

REFERENCES

Baxter, M., Dewasurendra, M., and Vajravelu, K. (2018). A method of directly defining the inverse mapping for solutions of coupled systems of nonlinear differential equations. *Numerical Algorithms* 77, 1199-1211.

Baxter, M., Robert, A., and Van Gorder, Vajravelu, K. (2013). On the choice of auxiliary linear operator in the optimal homotopy analysis of the Cahn-Hilliard initial value problem, *Numer Algor*.

Carr, J., Gurtin,M., and Slemrod,M. (1984) Structured phase transitions on a finite interval. *Arch. Ration.Mech. Anal*. **7**, 317.

Cahn, J., and Hilliard, J. (1958). Free energy of a nonuniform system. I. Interfacial free energy. *J. Chem. Phys.* 28, 258.

Constantin, P., and Foias, C. (1988). Navier–Stokes Equations.

Copetti, M.I.M., and Elliott, C.M. (1992). Numerical analysis of the Cahn-Hilliard equation with a logarithmic free energy. *Numer. Math*. 63, 39.

De Melloa, E.V.L., and Teixeira da Silveira Filho, O. (2005). Numerical study of the Cahn-Hilliard equation in one, two and three dimensions. *Phys. A*. 429, 347.

Dewasurendra, M., Baxter, M., and Vajravelu, K. (2018). A method of directly defining the inverse mapping for solutions of non-linear coupled systems arising in convection heat transfer in a second-grade fluid Applied Mathematics and Computation 339, 758-767.

Elliott, C., and French, D. (1987). Numerical studies of the Cahn-Hilliard equation for phase separation. *IMA J. Appl. Math*. 38, 97.

Elliott, C., and Songmu, Z. (1986). The Cahn-Hilliard equation. *Arch. Ration. Mech. Anal*. 28, 339.

Jaddoa, A.F. (2020). Solving Partial Differential Equations by Homotopy Perturbation Method, *journal of the college of basic education*.

Karunarathna, D., and Dewasurendra, M. (2023). Method of Directly Defining the Inverse Mapping for Nonlinear Ordinary and Partial Fractional-Order Differential Equations, *International Conference on Mathematics and Computing*, 379-389.

Liao, S., and Zhao Y. (2016) On the method of directly defining inverse mapping. *Numer Algor*.

Majda, A. J. (2002). Introduction to PDEs and Waves for the Atmosphere and Ocean.

Sahabandu, C.W., Dewasurendra, M., Juman, Z.A.M.S., Vajravelu, K., Chamkha, A.J. (2022). Semi-analytical method for propagation of harmonic waves in nonlinear magneto-thermo-elasticity, *Computers & Mathematics with Applications*, Volume 105,2022, Pages 107-111, ISSN 0898-1221.

Sahabandu, C.W., Karunarathna, D., Sewvandi, P., Juman, Z.A.M.S., Dewasurendra, M., and Vajravelu, K. (2021). A Method of Directly Defining the inverse Mapping for a nonlinear partial differential equation and for systems of nonlinear partial differential equations. *Computational and Applied Mathematics*. 40.6, 1-16.

Toral, R., Chakrabarti, A., and Gunton, J.D. (1988). Numerical study of the Cahn-Hilliard equation in three dimensions. *Phys. Rev. Lett.* 60, 2311.

Wazwaz, A.M. (2009). "Partial Differential Equations and Solitary Waves Theory", *Springer, Berlin*, P. 358.

Radio Arithmetic Mean Labeling of Cycles

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ABSTRACT

A graph G is a pair of sets $(V(G), E(G))$, where $V(G)$ and $E(G)$ are the set of vertices and the set of edges in G, connecting the pair of vertices, respectively. The diameter of a graph is the "longest shortest path" between any two graph vertices u and v, denoted by $max_{u,v}d(u,v)$, where $d(u,v)$ is the graph distance. The field of graph labeling has become one of the most active research areas today. Among all graph labeling methods, radiolabeling is the most practical labeling method. Radio labeling problem was first modeled by Hale in 1980. The concept of radio labeling of graph G was defined by Chartand in 2001. Also, Liu has found radio number of some graphs in 2004. In 2014, Ponraj introduced the notion of radio mean labeling of G and they found the radio mean number of graphs and subdivided graphs. Biology, physics and telecommunications are some of the areas in which radio labeling can be applied.

A radio labeling f of G is an assignment of positive integers to the vertices of G satisfying, $|f(u) - f(v)| \geq diam(G) + 1 - d(u,v)$, where $u, v \in V(G)$ and $d(u,v)$ is the distance between any two vertices in the graph. The above result is generalized by including arithmetic mean of labelings f instead of their difference, such that $\lceil [f(u) + f(v)]/2 \rceil \geq diam(G) + 1 - d(u,v)$. The radio mean number of f, $rmn(f)$ is the maximum number assigned to any vertex of G. The radio mean number of G, $rmn(G)$ is the minimum value of $rmn(f)$ taken over all radio mean labelings f of$G$. An alternative proof for radio arithmetic mean number of cycles is presented in this research work. The idea of labeling introduced here is simpler and creative than the existing methods.

Keywords **- Cycle, Radio Arithmetic Mean Labeling, Radio Mean Number**

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1. INTRODUCTION

In this work, we mainly focused on a special type of graph labeling method called radio labeling. Radio labeling is a famous graph labeling method and is an active research area in graph theory. And this labeling method is motivated by the channel assignment problem. The channel assignment problem is modeled to assign channels or frequencies to the transmitters in any optimal manner (Hale W.K., 1980). That means we must both avoid signal interference between radio stations and minimize the range of frequencies used. Radio labeling models this problem with a graph where each station or transmitter is a vertex and neighboring stations are connected by an edge. The distance between two stations is then the usual distance between vertices on a graph, and a station's assigned frequency is represented by a non-negative integer label of the corresponding vertex.

The radio number for special families of graphs has been studied widely in the literature after introducing the concept of radio labeling (Chartrand , G. *et al.* , 2001) . Radio number for trees and for square of cycles are some of them (Liu, D.D.-F. , 2008 ; Liu, D.D.-F. and Xie, M. , 2004). The results on the radio labeling motivated Ponraj et al. to introduce the notion of radio mean labeling of G and they found the radio mean number of graphs and subdivided graphs such that, three diameter graphs, lotus inside a circle, gear graph, Helms, sunflower graphs, subdivision of complete bipartite, corona of complete graph with path, one point union of cycle and wheel related graphs (Ponraj, R., Narayanan, S.S. and Kala, R. , 2015 ; Ponraj , R. and Narayanan, S.S. , 2014). The radio number of cycles and their total graphs is one of the mostly related studies to our research (Merlin, E.T. and Mangam, T.B. , 2018).

A radio labeling f of G is an assignment of positive integers to the vertices of G satisfying, $|f(u) - f(v)| \geq diam(G) + 1 - d\,(u\,, v)$, where $u, v \in V\,(G)$ and $d\,(u, v)$ is the distance between any two vertices in the graph. In this research work, the above result is generalized by including arithmetic mean of labelings f instead of their difference. The radio mean number of f, $rmn(\,f\,)$ is the maximum number assigned to any vertex of G. The radio mean number of G, $rmn(G)$ is the minimum value of $rmn(\,f\,)$ taken over all radio mean labelings f of G.

An alternate proof for radio arithmetic mean number of cycles is presented in this research work. In this work, we mainly divide cycles into four sub-categories such that even cycles with even diameter, even cycles with odd diameter, odd cycles with odd diameter, and odd cycles with odd diameter. And then we try to find radio arithmetic mean number of each sub-category. First, we consider cycles with even number of vertices and even diameter. Initially, we assign 0 to any vertex. Then, in accordance with the radio arithmetic mean labeling formula, we determine how much labeling remains for each vertex. Next, we consider cycles with even number of vertices and odd diameter, cycles with odd number of vertices and even diameter, and cycles with odd number of vertices and odd diameter. Throughout this paper we denote "d" as the diameter of the graph. $d = n =$

$(N/2)$, where N is the number of vertices in the even cycles. Let we define $f(u)$ as the general representation of the radio arithmetic mean labeling of any selected vertex which can take only non-negative integer.

2. MATIRIALS AND METHODS

In this section, it will be given the basic information to continue our work.

2.1 Preliminaries

Some important and useful definitions for the present investigation are stated below.

2.1.1 Definition 1 (Radio arithmetic mean labeling)

A radio arithmetic mean labeling f of G is an assignment of positive integers to the vertices of G satisfying, $\lceil [f(u) + f(v)]/2 \rceil \geq diam(G) + 1 - d(u,v)$, where $u, v \in V(G)$ and $d(u,v)$ is the distance between any two vertices in the graph.

2.1.2 Definition 2 (Cycles)

A cycle is a closed trail in which the "$Initial\ vertex = Last\ vertex$" is the only vertex that is repeated. If cycle has an odd length then cycle called "even cycle" and called "odd cycle" if has even length. This means that when a permutation is written as a product of disjoint cycles, it is an even permutation if the number of cycles of even length is even, and it is an odd permutation if the number of cycles of even length is odd.

2.1.3 Definition 3 (Diameter of a graph)

The graph diameter of a graph is the length $max_{u,v} d(u,v)$ of the "longest shortest path" between any two graph vertices u and v, where $d(u,v)$ is a graph distance.

3. RESULTS AND DISCUSSION

3.1 Theorem 1

$rmn(C_{2n}) = (3n - 1)$, where C_{2n} is an even cycle with even diameter d and $n \geq 2$.

Proof:

Consider C_{2n} even cycle with even diameter $d; n \geq 2$.

First, choose any vertex of the cycle and assign it the label "0". Then, select an unlabeled vertex at a distance of diameter (d) from previously assigned vertex. Using formula of definition 1, we have inequality $\lceil [f(u) + 0]/2 \rceil \geq d + 1 - d \rightarrow f(u) \geq 2$. Since 2 is the least value it can have, assign it the label "2".

Now, select an unlabeled vertex at a distance $(d - 1)$ from the secondly assigned vertex. Using same formula in definition 1, it is given $\lceil [f(u) + 0]/2 \rceil \geq d + 1 - [d - (d - 1)]$ by considering the firstly labeled vertex and considering the secondly labeled vertex we get $\lceil [f(u) + 2]/2 \rceil \geq d + 1 - (d - 1)$. They give $f(u) \geq 2d$ and $f(u) \geq -2$ respectively. Assign it label "$2d$" because $2d$ is the least number which maintains the labeling requirements for all already labeled vertices.

Further, find an unlabeled vertex at a distance of diameter (d) from previously assigned vertex. Considering the secondly labeled vertex we have $\lceil [f(u) + 2]/2 \rceil \geq d + 1 - [d - (d - 1)] \rightarrow f(u) \geq 2d - 2$ and assign label "$(2d - 2)$" for it.

Choose unlabeled vertex at a distance $(d-1)$ from the previously assigned vertex, $[[f(u)+0]/2] \geq d+1-[d-(d-1)+d-(d-1)] \rightarrow f(u) \geq 2d-2$ but $(2d-2)$ has been already used to label a vertex. Therefore, assign label "$[(2d-2)+1]$" for that selected vertex which is the least number it can have when it maintains the radio arithmetic mean labeling requirements of all labeled vertices.

Continuing this manner we have abled to find labels of first $(d+1)$ vertices are $0, 2, 2d, (2d-2), [(2d-2)+1], (2d-4), [(2d-4)+1], \ldots, [2d-(d-2)], [2d-(d-2)+1]$ with even diameter d.

For $(d+2)^{th}$ labeling, find an unlabeled vertex at a distance (d) from the previously assigned vertex. We have inequality $[[f(u)+0]/2] \geq d+1-[d/2] \rightarrow f(u) \geq d+2 = [2d-(d-2)]$. Since $(d+2)$ has been already used to label a vertex, assign it label "$(2d+1)$" which satisfies labeling requirements of all labeled vertices.

As the same way, assign label "$(2d+2)$" to the next unlabeled vertex which has been chosen from the previously assigned vertex at a distance $(d-1)$.

Continuing in this manner we see labels are $(2d+1), (2d+2), \ldots, (2d+d), [2d+(d-1)]$ for the last $(d-1)$ vertices in the graph where vertex labeling is started at $(d+2)^{th}$ vertex.

Continuing in this way, the label assigned to the second last vertex is $(2d+d) =$ "$3d$". The label assigned to the last vertex is "$(3d-1)$". This is the least value among all radio arithmetic mean labelings of the graph which maintains the labeling requirements of all other remaining labeled vertices.

Hence,

$$rmn(C_{2n}) = (3d-1) = (3n-1); n \geq 2$$

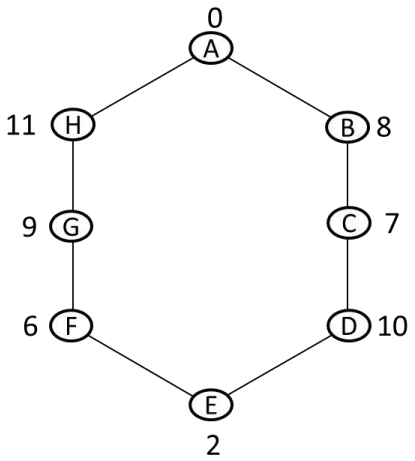

Figure 1. Radio Labeling of C_8

In Figure 1, it can be observed that $rmn(C_8)$ is 11.

3.2 Theorem 2

$rmn(C_{2n}) = (3n-2)$, where C_{2n} is an even cycle with odd diameter d and $n \geq 3$.

Proof:
Consider C_{2n} even cycle with odd diameter $d; n \geq 3$.

As same as proof of the Theorem 1, we have abled to prove this theorem using same procedure. In here also, vertex labeling is started from "0" by choosing any vertex in the cycle. An unlabeled vertex to be assigned the next label is alternatively selected by distance at a "d" and "$(d-1)$" from the previously assigned vertex.

$0, 2, 2d, (2d-2), [(2d-2)+1], (2d-4), [(2d-4)+1], \dots, [2d-(d-2)], [2d-(d-2)+1]$ is the pattern of labeling first $(d+2)$ vertices of even cycle with odd diameter.

For $(d+3)^{th}$ labeling, find an unlabeled vertex at a distance (d) from the previously assigned vertex. We have inequality $[[f(u)+0]/2] \geq d+1-[(d/2)+1] \rightarrow f(u) \geq d+3 = [2d-(d-2)+1]$. Since $[2d-(d-2)+1]$ has been already used to label a vertex, assign it label "$(2d+1)$" which is the smallest value satisfies labeling requirements of all labeled vertices. As the same way, assign label "$(2d+2)$" to the next unlabeled vertex which have been chosen from the previously assigned vertex at a distance $(d-1)$.

Continuing in this manner we see that the labels are $(2d+1), (2d+2), \dots, (2d+d), [2d+(d-2)]$ for the last $(d-2)$ vertices in the graph where the labeling is started at $(d+3)^{th}$ vertex.

Continuing in this way, the label assigned to the second last vertex is $[2d+(d-1)] =$ "$(3d-1)$". And the label assigned to the last vertex is "$(3d-2)$".

Hence,

$$rmn(C_{2n}) = (3d-2) = (3n-2); n \geq 3$$

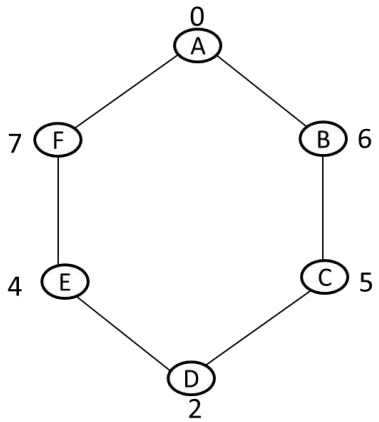

Figure 2. Radio Labeling of C_6

In Figure 2, it can be observed that $rmn(C_6)$ is 7.

3.3 Theorem 3

$rmn(C_{2n+1}) = (3n-1)$, where C_{2n+1} is an odd cycle with odd diameter d and $n \geq 2$.

Proof:
Consider C_{2n+1} odd cycle with odd diameter $d; n \geq 2$.

Choose any vertex of the cycle and assign it the label "0". Again, select an unlabeled vertex at a distance of diameter (d) from previously assigned vertex. Using the formula of definition 1 we have inequality $\lceil [f(u)+0]/2 \rceil \geq d+1-d \rightarrow f(u) \geq 2$. Since 2 is the least number it can have, assign it the label "2".

Now, select an unlabeled vertex at a distance (d) from the secondly assigned vertex. Using same formula in definition 1 it is given that $\lceil [f(u)+0]/2 \rceil \geq d+1-[d-(d-1)]$ by considering the firstly labeled vertex and considering the secondly labeled vertex we get $\lceil [f(u)+2]/2 \rceil \geq d+1-(d-1)$. They give $f(u) \geq 2d$ and $f(u) \geq -2$ respectively. Assign it label "$2d$" because $2d$ is the least number which maintains the labeling requirements of all already labeled vertices.

Further, find an unlabeled vertex at a distance of diameter (d) from previously assigned vertex then it is given that $\lceil [f(u)+2]/2 \rceil \geq d+1-[d-(d-1)] \rightarrow f(u) \geq 2d-2$ by considering the secondly labeled vertex. Then assign it label "$(2d-2)$" that maintains the label requirements of all labeled vertices.

Choose unlabeled vertex at a distance (d) from the previously assigned vertex, $\lceil [f(u)+0]/2 \rceil \geq d+1-[d-(d-1)+d-(d-1)] \rightarrow f(u) \geq 2d-2$ but $(2d-2)$ is already used to label a vertex. Therefore, we assign it label "$[(2d-2)+1]$" because $[(2d-2)+1]$ is the least value it can have while maintaining the label requirements of all labeled vertices.

Continuing this manner we have able to identify labels are $0, 2, 2d, (2d-2), [(2d-2)+1], (2d-4), [(2d-4)+1], \ldots, [2d-(d-3)], [2d-(d-3)+1], [2d-(d-1)], [2d-(d-1)+1]$ for first $(d+2)$ vertices with odd diameter d.

For $(d+3)^{th}$ labeling, find an unlabeled vertex at a distance (d) from the previously assigned vertex. We have inequalities $\lceil [f(u)+0]/2 \rceil \geq d+1-[(d-1)/2] \rightarrow f(u) \geq d+3 = [2d-(d-3)]$. Since $[2d-(d-3)]$ has been already used to label a vertex, assign it label "$(2d+1)$" that is the minimum value satisfies the radio arithmetic mean labeling requirements of all labeled vertices. As the same way, assign label "$(2d+2)$" to the next unlabeled vertex from the previously assigned vertex at a distance (d).

Continuing in this manner we see that the labels are $(2d+1), (2d+2), \ldots, (2d+d), [2d+(d-1)]$ for the last $(d-1)$ vertices where the labeling is started at $(d+3)^{th}$ vertex.

Continuing in this way, the label assigned to the second last vertex is $(2d+d) =$ "$3d$". The label assigned to the last vertex is, "$(3d-1)$". This is the least number among all radio arithmetic mean labelings which maintains the label requirements of all other remaining labeled vertices.

Hence,

$$rmn(C_{2n+1}) = (3d-1) = (3n-1); n \geq 2$$

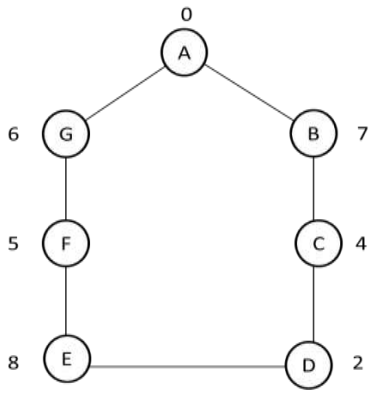

Figure 3. Radio Labeling of C_7

In Figure 3, it can be observed that $rmn(C_7)$ is 8.

3.4 Theorem 4

$rmn(C_{2n+1}) = (3n-1)$, where C_{2n+1} is an odd cycle with even diameter d and $n \geq 3$.

Proof:
Consider C_{2n+1} odd cycle with even diameter $d; n \geq 3$.

As same as proof of the theorem 3, we have abled to proof this theorem using same procedure.

In here also, first choose any vertex of the cycle and assign it label "0". An unlabeled vertex to be assigned the preceding label is selected from the previously assigned vertex at a distance "d".

For first $(d+1)$ vertices, we have able to find labels are $0, 2, 2d, (2d-2), [(2d-2)+1], (2d-4), [(2d-4)+1], \dots, [2d-(d-4)], [2d-(d-4)+1], [2d-(d-2)], [2d-(d-2)+1]$.

For $(d+2)^{th}$ labeling of an unlabeled vertex, find unlabeled vertex at a distance (d) from the previously assigned vertex. We have inequalities $\lceil [f(u)+0]/2 \rceil \geq d+1-[d/2] \rightarrow f(u) \geq d+2 = [2d-(d-2)]$. Since $[2d-(d-3)]$ has been already used to label a vertex, assign it label "$(2d+1)$" that is the minimum value maintains the label requirements of all labeled vertices.

Next, select an unlabeled vertex from the previously assigned vertex at a distance (d) for $(d+3)^{th}$ vertex labeling and assign it label "d".

Now, for the $(d+4)^{th}$ labeling, we have inequalities $\lceil [f(u)+0]/2 \rceil \geq d+1-[(d/2)-1] \rightarrow f(u) \geq d+4 = [2d-(d-4)]$. Since $[2d-(d-4)]$ is already taken as a label of vertex, assign it label "$(2d+2)$" which satisfies the labeling requirements of all already labeled vertices. Likewise, "$(2d+3)$" is the label of next unlabeled vertex.

Continuing in this manner we see that the labels are $(2d+2), (2d+3), \dots, (2d+d), [2d+(d-1)]$ for the last $(d-1)$ vertices in the graph where the labeling is started at $(d+4)^{th}$ vertex.

Continuing in this way, the label assigned to the second last vertex is $[2d-(d)] =$ "$3d$". The label assigned to the last vertex

is, "$(3d-1)$". This is the least number among all radio arithmetic mean labelings which maintains the label requirements of all other remaining labeled vertices.

Hence,

$$rmn(C_{2n+1}) = (3d-1) = (3n-1); n \geq 3$$

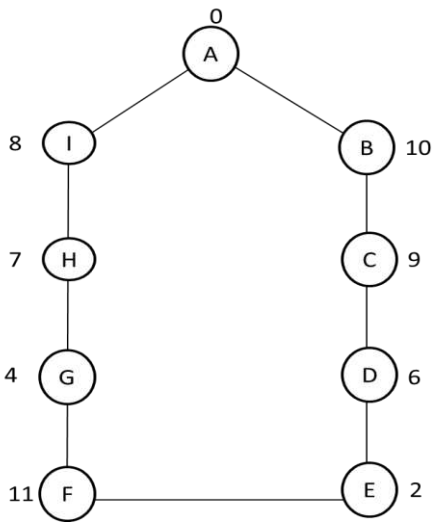

Figure 4. Radio Labeling of C_9

In Figure 4, it can be observed that $rmn(C_9)$ is 11.

4. CONCLUSION

In our research, radio labeling formula is generalized by adding arithmetic mean of the labelings f. Radio mean number and the patterns of labeling vertex are obtained for even and odd cycles by using that generalized formula. Under four theorems, we have given the method of finding radio mean number of even cycles with even diameter, even cycles with odd diameter, odd cycles with odd diameter and odd cycles with even diameter. As a future work, we are trying to use radio geometric mean labeling method for the cycles.

REFERENCES

Chartrand , G. *et al.* (2001) "Radio labeling of graphs," *Bull. inst. combin. Appl*, 33, pp. 77–85.

Hale, W.K. (1980) "Frequency assignment: Theory and applications," *Proceedings of the IEEE* , 68(12), pp. 1497–1514. Available at: <https://doi.org/10.1109/PROC.1980.11899>.

Liu, D.D.-F. (2008) "Radio number for trees," *Discrete Mathematics*, 308(7), pp. 1153–1164.

Liu, D.D.-F. and Xie, M. (2004) "Radio Number for Square of Cycles," *Congressus numerantium 169*, pp. 105–125.

Ponraj, R., Narayanan, S.S. and Kala, R. (2015) "Radio mean labeling of a graph," *AKCE International journal of graphs and Combinatorics 12*, 12(2-3), pp. 224–228.

Ponraj , R. and Narayanan, S.S. (2014) "On Radio Mean Number of Some Graphs," *International J.Math. Combin. Vil.*, 3, pp. 41–48. Available at: <https://www.researchgate.net/publication/268417633_On_Radio_Mean_Number_of_Some_Graphs>.

Merlin, E.T. and Mangam, T.B. (2018) "Radio Number of Cycles and their Total Graphs," *World Scientific News 101*, pp. 55–64. Available at: <https://www.worldscientificnews.com>.

Rainbow Connection Number of Generalized Helm Graph

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ABSTRACT

Let G be a nontrivial connected undirected graph. A rainbow k- coloring on G is a function $c: E(G) \rightarrow \{1,2,\dots,k\}$ for $k \in N$ where a path with edges made up entirely of different colors exists for any two vertices u and v in G (Surbakti et al., 2020). A path P in G, where all edges have no the same colors is called a rainbow path. An edge-colored graph G is rainbow-connected if every two distinct vertices are connected by a rainbow path. An edge coloring under which G is rainbow-connected is called rainbow coloring. The minimum number of colors (k) needed for a rainbow-connected graph, is called the rainbow connection number of G, denoted by $rc(G)$.(Chartrand et al., 2008). In this paper, we introduce a

new helm graph type and prove that graph is a rainbow-connected graph then we determine the rainbow connection number of the graph.

Keywords **- Rainbow-connected, Rainbow connection number, Helm graph**

1.INTRODUCTION

All graphs in this paper are simple, connected, and undirected graphs. Rainbow coloring is a famous graph coloring method and it is an active research area in graph theory. We are interested in constructing a rainbow coloring by using as small as number of colors. Thus, we define the rainbow connection number of a connected graph G, denoted $rc(G)$, as the smallest

number of colors needed in order to make G rainbow connected.(Fredlina et al., 2021) The concept of rainbow connection on the graph was first introduced by Chartrand in 2008 (Chartrand et al., 2008).

The Helm Graph is created by attaching a pendant edge to each cycle node in a wheel

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graph. We applied our research in this case to the Helm Graph, which contains two cycles. That is a special Helm Graph type made out of two cycles and a star graph. Here we introduce it as a *Generalized Helm Graph* and denoted as $GH_{2,n}$ where "2" means two cycles and "n" means the number of pendent vertices. In this research, we introduce rainbow coloring for our Generalized Helm Graph and we will further study our Generalized Helm Graph's rainbow connection number. We will provide some new results and also give some open problems. We hope that our work will contribute to the understanding of rainbow coloring of the Generalized Helm Graph.

2. THEOREM

The Generalized Helm Graph($GH_{2,n}$) is Rainbow-connected with $n \geq 5$. The Rainbow connection number of the Generalized Helm graph, $rc(GH_{2,n}) = n$, where n is the number of pendant vertices in the graph.

3. METHODOLOGY

Proof

Let $GH_{2,n}$ be a Generalized helm graph with,

$V(GH_{2,n}) = \{v_0\} \cup \{v_i | 1 \leq i \leq n\} \cup \{v_i' | 1 \leq i \leq n\} \cup \{v_i'' | 1 \leq i \leq n\}$

and

$E(GH_{2,n}) = \{v_0 v_i | 1 \leq i \leq n\} \cup \{v_i v_i' | 1 \leq i \leq n\} \cup \{v_i' v_i'' | 1 \leq i \leq n\} \cup \{v_i v_{i+1} | 1 \leq i \leq n-1\} \cup \{v_i' v_{i+1}' | 1 \leq i \leq n-1\} \cup \{v_1 v_n\} \cup \{v_1' v_n'\}$ as in Figure 1.

Every v_i'' is a pendant vertex and every $v_i' v_i''$ is a pendant edge, $1 \leq i \leq n$.

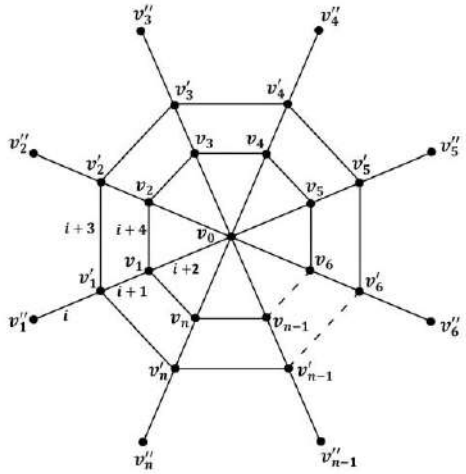

Figure 1. Generalized Helm Graph $GH_{2,n}$

Let c_k be any coloring all the edges of $GH_{2,n}$ by using k-colors, $k < n$. Then there are pendant edges $v_i' v_i''$ and $v_j' v_j''$, $i \neq j$ having the same color. Consequently, we have no rainbow v_i''- v_j'' path for some, $v_i'', v_j'' \in V(GH_{2,n})$. Thus c_k is not a rainbow coloring. This implies that $rc(GH_{2,n}) \geq n$. (Fauziah et al., 2021)

Then we define an edge coloring:

$E(GH_{2,n}) \rightarrow \{1,2,3,\dots,n\}$ by,

$$c(e) = \begin{cases} i, & if\ e = v_i' v_i'' \\ i+1, & if\ e = v_i v_i' \\ i+2, & if\ e = v_0 v_i \\ i+3, & if\ e = v_i' v_{i+1}' \\ i+4, & if\ e = v_i v_{i+1} \end{cases}$$

We will show that c_k is a rainbow coloring of $GH_{2,n}$, i.e. $GH_{2,n}$ consists of a rainbow $u-v$ path for every two vertices $u, v \in V(GH_{2,n})$.

If $u = v_i''$ and $v = v_{i+1}''$, then $d(u,v) = 3$, the three edges of path $P^3 : v_i'' - v_i' - v_{i+1}' - v_{i+1}''$ are colored by i, $i+3$, $and\ j$ respectively.

If $u = v_i''$ and $v = v_{i+2}''$, then $d(u,v) = 4$, the four edges of path $P^4 : v_i'' - v_i' - v_{i+1}' - v_{i+2}' - v_{i+2}''$ are colored by i, $i+3$, $j+3$ $and\ j$ respectively.

If $u = v_i''$ and $v = v_j''$, then $d(u,v) = 6$, then $n \geq 6$, $|i-j| \geq 3$ and the six edges of path $P^6 : v_i'' - v_i' - v_i - v_0 - v_j - v_j' - v_j''$ are colored by i, $i+1$, $i+2$, $j+2$, $j+1$ $and\ j$ respectively.

If $u = v_i''$ and $v = v_{i+1}$, then $d(u,v) = 3$, the three edges of path $P^3 : v_i'' - v_i' - v_i - v_{i+1}$ are colored by i, $i+1, and\ i+4$ respectively.

If $u = v_i''$ and $v = v_{i+2}$, then $d(u,v) = 4$, the four edges of path $P^4 : v_i'' - v_i' - v_{i+1}' - v_{i+2}' - v_{i+2}$ are colored by i, $i+3$, $j+3$ $and\ i+1$ respectively.

Now we may observe that for every two vertices $u, v \in V(GH_{2,n})$, there is a path $u - v$ consisted in path P^3, P^4 or $P^6$for some i, $1 \leq i \leq n$, there is a rainbow $u - v$ path. Thus c_k is a rainbow coloring of $GH_{2,n}$, and hence $rc\,(GH_{2,n}) = n$.

4. RESULTS & DISCUSSION

Let's consider a Generalized Helm graph with eight pendent vertices, $(GH_{2,8})$..

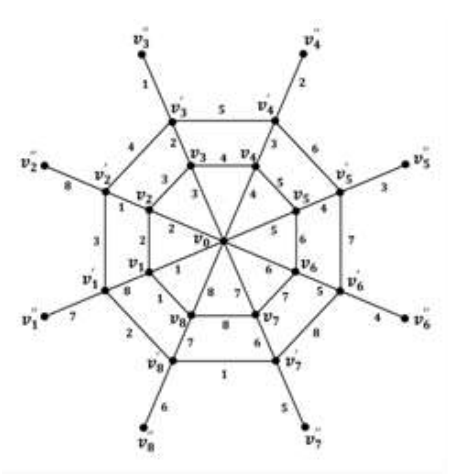

Figure 2. Generalized Helm Graph with eight pendant vertices, $GH_{2,8}$

$u = v_1''$ and $v = v_2'' \rightarrow P^3 : v_1'' - v_1' - v_2' - v_2''$ are colored by $7, 3, and\ 8$ respectively.

$u = v_1''$ and $v = v_8'' \rightarrow P^3 : v_1'' - v_1' - v_8' - v_8''$ are colored by $7, 2, and\ 6$ respectively.

$u = v_1''$ and $v = v_3'' \rightarrow P^4 : v_1'' - v_1' - v_2' - v_3' - v_3''$ are colored by $7, 3, 4\ and\ 1$ respectively.

$u = v_1''$ and $v = v_7'' \rightarrow P^4 : v_1'' - v_1' - v_8' - v_7' - v_7''$ are colored by $7, 2, 1\ and\ 5$ respectively.

$u = v_1''$ and $v = v_4'' \rightarrow P^6 : v_1'' - v_1' - v_1 - v_0 - v_4 - v_4' - v_4''$ are colored by $7, 8, 1, 4, 3\ and\ 2$ respectively.

$u = v_1''$ and $v = v_5'' \rightarrow P^6 : v_1'' - v_1' - v_1 - v_0 - v_5 - v_5' - v_5''$ are colored by $7, 8, 1, 5, 4\ and\ 3$ respectively.

$u = v_1''$ and $v = v_6'' \rightarrow$ $P^6 : v_1'' - v_1' - v_1 - v_0 - v_6 - v_6' - v_6''$ are colored by $1, 7, 8, 6, 5\ and\ 4$ respectively.

$u = v_1''$ and $v = v_2 \rightarrow$ $P^3 : v_1'' - v_1' - v_1 - v_2$ are colored by $7, 8\ and\ 2$ respectively.

$u = v_1''$ and $v = v_8 \rightarrow$ $P^3 : v_1'' - v_1' - v_1 - v_8$ are colored by $7, 8, and\ 1$ respectively.

$u = v_1''$ and $v = v_3 \rightarrow$ $P^4 : v_1'' - v_1' - v_2' - v_3' - v_3$ are colored by $7, 3, 4\ and\ 2$ respectively.

$u = v_1''$ and $v = v_7 \rightarrow$ $P^4 : v_1'' - v_1' - v_8' - v_7' - v_7$ are colored by $7, 2, 1\ and\ 6$ respectively.

Now we can see that there is a rainbow $u - v$ path for every pair of distinct vertices u and v in $GH_{2,8}$. Therefore we can say that the graph, $GH_{2,8}$ is rainbow connected. In this graph there are 8 pendant vertices and rainbow connection number of this graph, $rc(GH_{2,8}) = 8$.

We introduced in our research how the Generalized Helm Graph ($GH_{2,n}$) has a rainbow coloring. We have shown every two distinct vertices of $GH_{2,n}$ has a rainbow path and what those paths are. Also, we have shown the rainbow connection number of the $GH_{2,n}$ with providing new results. In here there is a open problem which is determine the rainbow connection number of $GH_{r,n}$, where r is the number of cycles in the graph and n is the number of pendant edges of the graph.

5. CONCLUSION

In our research, we discussed the rainbow connection number of the Generalized Helm graph($GH_{2,n}$). According to our theorem, we proved that the Generalized Helm graph($GH_{2,n}$) is rainbow-connected and the rainbow connection number of that graph is equal to the number of its pendant vertices (n). i.e. $rc(GH_{2,n}) = n$. As the number of pendent edges increases in the graph, the rainbow connection number increases accordingly. There is still a problem for the general case. For future study, one can prove (or disprove) that $GH_{r,n}$ is rainbow-connected for any value of r, where r is the number of cycles in the graph.

REFERENCES

Chartrand, G., Johns, G. L., McKeon, K. A., & Zhang, P. (2008). Rainbow connection in graphs. Mathematica Bohemica, 133(1), 85–98. https://doi.org/10.21136/MB.2008.133947

Fauziah, G. R., Purwanto, & Rahmadani, D. (2021). Strong rainbow connection numbers of helm graphs and amalgamation of lollipop graphs. Journal of Physics: Conference Series, 1836(1), 012003. https://doi.org/10.1088/1742-6596/1836/1/012003

Fredlina, K. Q., Salman, A. N. M., Julihara, I. G. P. K., Werthi, K. T., & Astawa, N. L. P. N. S. P. (2021). Rainbow Coloring of Three New Graph Classes. Journal of Physics: Conference Series, 1783(1), 012033. https://doi.org/10.1088/1742-6596/1783/1/012033

Surbakti, N. M., Silaban, D. R., & Sugeng, K. A. (2020). The rainbow connection number of graph resulting for operation of sun graph and path graph. 030010. https://doi.org/10.1063/5.0007807

Exploring *k* Graceful Labeling for Snake Graphs.

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ABSTRACT

There are many types of labeling in graph theory. Graceful labeling is one of them. We assign unique integers to every vertex in a graph in such a way that the resulting edge labels are also distinct when we use the absolute difference of the adjacent vertices labeling. In graceful labeling, the vertices labeling should always start with 0 *and the maximum integer which we can use for labeling a vertex is* $p + k - 1$ *where* p *is the total number of edges in the graph and* k *is a general representation of an integer which is greater than or equals to* 1*. In that case, the resulting edge labeling should be in between* k *and* $p + k - 1$*. In a snake graph, there are* n *number of squares and two squares share one vertex common. The objective of this paper is to prove that every snake graph is* k *graceful. If a snake graph with any number of* n *is* k *graceful it should be true for* $n = 1$*. That means a square with 4 vertices is* k *graceful. Then we try to collect those squares in the shape of a grid and present that the grid graphs are also graceful.*

Keywords **- Gracefullabeling, Squaregraphs,Gridgraphs**

1. INTRODUCTION

Graceful labeling is an interesting method which we can use for graph labelling. In 1967, this labeling method was introduced by Alexandar Rosa. [Smith and Johnson 1967]. The labelled graph resembles a graceful arrangement of integers [Miller and Joe 2011, Joseph and Daphne 2017, Joseph 2019]. That means if we take the absolute difference of the adjacent vertex labelling to label an edge both the labeling of vertices and edges should be distinct (any integer cannot be repeated). The study of this labeling method continues to be an active research area in graph theory. Graceful labeling method is used for cryptography and network design and mathematicians have extended the study of graceful labeling to various graphs. [Chartrand, Egan & Zhang 2019]. By adding squares with 4 vertices in such a way that two squares

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share one vertex common, we can make snake graphs. We can find general formulas for vertices labeling which we can use for any number of squares, but the graph remains graceful. By including a general representation of an integer to that formula we can get different labeling for the same graph again all the graphs remain graceful. So, the objective of this paper is to introduce a general formula for vertices labelling where the graph remains graceful for any number of squares and for any positive integer for general integer representation (k). In that case we are getting different labelling for the same graph, but all the graphs satisfy the conditions to be graceful graph.

Definition 1: (k - Graceful Labeling) Let $G = G(V, E)$ be a graph with $p = |E(G)|$, where $V(G)$ and $E(G)$ denote the set of vertices and edges, respectively. A graceful labeling of G is a vertex labeling f: $V \rightarrow [0, p + k - 1]$
such that f is injective and the edge labelling $f\gamma$: $E \rightarrow [k, p + k - 1]$ defined by $f\gamma:(uv) = |f(u) - f(v)|$ is also injective. Such a graph is called a k graceful graph. When $k = 1$, it is called ordinary graceful labeling.

Definition 2: (Square Snake Graphs)

The square snake graph is the graph with n squares and m vertices starting with the path graph p_{2n+1} and adding $2n - 1$ edges to the graph where n increases by 1 when m increases by 3.

Definition 3: (Grid Graph)

A two-dimensional grid graph, also known as a rectangular grid graph or two-dimensional lattice graph [Acharya and Gill 1981], is an $m \times n$ lattice graph that is the graph Cartesian product $p_n \times p_m$ of path graphs on m and n vertices. The $m \times n$ grid graph is sometimes denoted as $L_{(m,n)}$

2. METHODOLOGY

Theorem 1:

Every Snake Graph is k graceful.

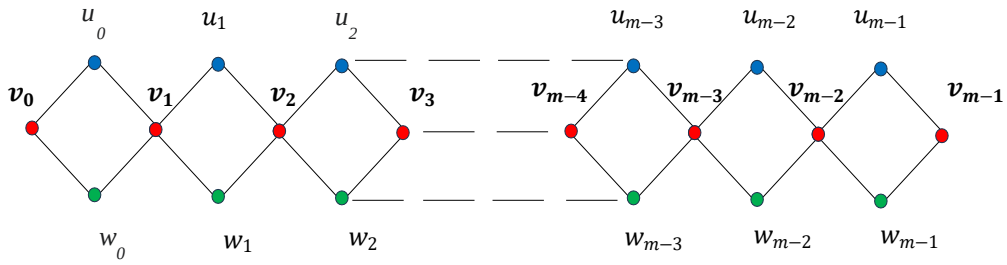

Figure 1: General snake graph with 3n+1 vertices and n squares

Proof:

Here we consider 2 cases. For both cases, vertex labeling is taken as f and as the above figure the vertices from the 1st, 2nd and 3rd lines are labelled from $u0$ to um-1, $v0$ to vm-1 and $w0$ to wm-1 respectively. n is taken as the number of squares in a graph.

Case 1: When n is odd.

$$f(u_i) = \begin{cases} 4n+k-1-i; i = 0,2,4,\dots,n-1 \\ 2n+k-1-\frac{i+1}{2}; i = 1,3,5,\dots,n-2 \end{cases}$$

$$f(v_i) = \{ \quad i \quad ; i = 0,1,2,\dots,n$$

$$f(w_i) = \begin{cases} 2n+k-1-i; i = 0,2,4,\dots,n-1 \\ 4n+k-1-\frac{i+1}{2}; i = 1,3,5,\dots,n-2 \end{cases}$$

Case 2: When n is even.

$$f(u_i) = \begin{cases} 4n+k-1-i; i = 0,2,4,\dots,n-2 \\ 2n+k-1-\frac{i+1}{2}; i = 1,3,5,\dots,n-1 \end{cases}$$

$$f(v_i) = \{ \quad i \quad ; i = 0,1,2,\dots,n$$

$$f(w_i) = \begin{cases} 2n+k-1-i; i = 0,2,4,\dots,n-2 \\ 4n+k-1-\frac{i+1}{2}; i = 1,3,5,\dots,n-1 \end{cases}$$

By substituting the k, n values where $k, n \in Z^+$, we can get a snake graph which is labelled k gracefully. Next, we are heading to make grid graphs.

3. RESULTS AND DISCUSSION

We'll discuss a couple of examples by illustrating the above theorem.

When $n = 3$

$k = 1$ (Ordinary graceful labeling)

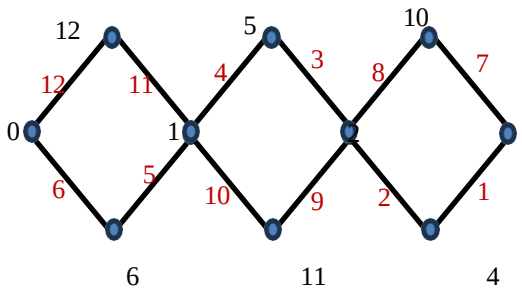

Figure 2: 1 graceful labeling of 3 square snake graph

$k = 3$

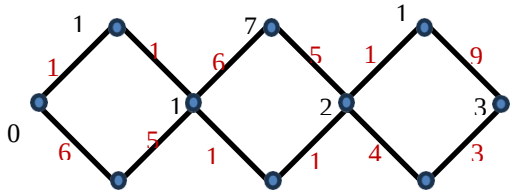

Figure 3: 3 graceful labeling of 3 square snake graph

When $n = 5$

$k = 1$

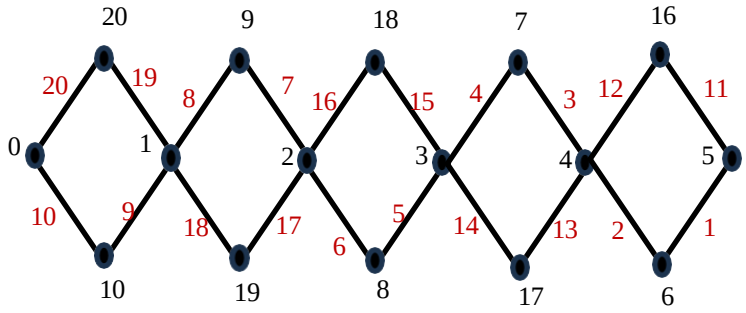

Figure 4: 1 graceful labeling of 5 square snake graph

$k = 3$

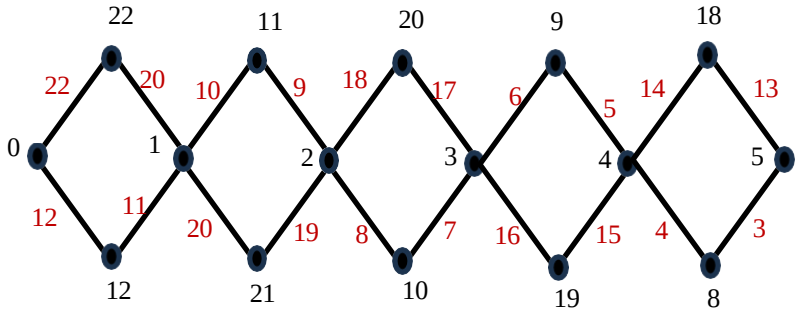

Figure 5: 3 graceful labeling of 5 square snake graph

The integers which were used for edge labeling decreases one by one in a shape of a snake.

Now we are heading to make grid graph by using squares in a snake graph.

If a snake graph with any n is k graceful it should be graceful for n = 1

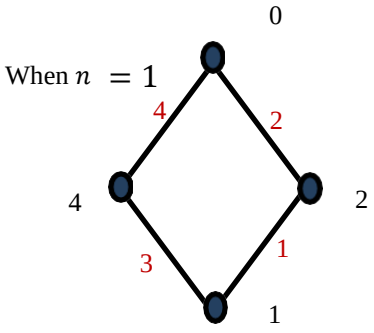

Figure 6: Grid graph with one square

By adding 4 squares we can make a 2-2 grid and we can label it gracefully. Same thing happens when there are 9 squares. It is also graceful. Here is an example for a gracefully labelled grid graph with 16 squares.

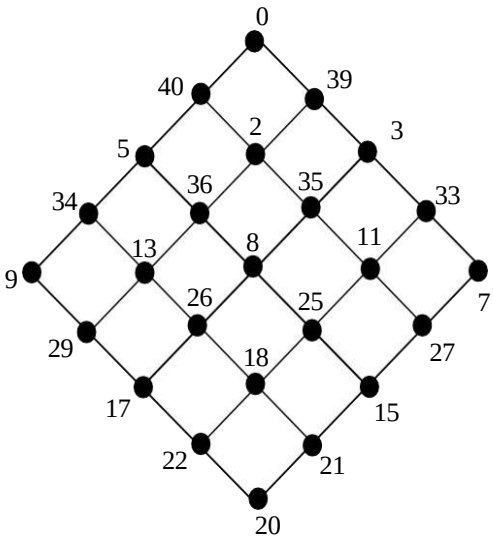

Figure 7: Grid graph with 16 squares

4. CONCLUSION

In conclusion, this research article provides a graceful labeling in graph theory, with a particular focus on snake graphs and grid graphs. The primary goal of this research article was to establish the graceful nature of snake graphs, demonstrating that they can be labelled by using distinct integers for vertices in such a way that the resulting edge labels are also distinct and fall within the range of k to $p + k - 1$. The research successfully achieves this objective, ultimately proving that every snake graph is k graceful. First, we identified a pattern. Next we found out general formulas with a general integer representation and also we included a term for number of squares. In that case we could use this formula for any snake graph with any number of squares.

Furthermore, the study extends its findings of graceful labeling to grid graphs, showing that by collecting squares in the shape of a grid. These grid graphs also satisfy graceful labeling properties. This implies that graceful labeling is not limited to snake graphs but can be applied to more complex structures formed by combining these squares.

As our future work we are planning to provide general formula for vertices labeling for snake graphs with connected end vertices and snake path chain. And we can try graceful labeling for snake graphs with different polygon instead of squares. In cryptography we convert message into nonreadable form. Furthermore, we are planning to use graceful labelling in cryptography.

Overall, this research contributes to our understanding of graceful labeling in graph theory.

5. REFERENCES

Chartrand, G., Egan, C., Cooroo, & Zhang, P. (2019). Graceful Labelings. In How to Label a Graph, Springer Briefs in Mathematics (pp. 13-38).

Gallian, J. A., & Liu, D. (2017). Graceful, Harmonious and Magic Type Labelings.

Gallian, J. A. (2019). Graceful Labelings. In Graph Labelings, Springer, pp. 9-28.

Indunil, W. K. M. (2023). k-Graceful labeling for the ladder graph and the roach graph.

Kader, M. A., Sharmin, M., Ankon, T.M. (2014). A critical Assessment of Graceful Graphs and Trees: Study and Development of New Approaches.

Miller, M., & Ryan, J. (2011). Graceful Labelling: State of the Art, Applications and Future Directions. Mathematics in Computer Science, 5(2), 101-123.

Smith, J. A., & Johnson, B. C. (1967). "On the Introduction of Graceful Labeling in Graph Theory." Journal of Mathematical Structures, 15(3), 45-62.

Velmurugan, C., & Ramachandran, V. (2020). Algorithm for M modulo N Graceful Labeling of Ladder and Subdivision of Ladder Graphs.

On the Inverse Semigroups of Partial Permutation Matrices

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ABSTRACT

Inverse semigroup theory has emerged as a vibrant research area in recent years, finding applications in various mathematical domains, such as mathematical biology, combinatorics, graph theory, and automata theory. In contrast to finite group theory, where representations, permutations, and matrices are standard tools for computations, the analogous tools in the context of finite inverse semigroups are not as readily available in the literature. This work addresses this gap by utilizing a specific type of 0, 1-matrices known as partial permutation matrices. Although we suspect that the results presented here are well-known to experts in this field, they have not been formally documented in the existing literature. Therefore, we believe it is essential to establish these results readily accessible to a wider mathematical audience, for pedagogical purposes, and make this framework available for computational purposes.

Keywords **- Inverse Semigroups, Symmetric Inverse Semigroups, Partial Permutation Matrices**

1. INTRODUCTION

Inverse semigroup theory is founded on the idea of a partial symmetry, or a partial bijections that preserve a certain structure. The idea of a partial bijection (or partial permutation) therefore serves as the foundation for inverse semi-group theory. According to Cayley's theorem, every group is isomorphic to a subgroup of a symmetric group. The analogous result for inverse semigroups, the Wagner-Preston theorem says that each inverse semigroup is isomorphic to an inverse subsemigroup of a symmetric inverse monoid,[1]

Partial Permutation matrices emerged as a natural extension of permutation matrices in the field of combinatorics. It is a mathematical tool used to represent partial permutations, and their development and use can be attributed to the collective work of mathematicians and researchers in the field of linear algebra, combinatorics, and graph theory.

2. PRELIMINARIES

2.1 Inverse Semigroups

An *inverse semigroup* is a set S equipped with an associative binary operation called multiplication and an involutive unary operation $*$ called inversion satisfying $aa^*a = a$ for all $a \in S$, [2].

2.2 Symmetric Inverse Semigroup

The *symmetric inverse semigroup* on a set X, denoted by $\mathrm{SymInv}(X)$, is the collection of all bisections between subsets of X with composition and inversion as algebraic operations.

The (total) identity map on X act as the two-sided multiplicative identity of this semigroup, and therefore it is also a monoid.

2.3 Wagner-Preston Representation Theorem

Every inverse semigroup can be isomorphically embedded in a symmetric inverse monoid, [1].

2.4 Partial Permutation Matrices

An $n \times n$ square matrix $P \in M_n(\mathbb{Z}_2)$ is said to be a *partial permutation matrix* if it has at most one non-zero entry in each row and column and these non-zero entries (if any) are all 1, [3]. When there is no ambiguity we will denote the set of all partial permutations, of a fixed size, by PPM.

3. RESULTS

It is classical theorem of group theory that any finite group is isomorphic to a subgroup of permutation matrices of the same order. Here we extend this result for symmetric inverse semigroups and partial permutation matrices.

Theorem 1

The set of $n \times n$ partial permutation matrices form an inverse semigroup under matrix multiplication and taking transpose (Moore-Penrose inversion).

Proof:

- Closed under multiplication

Let π, ρ be two partial permutations, and P_π, P_ρ be corresponding partial permutation matrices. Since these matrices are compatible, we can multiply them. Recall that any partial permutation matrix has at most one non-zero entry in each row and column, and these non-zero entries (if any) are all 1. Hence, matrix multiplication results in at most one entry (if any) along each row and column, and each non-zero entry must be 1. Therefore, a product of partial permutation matrices is again a partial permutation matrix.

- Closed under inversion

In general, inversion must be the Moore-Penrose pseudo-inversion, and here it turns out to be the transpose of the matrix which can be explained using the fact that non-zero columns (and rows) are orthogonal. Moreover, transpose of a partial permutation matrix is again of the same kind.

Theorem 2

Let S be a finite set with n elements. The symmetric inverse semigroup on S, denoted by $\mathrm{SymInv}(S)$, is isomorphic to the inverse semigroup of partial permutation matrices, PPM, of order n.

Proof:

Here we must establish a bijective homomorphism

$$P : \text{SymInv}(S) \to \text{PPM}.$$

A partial permutation

$$\pi : \{1, 2, \dots, n\} \to \{1, 2, \dots, n\}$$

is traditionally represented in the two-line notation

$$\pi = \begin{pmatrix} 1 & 2 & \cdots & n \\ \pi(1) & \pi(2) & \dots & \pi(n) \end{pmatrix}.$$

The corresponding entries of elements that are not in the domain of π kept empty. The partial permutation matrix representation of π is an $n \times n$ matrix

$$P_\pi = \begin{pmatrix} e_{\pi(1)} & e_{\pi(2)} \dots & e_{\pi(n)} \end{pmatrix}$$

Whose entries in column i are all zeros except a 1 appears in row $\pi(i)$ if it maps to an element in the codomain. This defines a map $\pi \mapsto P_\pi$.

First, we shall show that $P_{\rho\pi} = P_\rho . P_\pi$

Let

$$\rho = \begin{pmatrix} 1 & 2 & \cdots & n \\ \rho(1) & \rho(2) & \dots & \rho(n) \end{pmatrix}$$

and

$$\pi = \begin{pmatrix} 1 & 2 & \cdots & n \\ \pi(1) & \pi(2) & \dots & \pi(n) \end{pmatrix}$$

Then,

$$\rho\pi = \begin{pmatrix} 1 & 2 & \cdots & n \\ \rho\pi(1) & \rho\pi(2) & \dots & \rho\pi(n) \end{pmatrix}$$

and

$$P_{\rho\pi} = \begin{pmatrix} e_{\rho\pi(1)} & e_{\rho\pi(2)} \dots & e_{\rho\pi(m)} \end{pmatrix}.$$

- $e_{\rho\pi(i)} = 0$ for all entries in the i^{th} column if i is not in the domain of π or $\pi(i)$ is not in the domain of ρ. In the former case i^{th} column of P_π contains only zero entries. In the latter case $\pi(i)^{\text{th}}$ column of P_ρ contains only zero entries.
- $e_{\rho\pi(j)} = e_i \implies \rho\pi(j) = i$

$\implies \pi(j) = k$ and $\rho(k) = i$ for some k.

$$\implies e_{\pi(j)} = e_k \text{ and } e_{\rho(k)} = e_i.$$

i.e., i^{th} row of P_ρ that contains k^{th} column entry as 1, and the k^{th} row of P_π that contains j^{th} column entry as 1. Result of multiplying these two matrices together contains i^{th} row and j^{th} column entries as 1. Hence

$$P_{\rho\pi} = P_\rho P_\pi.$$

Next, we must show that $P_{\rho^*} = P_\rho{}^*$

Suppose $\rho(j) = i$. Then i^{th} row and j^{th} column entry of the matrix P_ρ is 1. In the transpose $P_\rho{}^*$ we have j^{th} row and i^{th} column entry as 1. One can compare this with the fact that $\rho^*(i) = j$. Similarly, we can argue for the zero entries and establish the fact that

$$P_{\rho^*} = P_\rho{}^*.$$

Therefore P is a homomorphism of inverse semigroups. Moreover, one can easily reverse the construction of a matrix from a partial permutation to obtain a symmetric inverse semigroup. Consequently, P is an isomorphism.

4. DISCUSSION

To illustrate the theorems that we proved in the last section, let $S = \{1,2\}$. The symmetric inverse semigroup of S consists of following partial bijections:

$$\theta = \begin{pmatrix} 1 & 2 \\ - & - \end{pmatrix}$$

$$\sigma_1 = \begin{pmatrix} 1 & 2 \\ 1 & - \end{pmatrix}, \qquad \sigma_2 = \begin{pmatrix} 1 & 2 \\ 2 & - \end{pmatrix}$$

$$\sigma_3 = \begin{pmatrix} 1 & 2 \\ - & 1 \end{pmatrix}, \ \sigma_4 = \begin{pmatrix} 1 & 2 \\ - & 2 \end{pmatrix}$$

$$\rho_1 = \begin{pmatrix} 1 & 2 \\ 2 & 1 \end{pmatrix}, \ \rho_2 = \begin{pmatrix} 1 & 2 \\ 1 & 2 \end{pmatrix}$$

Corresponding partial permutation matrices are

$$P_\theta = \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}$$
$$P_{\sigma_1} = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}, \quad P_{\sigma_2} = \begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix}$$
$$P_{\sigma_3} = \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}, \quad P_{\sigma_4} = \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}$$
$$P_{\rho_1} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad P_{\rho_2} = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}.$$

Below are the multiplication and inversion tables for the symmetric inverse semigroup of S.

Table 1: Inversion table for the Symmetric inverse semigroup of S.

	θ	σ_1	σ_2	σ_3	σ_4	ρ_1	ρ_2
$*$	θ	σ_1	σ_3	σ_2	σ_4	ρ_1	ρ_2

Table 2: Multiplication table for the Symmetric inverse semigroup of S.

$\times$	θ	σ_1	σ_2	σ_3	σ_4	ρ_1	ρ_2
θ	θ	θ	θ	θ	θ	θ	θ
σ_1	θ	σ_1	θ	σ_3	θ	σ_3	σ_1
σ_2	θ	σ_2	θ	σ_4	θ	σ_4	σ_2
σ_3	θ	θ	σ_1	θ	σ_3	σ_1	σ_3
σ_4	θ	θ	σ_2	θ	σ_4	σ_2	σ_4
ρ_1	θ	σ_2	σ_1	σ_4	σ_3	ρ_2	ρ_1
ρ_2	θ	σ_1	σ_2	σ_3	σ_4	ρ_1	ρ_2

isomorphic, they have essentially the same multiplication table, up to labeling elements.

REFERENCES

Lawson, Mark V. "Primer on inverse semigroups I." *arXiv preprint arXiv:2006.01628* (2020).

Lawson, Mark V. *Inverse semigroups, the theory of partial symmetries*. World Scientific, 1998.

Lankham, Isaiah, Bruno Nachtergaele, and Anne Schilling. "Permutations and the Determinant." (2006).

Dahl, Geir. "Permutation matrices related to Sudoku." *Linear Algebra and its Applications* 430.8-9 (2009): 2457-2463.

The Subalgebra of Conjugatable Elements of a Degree Three Hyper-Complex Extension of Real Numbers

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ABSTRACT

It is well known that Clifford algebra generalizes even dimensional associative algebras. However, many other interesting classes of algebras do not belong to this category. They include some important classes of algebras such as Lie algebras, Malcev algebras, Alternative algebras, and Jordan algebras. Two familiar explicit examples are hyperbolic quaternions and octonions. All these examples are not Clifford algebras as they are non-associative. In this work we study another such number system which is associative over $\mathbb{R}$*.We believe that having seen such examples is necessary for students and early career researchers.*

Keywords **- Hypercomplex, Number System, Associative Real Algebra**.

1. INTRODUCTION

The theory of number systems is well developed concept in the real and complex numbers. These systems play huge role in the mathematics. However, complex number system has been used in many real-world applications related to science and engineering. In many scenarios, it is helpful to solve a problem by transforming real data into complex space, and it can be solved using methods of arithmetic in number systems. Then transfer the solution in complex plane back to the real plane.

The arithmetic of complex numbers can be generalized same as the arithmetic of real number, together with the addition and multiplication by real numbers, the inverse and division are defined. This kind of arithmetic exists not only for these number systems also exists for other numbers such as quaternions and octonions. These type of number systems are used in many applications such as bioinformatics, navigation systems, and image and video processing.

In this study, we discuss the basics of the newly introduced hypercomplex number system called complex numbers type degree

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three extension of real numbers. This system is obtained by introducing a special unit j such that All numbers are in the form $\mathbb{R}[j] = \{x + yj + zj^2; x, y, z \in \mathbb{R} \text{ and } j^3 = -1\}$. In addition to that, we have described the main operations and properties of these such numbers and interpret those are using matrix algebra. Finally, introduce a conjugate element for a special number which is in the form $w = x + yj - yj^2$.

2. MATERIALS AND METHODS

In this section, we introduce the new algebra and establishes its basic algebraic properties.

$$\mathbb{R}[j] = \{\, x + yj + zj^2 \mid x, y, z \in \mathbb{R} \text{ and } j^3 = -1 \,\}$$

with addition and multiplication defined canonically. This defines a commutative and associative algebra over $\mathbb{R}$, whose dimension as a real vector space is 3.

Let $w_i = x_i + y_i j + z_i j^2$, where $x_i, y_i, z_i \in \mathbb{R}$ and $j^3 = -1$ for $i = 1, 2, 3$.

Addition is commutative:
Consider,

$$\begin{aligned} w_1 + w_2 &= (x_1 + y_1 j + z_1 j^2) \\ &\quad + (x_2 + y_2 j + z_2 j^2) \\ &= (x_1 + x_2) + (y_1 + y_2) j \\ &\quad + (z_1 + z_2) j^2 \\ &= (x_2 + x_1) + (y_2 + y_1) j \\ &\quad + (z_2 + z_1) j^2 \\ &= (x_2 + y_2 j + z_2 j^2) \\ &\quad + (x_1 + y_1 j + z_1 j^2) \\ &= w_2 + w_1 \end{aligned}$$

Addition is associative:

$$\begin{aligned} (w_1 + w_2) + w_3 &= [(x_1 + y_1 j + z_1 j^2) \\ &\quad + (x_2 + y_2 j + z_2 j^2)] \\ &\quad + (x_3 + y_3 j + z_3 j^2) \\ &= (x_1 + y_1 j + z_1 j^2) \\ &\quad + [(x_2 + y_2 j + z_2 j^2) \\ &\quad + (x_3 + y_3 j + z_3 j^2)] \\ &= w_3 + (w_2 + w_3) \end{aligned}$$

Multiplication is commutative:

$$\begin{aligned} w_1 w_2 &= (x_1 + y_1 j + z_1 j^2)(x_2 + y_2 j \\ &\quad + z_2 j^2) \\ &= (x_1 x_2 - y_1 z_2 - z_1 y_2) \\ &\quad + (x_1 y_2 + y_1 x_2 - z_1 z_2) j \\ &\quad + (x_1 z_2 + y_1 y_2 + z_1 x_2) j^2 \\ &= (x_2 x_1 - z_2 y_1 - y_2 z_1) \\ &\quad + (y_2 x_1 + x_2 y_1 - z_2 z_1) j \\ &\quad + (z_2 x_1 + y_2 y_1 + x_2 z_1) j^2 \\ &= (x_2 x_1 + x_2 y_1 j + x_2 z_1 j^2) \\ &\quad + (-y_2 z_1 + y_2 x_1 j + y_2 y_1 j^2) \\ &\quad + (-z_2 y_1 - z_2 z_1 j + z_2 x_1 j^2) \\ &= x_2 (x_1 + y_1 j + z_1 j^2) \\ &\quad + y_2 (-z_1 + x_1 j + y_1 j^2) \end{aligned}$$

$$+z_2(-y_1 - z_1 j + x_1 j^2)$$

$$= x_2(x_1 + y_1 j + z_1 j^2)$$

$$+y_2(z_1 j^3 + x_1 j + y_1 j^2)$$

$$+z_2(y_1 j^3 + z_1 j^4 + x_1 j^2)$$

$$= x_2(x_1 + y_1 j + z_1 j^2)$$

$$+y_2 j(z_1 j^2 + x_1 + y_1 j)$$

$$+z_2 j^2(y_1 j + z_1 j^2 + x_1)$$

$$= (x_2 + y_2 j + z_2 j^2)(x_1 + y_1 j + z_1 j^2)$$

$$= w_2 w_3$$

Similarly, we can prove that the associativity property under multiplication,

$$(w_1 w_2) w_3 = w_1 (w_2 w_3)$$

Also, it satisfies distributive law as well. i.e.,

$$w_1(w_2 + w_3) = (w_1 w_2) + (w_1 w_3)$$

While this algebra has many algebraic properties similar to those of complex numbers, it is worthwhile to notice that some elements of $\mathbb{R}[j]$ do not possess a conjugate. For $w \in \mathbb{R}[j]$ its conjugate, if exists, is the unique $\overline{w} \in \mathbb{R}[j]$ such that $w + \overline{w},\ w\overline{w} \in \mathbb{R}$.

Let $w = x + yj + zj^2$ and suppose $\overline{w} = a + bj + cj^2$ for some $w \in \mathbb{R}[j]$.
To have a $w + \overline{w} \in \mathbb{R}$, coefficients of both j and j^2 must be zero.
i.e., $y + b = 0$ and $z + c = 0$.
$\Longrightarrow b = -y$ and $c = -z$.

Similarly, the coefficients of j and j^2 in $w\overline{w} = (xa - yc - zb) + (xb + ya - zc)j + (xc + yb + za)j^2$ must be zero.
i.e.
$\Longrightarrow\ xb + ya - zc = 0$ and
$xc + yb + za = 0$

By solving these equations, we can see that in order for a conjugate to exist w must be of the form

$$w = x + yj - yj^2$$

and when this happens

$$\overline{w} = (x - y) - yj + yj^2.$$

Furthermore, using this conjugate we can show the following properties:

i) $w = \overline{w}$ if and only if $w \in \mathbb{R}$
ii) $\overline{\overline{w}} = w$
iii) $\overline{w_1 + w_2} = \overline{w_1} + \overline{w_2}$
iv) $\overline{w_1 w_2} = \overline{w_1} \cdot \overline{w_2}$
v) $\overline{\alpha w} = \alpha \overline{w}$ for any $\alpha \in \mathbb{R}$
vi) $\overline{w^{-1}} = (\overline{w})^{-1}$, if w^{-1} exists.

Also,

$$w\overline{w} = (x + yj - yj^2)\big((x - y) - yj + yj^2\big)$$
$$= x^2 - xy - 2y^2$$
$$= (x + y)(x - 2y)$$

This expression need not always be positive, as in the case of regular complex numbers. In addition to that, it can be defined as the complex valued- norm such that
$N(w) = \sqrt{x^2 - xy - 2y^2}$.
This norm is multiplicative. i.e., $N(w_1 w_2) = N(w_1) N(w_2)$. We can prove the multiplicativity as follows.

$$w_1w_2 = (x_1 + y_1j - y_1j^2)(x_2 + y_2j - y_1j^2)$$

$$= (x_1x_2 + 2y_1y_2)$$

$$+(x_1y_2 + y_1x_2 - y_1y_2)j$$

$$-(x_1y_2 + y_1x_2 - y_1y_2)j^2$$

Therefore,

$(w_1w_2)(\overline{w_1w_2}) =$

$(x_1x_2 + 2y_1y_2)^2 -$

$(x_1x_2 + 2y_1y_2)(x_1y_2 + y_1x_2 - y_1y_2)$

$$-2(x_1y_2 + y_1x_2 - y_1y_2)^2$$

$$= (x_1.x_2)^2 + 4(y_1y_2)^2 + x_1x_2y_1y_2$$

$+2x_1y_1{y_2}^2 + 2{y_1}^2x_2y_2$

$$-{x_1}^2y_2(x_2 + 2y_2) - {x_2}^2y_1(x_1 + 2y_1)$$

$= K$ (say) ……..(1)

Therefore,

$$N(w_1w_2) = \sqrt{K}$$

Also, consider,

$$w_1\overline{w_1} = {x_1}^2 - x_1y_1 - 2{y_1}^2$$

and

$$w_2\overline{w_2} = {x_2}^2 - x_2y_2 - 2{y_2}^2$$

Then,

$(w_1\overline{w_1})(w_2\overline{w_2}) =$

$({x_1}^2 - x_1y_1 - 2{y_1}^2)({x_2}^2 - x_2y_2 - 2{y_2}^2)$

$$= (x_1x_2)^2 + 4(y_1y_2)^2 + x_1x_2y_1y_2$$

$+2x_1y_1{y_2}^2 + 2{y_1}^2x_2y_2$

$$-{x_1}^2y_2(x_2 + 2y_2) - {x_2}^2y_1(x_1 + 2y_1)$$

$= k$ (from (1))

Hence,

$$N(w_1)N(w_2) = \sqrt{K}$$

i.e., $N(w_1w_2) = N(w_1)N(w_2)$.

Because there is no sum of three squares identity, this is quite remarkable.

All multiplicatively invertible elements of $\mathbb{R}[j]$ are precise the those with the non-zero norm. In that case, the inverse is given by,

$$w^{-1} = \overline{w}\left(N(w)\right)^{-2}$$

To understand this algebra from a different perspective, observe that 3×3 invertible matrix,

$$J = \begin{pmatrix} 0 & 0 & -1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}$$

has the property that $j^3 = -I$ where I is an identity matrix with order 3, and consequently we can identify $\mathbb{R}[j]$ with the set of matrices of the form,

$$xI + yj + zj^2$$
$$= x\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} + y\begin{pmatrix} 0 & 0 & -1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix} + z\begin{pmatrix} 0 & -1 & 0 \\ 0 & 0 & -1 \\ 1 & 0 & 0 \end{pmatrix}$$
$$= \begin{pmatrix} x & -z & -y \\ y & x & -z \\ z & y & x \end{pmatrix}$$

for $x, y, z \in \mathbb{R}$.

In addition, there is a mapping

$$\varphi(x+yj+zj^2)=\begin{pmatrix} x & -z & -y \\ y & x & -z \\ z & y & x \end{pmatrix}$$

satisfying the following algebraic properties.

i) $\varphi(a+b)=\varphi(a)+\varphi(b)$
ii) $\varphi(a\cdot b)=\varphi(a)\cdot\varphi(b)$
iii) $\varphi(\alpha a)=\alpha\varphi(a)$
for all $\alpha\in\mathbb{R}$ and $a,b\in\mathbb{R}[j]$.

Let $\mathbb{E}=\{x+ky : x,y\in\mathbb{R}, k=j-j^2, \text{and } j^3=-1\}$. Then k has the minimal polynomial $k^2-k-2=(k+1)(k-2)$ and this shows that $\mathbb{E}=\mathbb{R}[k]/(k+1)(k-2)$.

Moreover, $\mathbb{E}$ is isomorphic to $\mathbb{R}^2$ (as $\mathbb{R}$-algebras) equipped with component wise addition, multiplication via $x+ky\mapsto(x-y,x+2y)$ and conjugation is the operation that changes two components of the corresponding element of $\mathbb{R}^2$. Observe that addition and multiplication on $\mathbb{E}$ is given by

$$(x_1+ky_1)+(x_2+ky_2)=(x_1+x_2)+k(y_1+y_2)$$

$$(x_1+ky_1)(x_2+ky_2)=(x_1x_2+2y_1y_2)+k(x_1y_2+x_2y_1+y_1y_2)$$

and this corresponds to the matrix addition and multiplication

$$\begin{pmatrix} x_1 & y_1 \\ 2y_1 & x_1+y_1 \end{pmatrix}+\begin{pmatrix} x_2 & y_2 \\ 2y_2 & y_1x_1+y_2 \end{pmatrix}=\begin{pmatrix} 2(y_1+y_2) & (x_1+x_2)+(y_1+y_2) \end{pmatrix}$$

$$\begin{pmatrix} x_1 & y_1 \\ 2y_1 & x_1+y_1 \end{pmatrix}\begin{pmatrix} x_2 & y_2 \\ 2y_2 & x_2+y_2 \end{pmatrix}=\begin{pmatrix} A & B \\ C & D \end{pmatrix}.$$

$A=x_1x_2+2y_1y_2,$

$B=x_1y_2+x_2y_1+y_1y_2$

$C=2(x_1y_2+x_2y_1+y_1y_2)$ and

$D=(x_1x_2+2y_1y_2)+(x_1y_2+x_2y_1+y_1y_2)$

Thus, we have established a bijective correspondence between $\mathbb{E}$ and a subalgebra of $M_{2\times2}(\mathbb{R})$. Moreover, we can identify the norm of an element of $\mathbb{E}$ with the determinant of the corresponding matrix.

3. RESULT AND DISCUSSION

In this work, we have introduced a new hypercomplex number system and established its basic algebraic properties. $\mathbb{R}[j]$

$=\{x+yj+zj^2 \mid x,y,z\in\mathbb{R} \text{ and } j^3=-1\}$

with addition and multiplication defined canonically and this algebra has many algebraic properties similar to complex numbers. We have shown that this algebra satisfies commutative and associative properties for the operations addition and multiplication. Also, there is a complex valued- norm such that
$N(w)=\sqrt{x^2-xy-2y^2}$.

In addition to that the above algebra can be represented using matrices of the form

$$\varphi(x+yj+zj^2)=\begin{pmatrix} x & -z & -y \\ y & x & -z \\ z & y & x \end{pmatrix}.$$

4. CONCLUSION

Here we have studied the algebraic properties of a $\mathbb{R}[x]/(x^3+1)$. While this may seem obvious, it helps us to realize that existing of conjugates is a very delicate property of complex numbers. Seeing this kind of non-traditional examples is essential for pedagogical purposes and having them in the disposal is inevitable for early researchers.

REFERENCES

Dummit, D. S., and Foote, R. M., (2004). Abstract Algebra (3rd ed.), John Wiley and Sons, Inc.

Grigoryan, A. M., Jenkinson, J., and Agaian, S. S. (2015). Quaternion Fourier transform based alpha-rooting method for color image measurement and enhancement, *SIGPRO-D-14-01083R1, Signal Processing, 109, 269–289.*

Kantor, I. L., and Solodovnikov, A. S., (1973). Hypercomplex Numbers, Nauka, Moskow.

Kuipers, J. B., (2002). Quaternions and Rotation Sequences: A Primer with Applications to Orbits, Aerospace and Virtual Reality, Princeton University Press, Princeton.

Weisstein, Eric W. "Hypercomplex Number."From *MathWorld*--A Wolfram Web Resource. https://mathworld.wolfram.com/HypercomplexNumber.html.

Chromatic Number Based on Incidence Colouring for Ladder Graph Family

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ABSTRACT

We present a comprehensive study on incidence colouring for ladder graphs, an intriguing class of graphs resembling the rungs of a ladder. Incidence colouring extends traditional graph colouring by assigning colours to incidences with constraints on consecutive incidences. We investigate the incidence chromatic number χi(G) for ladder graphs of varying sizes, revealing patterns and complexities. Practical applications of incidence colouring in ladder graphs, such as communication networks and resource allocation, are explored, emphasizing conflict avoidance in adjacent incidences. Novel techniques for determining χi(G) are proposed, drawing insights from previous research on star graphs. Our findings contribute to the field of incidence colouring, advancing knowledge on graph theory applications. The study of ladder graphs sheds light on graph interconnections and lays the groundwork for future investigations into incidence chromatic numbers for other graph classes.

Keywords **- Incidence colouring, Ladder graphs, Incidence chromatic number, Graph theory, Graph colouring.**

1. INTRODUCTION

Graph theory, a profound field of mathematics, encompasses a wide range of intriguing concepts and their real-world applications. Among these, graph coloring has emerged as a significant area of study, involving the assignment of colors to the vertices of a graph, with the constraint that adjacent vertices should have distinct colors, yielding a "nicely colored graph." This paper explores finite, simple, undirected, and loopless graphs, where each edge represents a unique connection between two vertices.

Consider G, a graph, with V(G) denoting its vertex set and E(G) its edge set. The maximum degree of G is denoted by Δ(G). In 1993, Brualdi and Massey introduced the concept of incidence coloring, a novel extension of traditional graph coloring. The order of graph G is represented by the cardinality of its vertex set, |V(G)|, and the size of G is determined by the cardinality of its edge set, |E(G)|.

Let,

$$I(G) = \{(v, e), where\ v \in V(G)\ and\ e \in E(G), v\ incident\ with\ e\ \}$$

Incidence coloring presents a fresh perspective on graph theory by considering incidences as ordered pairs (v, e), where v ∈ V(G) and e ∈

E(G), with vertex v incident with edge e. Two incidences (v, e) and (w, f) are deemed "nearby" under the following conditions:

(i) v = w,
(ii) e = f, or
(iii) the edge vw = e or vw = f.

The concept of incidence coloring revolves around assigning colors to incidences, subject to constraints on nearby incidences, thereby ensuring an elegant and conflict-free coloring scheme.

In this paper, our primary focus lies on the study of incidence coloring for ladder graphs—a captivating class of graphs resembling the rungs of a ladder. Ladder graphs are characterized by their simplicity, yet they present intriguing graph interconnections that warrant detailed exploration. The main objectives of our study are fourfold:

(1) To establish the scope and purpose of our research, delving into the intricacies of incidence coloring for ladder graphs and its relevance in various graph theory applications.
(2) To provide a concise review of the relevant literature, summarizing key prior research on graph coloring, incidence coloring, and ladder graphs.
(3) To describe the techniques employed in our investigation, including the novel methods proposed for determining the incidence chromatic number $\chi i(G)$ specifically tailored for ladder graphs.
(4) To present an overview of the principal findings of our study, unveiling patterns and complexities observed within the incidence chromatic numbers $\chi i(G)$ for ladder graphs of varying sizes, and exploring practical applications in communication networks and resource allocation, with a particular emphasis on conflict avoidance in adjacent incidences.

Given the unique characteristics of ladder graphs, our study aims to advance the understanding of incidence coloring and its applications in this intriguing graph class. The insights gained from this investigation hold promise not only in enriching the theoretical foundations of incidence coloring but also in providing practical implications for designing efficient communication networks and resource allocation systems tailored to ladder graph structures.

2. MATERIALS AND METHODS

In this section will be given the basic information to continue our work.

Preliminaries

So, we will introduce some fundamental definitions first.

Definition 1: Graph Labeling and Colouring.

Graph labeling is a fundamental concept in graph theory, involving the assignment of labels to the vertices, edges, or other elements of a graph based on predefined rules or constraints. A commonly studied type of graph labeling is graph coloring, where the vertices of a graph are assigned colors such that no two adjacent vertices share the same color. The minimum number of colors required to achieve this property is known as the chromatic number of the graph, denoted by $\chi(G)$. Proper coloring ensures that no two adjacent vertices are assigned the same color, and a graph that can be colored using $\chi(G)$ colors is said to be $\chi(G)$-colorable. Graph labeling, encompassing various types of labelings such as vertex labeling, edge labeling, and more, plays a crucial role in numerous applications, including network routing, graph algorithms, and graph

visualization, facilitating the representation and analysis of graph structures in diverse contexts.

Definition 2: Incidence Colouring.

The incidence graph $I(G)$ of a graph $G(v.e)$ with vertex set V and edge set E is defined as the graph with vertex set $V(I(G))$ and edge set $E(I(G))$.

Definition 3: Chromatic number.

The chromatic number of a graph G is the least number of colors required to color the vertices of G , denoted by $\chi i(G)$in such a way that no two adjacent vertices share the same color (Skiena 1990, p. 210), i.e., the smallest value of k achievable to get k-coloring. The minimal colorings and chromatic numbers for a selection of graphs are shown above.

Definition 4: Chromatic number based on Incidence Colouring.

The incidence chromatic number, denoted by χi(G), of a graph G is the minimum number of colors needed to properly color the incidences of its incidence graph I(G), ensuring that no two nearby incidences share the same color. The incidence graph I(G) is formed by representing each vertex v ∈ V as an incidence (v, e) for every edge e ∈ E incident with v, with vertex set V(I(G)) and edge set E(I(G)). Two incidences (v, e) and (w, f) are considered "nearby" if v = w, e = f, or the edge vw = e or vw = f. The incidence chromatic number χi(G) represents the smallest value of k achievable for a k-coloring of the incidences in I(G) such that no two nearby incidences have the same color, resulting in a properly colored incidence graph.

Definition 5: Ladder Grpahs.

The ladder graph family is a class of graphs characterized by a ladder-like structure, resembling the rungs of a ladder. Formally, a ladder graph L_n is defined as an undirected graph with 2n vertices and 3n - 2 edges, organized into two sets of n vertices each, denoted as V1 = {v1, v2, ..., vn} and V2 = {u1, u2, ..., un}, where vi ∈ V1 and ui ∈ V2 for 1 ≤ i ≤ n. The edges of the ladder graph are arranged as follows:

For 1 ≤ i ≤ n-1, there is an edge between vi and ui.

For 1 ≤ i ≤ n, there is an edge between vi and vi+1.

For 1 ≤ i ≤ n, there is an edge between ui and ui+1.

The ladder graph L_n can be represented as L_n = (V, E), where V = V1 ∪ V2 represents the set of vertices, and E represents the set of edges.

Mathematically, the ladder graph L_n can be defined as follows:

L_n = (V1 ∪ V2, {(vi, ui) | 1 ≤ i ≤ n-1} ∪ {(vi, vi+1) | 1 ≤ i ≤ n-1} ∪ {(ui, ui+1) | 1 ≤ i ≤ n-1})

In this definition, the ladder graph L_n is represented as the union of two sets of vertices, V1 and V2, with specific edge connections between these vertices, creating the ladder-like structure. The ladder graph family exhibits interesting properties and has been widely studied in graph theory due to its simplicity and rich connectivity patterns.

3. RESULTS AND DISCUSSION

Theorem

Chromatic number based on incidence coloring of the ladder graph is 6 where n>4

First, we must consider the structure of the ladder graphs. When we consider a ladder graph with order mote than 4. It has,

1. Four vertices with degree two
2. (n-2)*2 vertices with degree three

Whenever we consider the four vertices with degree two, they have 2sides to color. While other (n-2)*2 vertices have three sides to color.

First, let us consider the as follows

For degree two vertices;

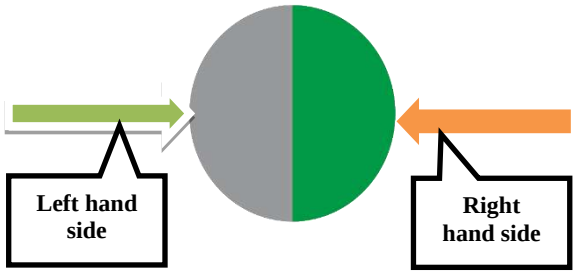

Figure 1: Vertex with degree 2

For the vertices with degree three in the top line

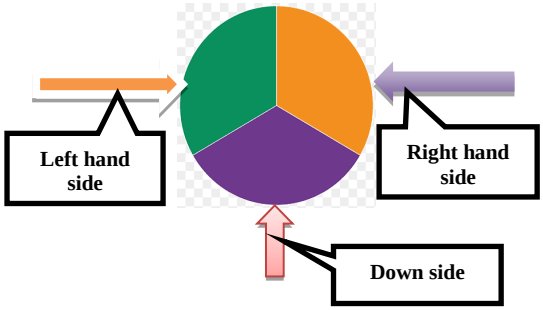

Figure 2: Vertex with degree 3 at top raw

For the vertices with degree three in the bottom line

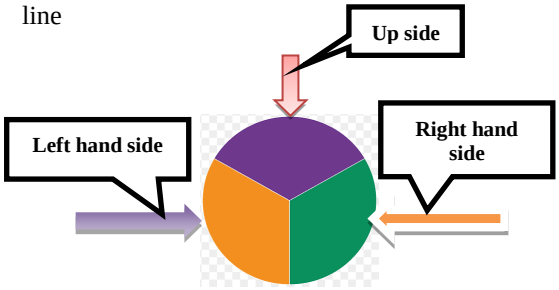

Figure 3: Vertex with degree 3 at bottom raw

Proof:

Proof using combinatorial methods

Let us start coloring with the left hand side of the left above degree two vertex. Give it color number one. As All down sides of the degree three vertices in the top row are not adjacent to each other and not adjacent to the left hand side of the left above degree two vertex and also to the right hand side of the right above degree two vertex we can give the taken color number one for all them.

After we color them all,

We can follow the same procedure for the bottom line. That is,

Start coloring with the left hand side of the left below degree two vertex. Give it color number two. As All up sides of the degree three vertices in the bottom row are not adjacent to each other and not adjacent to the left hand side of the left below degree two vertex and also to the right hand side of the right below degree two vertex we can give the taken color number two for all them.

Then,

Start coloring with the right-hand side of the left above degree two vertex. Give it color number three. Then follow the zig-zag pattern to color the left-hand sides of degree three vertices and reach the right-hand side.

For example :

Right-hand side of the left above degree two vertex --- left hand side of the degree three vertex at the bottom line in the next step --- left hand side of the degree three vertex at the top line in the next step --- left hand side of the degree three vertex at the bottom line in the next step --- left hand side of the degree three vertex at the top line in the next step --- --- left hand

side of the degree three vertex at the bottom line in the next step --- … --- right side

Here;

We have two cases'

1. For an odd ladder graph, we would stop at the right-hand side of the right below degree two vertex.
2. For an even ladder graph, we would stop at the right-hand side of the right above degree two vertex.

We can follow the same procedure for the bottom line. That is,

Start coloring with the right-hand side of the left below degree two vertex. Give it color number four. Then follow the zig-zag pattern to color the left-hand sides of degree three vertices and reach the right-hand side.

For example :

Right-hand side of the left below degree two vertex --- left hand side of the degree three vertex at the top line in the next step --- left hand side of the degree three vertex at the bottom line in the next step --- left hand side of the degree three vertex at the top line in the next step --- --- left hand side of the degree three vertex at the bottom line in the next step --- … --- right side

Here;

We have two cases'

1. For an odd ladder graph, we would stop at the right-hand side of the right above degree two vertex.
2. For an even ladder graph, we would stop at the right-hand side of the right below degree two vertex.

Then we should follow the same zig-zag coloring, method to color the remaining sides. That is,

Start coloring with the right-hand side of the degree three vertex at the top line in the second step. Give it color number five. Then follow the zig-zag pattern to color the left-hand sides of degree three vertices and reach the right-hand side.

For example:

Right hand side of the degree three vertex at the top line in the second step --- right hand side of the degree three vertex at the bottom line in the next step --- right hand side of the degree three vertex at the top line in the next step --- right hand side of the degree three vertex at the bottom line in the next step --- right hand side of the degree three vertex at the top line in the next step --- --- right hand side of the degree three vertex at the bottom line in the next step --- … --- right side

Here;

We have two cases'

1. For an odd ladder graph, we would stop at the right-hand side of the last degree three vertex at top line.
2. For an even ladder graph, we would stop at the right-hand side of the last degree three vertex at bottom line.

Then

Start coloring with the right-hand side of the degree three vertex at the bottom line in the second step. Give it color number six. Then follow the zig-zag pattern to color the left-hand sides of degree three vertices and reach the right-hand side.

For example:

Right hand side of the degree three vertex at the bottom line in the second step --- right hand side of the degree three vertex at the top line in the next step --- right hand side of the degree three vertex at the bottom line in the next step --- right hand side of the degree three vertex at the top line in the next step --- --- right hand side of the degree three vertex at the bottom line in the next step --- … --- right side

Here;

We have two cases'

1. For an odd ladder graph, we would stop at the right-hand side of the last degree three vertex at bottom line.
2. For an even ladder graph, we would stop at the right-hand side of the last degree three vertex at top line.

In that way we can color the any kind of ladder graph of order more than four with 6 colors. Therefore, the Chromatic number based on incidence coloring of the ladder graph is 6 where n>4.

Alternative proof:

Proof:

Consider a ladder graph with order n, where n > 4. The ladder graph consists of two rows of vertices connected by vertical edges and rungs. We will show that the graph can be colored with 6 colors using an incidence coloring approach.

Let's label the vertices of the ladder graph as follows:

Top row vertices: v_1, v_2, v_3, ..., v_(n-1), v_n

Bottom row vertices: u_1, u_2, u_3, ..., u_(n-1), u_n

First, we observe the degrees of the vertices in the ladder graph:

The four corner vertices (v_1, v_n, u_1, u_n) have degree 2.

The remaining (n-2) vertices on each row (v_2, v_3, ..., v_(n-1) and u_2, u_3, ..., u_(n-1)) have degree 3.

To perform the incidence coloring, we will assign colors to the sides of the ladder graph. We will use the numbers 1 to 6 to represent the colors.

Step 1: Coloring the degree two vertices

We start by coloring the sides adjacent to the degree two vertices. Without loss of generality, let's focus on the top row degree two vertices (v_1 and v_n).

We color the left side of v_1 with color 1. Then, since the down sides of the degree three vertices in the top row are not adjacent to each other or to v_1 or v_n, we can assign color 1 to all those sides as well.

Next, we color the right side of v_n with color 3. Using a zig-zag pattern, we color the left sides of the degree three vertices in the top row, starting from v_n and moving towards v_1. The color used for these sides will be 3. We continue this zig-zag pattern until we reach the right side of v_1.

Similarly, we can follow the same procedure for the bottom row degree two vertices (u_1 and u_n) and color their adjacent sides with colors 2 and 4, respectively.

Step 2: Coloring the remaining sides

After coloring the sides adjacent to the degree two vertices, we move on to coloring the remaining sides of the ladder graph.

Starting from the right side of the top row, adjacent to v_n, we color it with color 5. Using a zig-zag pattern, we continue coloring the left sides of the degree three vertices in the top row with color 5 until we reach the right side of the last degree three vertex at the top row.

Next, starting from the right side of the bottom row, adjacent to u_n, we color it with color 6. Again, using a zig-zag pattern, we continue

coloring the left sides of the degree three vertices in the bottom row with color 6 until we reach the right side of the last degree three vertex at the bottom row.

At this point, all sides of the ladder graph have been assigned colors, and we have used 6 colors in total.

It is important to note that the zig-zag patterns ensure that adjacent sides do not receive the same color throughout the coloring process. This guarantees a valid incidence coloring of the ladder graph.

Therefore, we have shown that the chromatic number based on incidence coloring of a ladder graph with order n, where n > 4, is 6.

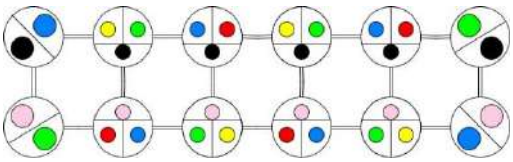

Figure 4: Incidence coloring for L_6

4. CONCLUSION

In this paper, we conducted a comprehensive study on incidence coloring for ladder graphs a captivating class of graphs resembling the rungs of a ladder. Incidence coloring extends traditional graph coloring by assigning colors to incidences with constraints on nearby incidences. Through combinatorial methods, we proved that the chromatic number based on incidence coloring for ladder graphs of order greater than four is 6. This efficient coloring approach ensures no two adjacent incidences share the same color, contributing to conflict avoidance in communication networks and resource allocation. Our findings advance incidence coloring and provide valuable insights into the properties of ladder graphs, opening avenues for future research in graph theory applications. The practical implications of this work have the potential to impact diverse fields, empowering the design and optimization of real-world systems.

REFERENCES

D. J. A. Welsh, M. B. Powell. 1967. "An upper bound for the chromatic number of a graph and its application to timetabling problems." *The Computer Journal, Volume 10* 85–86.

Goloshchapova, Nataliia. 2022. "Dynamical and variational properties of the NLS-δs′ equation on the star graph." *Journal of Differential Equations* pp. 1-44.

Guiduli, B. 1997. "On incidence coloring and star arboricity of graphs." *Discrete Math* . 1–.

Li, X. K. Liu and Y. 2004. "Algorithm for graph incidence coloring base on hybrid genetic algorithm." *Chinese J. Engrg. Math* 1, 41–47.

Sopena, Eric. 1997. "The Chromatic Number of Oriented Graphs." *Journal of Graph Theory* 191 - 205.

Quadratic Differentials Associated to Jacobi And Lemniscate Elliptic Functions

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ABSTRACT

A quadratic differential refers to a meromorphic differential form of degree two defined on a Riemann surface, and they play a significant role in visualizing geometric aspects of meromorphic functions. On a domain $D \subseteq \mathbb{C}$ *a quadratic differential has the form* $Q(z)dz^2$*, where* $Q : D \to \overline{\mathbb{C}}$ *is meromorphic. Quadratic differentials are invariant under conformal mappings between Riemann surfaces. In particular, given a holomorphic function* $f : D' \to D$ *this conformally transformed to a quadratic differential on* D' *by the rule* $Q(z)dz^2 = Q\big(f(w)\big)\big(f'(w)\big)^2 dw^2$*. The condition* $Q(z)dz^2 > 0$ *defines a field of infinitesimal line elements on the surface, with singularities at the zeros and poles of the differential. The integral curves of this field are called the trajectories of the differential, and they provide insights into the zeros and poles of the associated meromorphic function. This study focuses on examining the trajectory structure of Jacobi elliptic functions within their respective fundamental rectangles, employing Python programming for visualization. As it is well-known, when the parameter takes values on the imaginary axis, Jacobi elliptic functions reduce to Lemniscate elliptic functions while maintaining a single simple zero and a simple pole within the fundamental parallelogram. This allows for the extension of our results to Lemniscate elliptic functions with almost no modifications.*

Keywords **- Jacobi Elliptic Functions, Lemniscate Elliptic Functions, Quadratic Differentials.**

1. INTRODUCTION

Complex analysis provides variety of powerful tools for studying complex-valued functions of complex variables, and one such instrument is quadratic differentials.

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Quadratic differentials play a significant role in visualizing geometric aspects of complex functions. A quadratic differential refers to a meromorphic differential form of degree two defined on a Riemann surface. On a domain $D \subseteq \mathbb{C}$ a quadratic differential has the form $Q(z)dz^2$, where Q is meromorphic function on D, and provided a holomorphic function $f : D' \to D$ this conformally transformed to a quadratic differential on D' according to the rule,

$$Q(z)dz^2 = Q\big(f(w)\big)\big(f'(w)\big)^2 dw^2.$$

Geometrically, a quadratic differential induces a field of trajectories on its domain whose behavior provides insights into the zeros and poles of the associated meromorphic function. Also, according to the location and order of the zeros/poles, the quadratic differential partition the domain into a collection of simple configurations.

The other ingredient of our study is fundamental concept in complex analysis: doubly periodic functions, which are also known as elliptic functions. There has been extensive research focused on doubly periodic functions, and they have garnered significant attention due to their wide-ranging applications in various mathematical and scientific disciplines. An elliptic function f on the complex plane is a meromorphic function satisfies the condition that,

$$f(z) = f(z + \omega_1) = f(z + \omega_2)$$

$$\forall z \in \mathbb{C}$$

where ω_1, ω_2 are two $\mathbb{R}$-linearly independent complex numbers known as the periods of f. The parallelogram whose vertices are at $0, \omega_1, \omega_2$ and $\omega_1 + \omega_2$ is considered a fundamental period parallelogram if ω_1 and ω_2 have been chosen as the minimal periods, i.e., no other ω lies within the parallelogram (including the boundaries but excluding the vertices), satisfying the condition

$$f(z) = f(z + \omega) \ \forall z \in \mathbb{C}.$$

Because of the doubly periodic nature, an elliptic function repeats its values on the fundamental parallelogram. In other words, its domain can be considered to be a torus. Depending on the type of singularities within the fundamental parallelogram there are several types of elliptic functions, and some of them, including, Jacobi elliptic functions, Lemniscate elliptic functions, Weierstrass $\mathcal{P}$-function, and Dixon elliptic functions have been extensively studied.

The Jacobi elliptic functions are a set of twelve functions denoted by $pq(u, m)$, where p and q can be any of the letters c, s, n, d and u is the argument, and m is known as the parameter (both of which can be complex). While trigonometric functions are defined in terms of a circle, Jacobi's elliptic functions are a generalization that applies to ellipses. In particular

$$\mathrm{sn}(u, 0) = \sin u, \mathrm{cn}(u, 0) = \cos u\,,$$
$$\mathrm{dn}(u, 0) = 1.$$

The fundamental parallelogram of a Jacobi elliptic function is a rectangle with a simple pole at one corner (denoted as p) and a simple zero at the opposite corner (denoted as q). When the parameter m is imaginary, Jacobi elliptic functions reduce to Lemniscate elliptic functions. In this

scenario, the characteristics of the functions change, but they still maintain a single simple zero and a pole within the fundamental parallelogram. Although several types of elliptic functions have been comprehensively investigated, there has been a notable absence of studies on the quadratic differentials of elliptic functions, except for research on the Weierstrass $\mathcal{P}$-function. In this study, we focus on studying trajectory structure of Jacobi and Lemniscate elliptic functions within their fundamental rectangles.

2. MATERIALS AND METHODS

In this study, we utilize the following definitions and theorems to calculate and visualize the geometric representation of quadratic differentials (trajectories) through the implementation of Python programming.

Definition I (Arc of a Trajectory)

Let $\gamma \subset D$ be an open smooth arc or smooth Jordan curve and let $dz \neq 0$ be the tangent vector to γ at $z \in \gamma$. Then the arc γ is called an arc of trajectory of $Q(z)dz^2$ if $Q(z)dz^2 > 0$ for all $z \in \gamma$. The arc γ is called an orthonormal trajectory of $Q(z)dz^2$ if $Q(z)dz^2 < 0$ for all $z \in \gamma$.

Definition II

If at least one of the endpoints of a trajectory γ is a finite critical point of $Q(z)dz^2$, then γ is called critical trajectory.

Let γ be an arc of trajectory. As on γ, $Q(z)dz^2 > 0$ and $dz \neq 0$ then we have, $arg(Q(z)) + 2arg(dz) = 0\ (mod\ 2\pi)$.

Let z_0 be a finite critical point of order n ($n > 0$ for a zero, $n = -1$ for a simple pole) and then the following properties hold.

- There exist $n + 2$ trajectories with limiting end points at z_0 and limiting tangential directions there spaced at equal angles equal to $2\pi/(n + 2)$.
- Let the point z_0 be a pole of order n ($n > 2$). If a trajectory has a limiting end point at z_0 it tends to z_0 in one of $n - 2$ directions and these limiting directions are equally spaced at angles of $2\pi/(n - 2)$.
- There is a neighborhood of z_0, every trajectory trough a point $z \in u$ is either in both directions tends to z_0 and in the other direction leaves u.

Let $\bar{\varphi}$ denote the closure of set of all points of critical trajectories of $Q(z)dz^2$. Then the set $C\backslash\bar{\varphi}$ consists of finite number of circle, ring, strip, and end domains. The collection of all these domains together with so-called density domains constitute the so-called domain configuration of $Q(z)dz^2$.

3. RESULTS

Intuitively, dz represents an infinitesimally small line element of at the point z whose angle with the positive real axis is given by the formula $\arg(dz) = -\frac{1}{2}\arg\big(Q(z)\big)\ mod(\pi)$. To investigate the trajectory behavior of a quadratic differential, we calculate the argument of dz at each point of the domain. By using a Python implementation, we obtained images for elementary quadratic differentials.

Images for elementary quadratic differentials near the simple zero and simple pole are as follows:

Figure 1. Elementary Quadratic Differential near the Simple Zero.

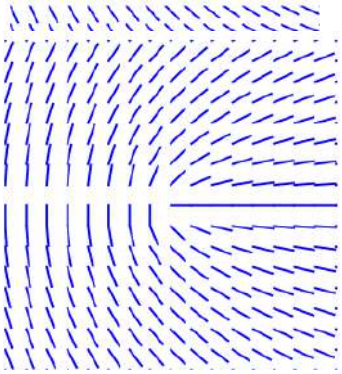

Figure 2. Elementary Quadratic Differential near the Simple Pole.

These images provide visual representations of the behavior of quadratic differentials near these specific points. Using the above-mentioned definitions theorems and Python implementation, we have plotted the orthogonal and critical trajectories near the simple zero and simple pole as follows:

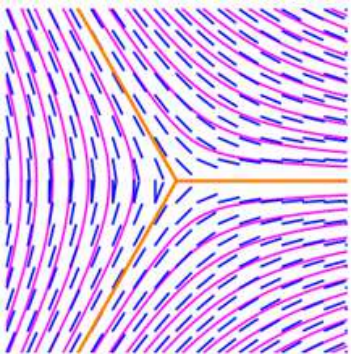

Figure 3. Orthogonal Trajectories and Critical Trajectories near the Simple Zero.

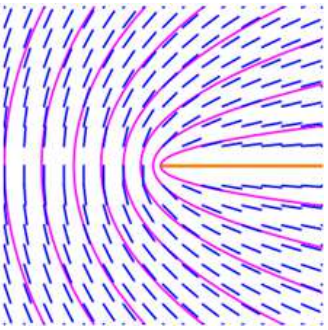

Figure 4. Orthogonal Trajectories and Critical Trajectories near the Pole.

By extending the results, we can visualize the trajectory structure of quadratic differentials with higher order critical points. This will provide insights into the behavior of trajectories near these critical points. To accomplish this, we can use the same definition theorems and Python implementation. By considering quadratic differentials $Q(z)dz^2 = z^n dz^2$ with higher order critical points, we can plot the orthogonal and critical trajectories to gain a better understanding of their structure.

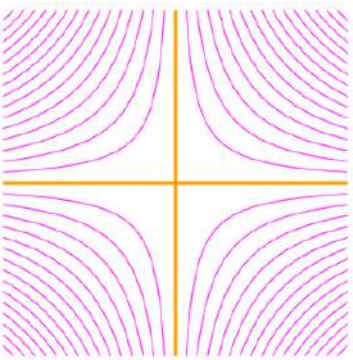

Figure 5. Orthogonal Trajectories and Critical Trajectories of z^2dz^2 (For n=2).

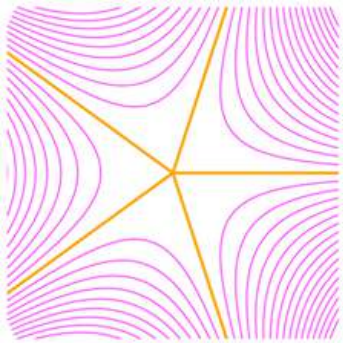

Figure 6. Orthogonal Trajectories and Critical Trajectories of z^3dz^2 (For n=3).

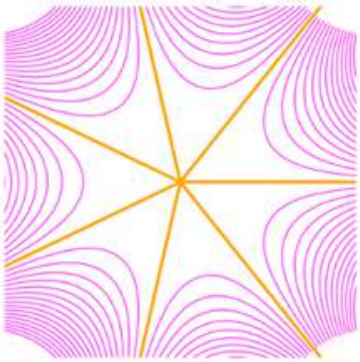

Figure 7. Orthogonal Trajectories and Critical Trajectories of z^4dz^2 (For n=4).

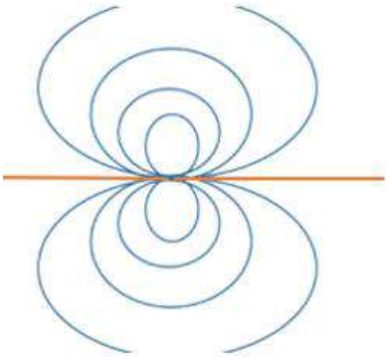

Figure 8. Orthogonal Trajectories and Critical Trajectories of $\frac{1}{z^4}dz^2$ (For n = - 4).

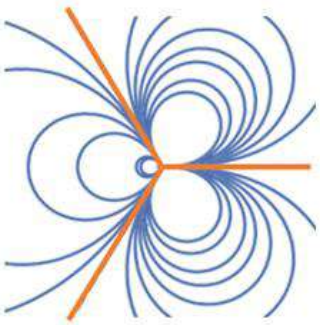

Figure 9. Orthogonal Trajectories and Critical Trajectories of $\frac{1}{z^5}dz^2$ (For n = - 5).

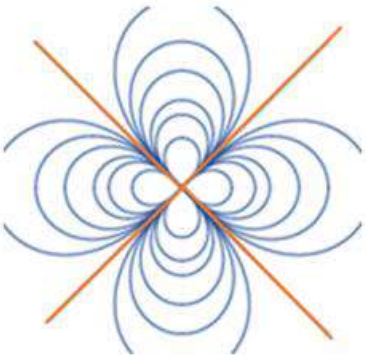

Figure 10. Orthogonal Trajectories and Critical Trajectories of $\frac{1}{z^6}dz^2$ (For n = - 6).

To visualize the trajectory structure of a quadratic differential at infinity, we can change the variable from the z-plane to the w-plane using a conformal mapping. This transformation helps us gain insight into the

behavior of trajectories as they approach infinity.

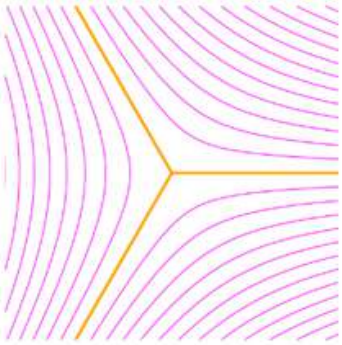

Figure 11. Orthogonal Trajectories and Critical Trajectories near the Simple Zero in z-plane

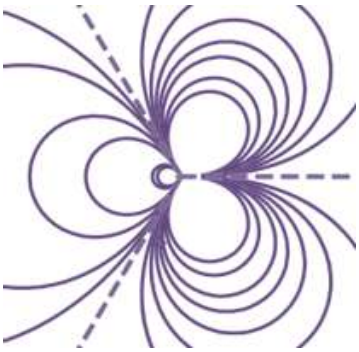

Figure 12. Orthogonal Trajectories and Critical Trajectories near the Simple Zero in w-plane

This plot showcases the trajectory structure near the infinity in the w-plane, obtained through the conformal mapping from the z-plane. It allows us to observe the behavior and patterns of trajectories as they approach infinity in the original quadratic differential. Next, we visualize the trajectory behavior of the quadratic differential in the fundamental parallelogram of Jacobi's sn function as follows.

In examining the orthogonal trajectory structure of the Jacobi elliptic function sn within its fundamental rectangle, we utilized the equation $\arg(dz) = -\frac{1}{2}\arg\big(Q(z)\big)\ mod(\pi)$ alongside specific values of the Jacobi sn function. This approach facilitated the determination of the phase angle $arg(dz)$ at each point within the fundamental rectangle, allowing the calculation of $arg(dz)$ for investigating the function's orthogonal trajectory configuration. Notably, at the poles and zeros of a function, the concept of $arg(dz)$ loses its significance due to undefined or zero values. These specific values of the Jacobi sn function serve a critical role in verifying the placement of poles and zeros within the fundamental rectangle and also in identifying the critical trajectory within this area as follows.

z	sn	
0	0	Simple Zero
$4K$	0	Simple Zero
iK	∞	Simple Pole
$4iK$	0	Simple Zero
$4K + iK$	∞	Simple Pole
$4K + 4iK$	0	Simple Zero

Table 1. specific values of the Jacobi sn function within the fundamental rectangle.

The calculated $arg\,(dz)$ values ($at\ z = 2K + iK,\ arg\,(dz) = \frac{\pi}{2}$ and $at\ z = 2K + 3iK,\ arg\,(dz) = \frac{\pi}{2}$) in each point of the fundamental rectangle provide substantive confirmation of the trajectories behavior of jacoby sn function within the fundamental rectangle.

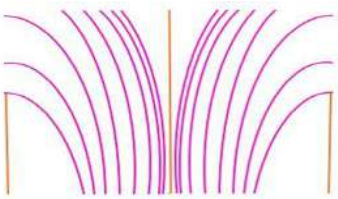

Figure 13. Orthogonal Trajectories and Critical Trajectories in the fundamental rectangle

4. CONCLUSION(S)

Here, we will focus on the Jacobi sn function and its trajectory behavior within the fundamental rectangle. Similarly, we can explore the other 11 Jacobi elliptic functions and their respective trajectory behaviors. Considering the trajectory behavior within the fundamental rectangle, these results can be extended and visualized to the other Jacobi elliptic functions in a mutatis-mutandis fashion. When the parameter m is imaginary, Jacobi elliptic functions reduce to Lemniscate elliptic functions. These new functions still exhibit a single simple zero and a pole inside the fundamental parallelogram. Consequently, our results can be extended to Lemniscate elliptic functions with minimal modifications required.

REFERENCES

Buser, P., & Semmler, K.D. (2017). Study Paths, Riemann Surfaces and Strebel Differentials. *Journal of Learning Analytics*, *4*(2), 62-75.

Don, M.D. (2020). *Geometric properties of special functions and related quadratic differentials* (Doctoral dissertation).

Jacobi, C. G. J. (1835). De functionibus duarum variabilium quadrupliciter periodicis, quibus theoria transcendentium Abelianarum innititur.

Jenkins, J.A. (2013). *Univalent functions and conformal mapping* (Vol. 18). Springer-Verlag.

Jenkins, J. A., & Spencer, D. C. (1951). Hyperelliptic trajectories. *Annals of Mathematics*, 4-35.

Schaeffer, A.C., Schiffer, M., & Spencer, D. C. (1949). The coefficient regions of schlicht functions.

Solynin, A.Y. (2020). Fingerprints, lemniscates, and quadratic differentials. *arXiv:2011.03855*.

A Review on Godunov Scheme Finite Volume Method to Solve One-Dimensional Two-Layer Shallow Water Equations

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ABSTRACT

The one-dimensional (1-D) two-layer shallow water equations (SWEs) are in the form of the non-linear partial differential equations system. This system of equations can be derived using the principles of conservation of mass and linear momentum. The two-layer shallow water system is conditionally hyperbolic because of the coupling terms between the layers. By solving this system of equations, we can predict the velocity and height of the wave, as well as where the water will flow and the area it will impact. In this study, the finite volume method with the Godunov scheme is used to numerically solve the 1-D two-layer SWEs. This method takes control volumes to resolve the system of equations and discrete them into a new equation. The domain can be divided into many cells, and each cell takes the average speed and height using linearization at the end of each cell, which is updated by the flux approach. Some results of numerical experiments are also demonstrated using MATLAB software for the existing parameters. This numerical simulation of the test examples' results can be used to predict the perturbation and velocity changes of the 1-D two-layer SWEs in the increasing time steps. We can conclude from the test experiments that, because of the wave spreading, interactions between the layers, and topography changes, the lower layer velocity changes faster than the upper layer.

Keywords — **Finite volume method, Godunov numerical scheme, Two-layer shallow water equations,**

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1. INTRODUCTION

The Shallow Water Equations (SWEs) are a system of hyperbolic partial differential equations (PDES) governing fluid flow in the oceans, coastal regions, estuaries, rivers, and channels. The SWEs describe a thin layer of fluid of constant density in hydrostatic balance where the horizontal scale of the flow (l) is greater than the layer depth (h), that is $\frac{h}{l} \ll 1$. These layers are bound from below by the bottom topography and from above by a free surface. Using this hypothesis, we can define SWEs to describe the propagation of waves.

The SWEs exhibit a rich variety of features because they have an infinite number of conservation laws, such as conservation of mass and linear momentum. SWEs are generally used for modeling environmental fluid dynamics when the field of the flow has one component that is insignificant with respect to other components.

The multi-layer SWE system is derived by depth-averaging the incompressible Navier-Stokes equations with hydrostatic assumptions within layers. The two-layer SWEs system is accepted as a numerical model not only for flows with different densities but also for the underwater landslides generated by tsunamis. (Jihwan Kim & Randall J. LeVeque)

This study will consider One-Dimensional (1-D) two-layer SWEs numerical solutions by the finite volume method with Godunov schemes. This scheme is a conservative numerical scheme found by S.K. Godunov in 1959, also referred to as the REA algorithm, known as Reconstruct, Evolve and, Average. These techniques are mostly used in FVM by approximating the solution as the sum of the piecewise function at each cell-grid.

The paper is organized as follows: We have provided an introduction to the two-layer SWEs, their applications in real-world environments, and the objective of this study. Then the governing equations and the numerical solutions to the two-layer SWEs using the finite volume method with Godunov schemes are presented in the methodology section. Similarly, in the results section, we have analyzed the numerical solutions of the derived equations by using MATLAB coding to get the numerical results and the graphical representations. Also, the study has been summarized in the conclusion section.

2. METHODOLOGY

In the two-layer shallow water equations system, the vertical velocity of the fluid (water) is assumed to be negligible and the horizontal velocity $u(x,t)$ is roughly constant throughout the channel cross section. This can be said to be true for small waves with a wave length greater than the depth. The depths of fluid and horizontal velocities of the upper and lower layers respectively, are given by $h_i(x,t)$ and $u_i(x,t)$, $i = 1,2$ are the variables for which we seek solutions.

2.1 The Governing Equations

The 1-D two-layer shallow water system of equations can be written as

$$\frac{\partial h_1}{\partial t} + \frac{\partial (h_1 u_1)}{\partial x} = 0 \qquad -----(1a)$$

$$\frac{\partial(h_1u_1)}{\partial t} + \frac{\partial}{\partial x}\left(h_1u_1^2 + \frac{1}{2}gh_1^2\right) = -gh_1\left[\frac{\partial(h_2)}{\partial x} - \frac{\partial(b)}{\partial x}\right] \quad -----(1b)$$

$$\frac{\partial h_2}{\partial t} + \frac{\partial(h_2u_2)}{\partial x} = 0 \quad -----(1c)$$

$$\frac{\partial(h_2u_2)}{\partial t} + \frac{\partial}{\partial x}\left(h_2u_2^2 + \frac{1}{2}gh_2^2\right) = -\rho_0 gh_2\frac{\partial(h_1)}{\partial x} - gh_2\frac{\partial(b)}{\partial x} \quad -----(1d)$$

Here, h_1 and u_1 represent the fluid depth and the fluid velocity of the upper layer and h_2 and u_2 correspond to the lower layer. Also g is the gravity constant $\rho_0 = \frac{\rho_1}{\rho_2}$, which is the ratio of the densities and $b(x)$ is the bottom topography of function of x, illustrated in Figure 01.

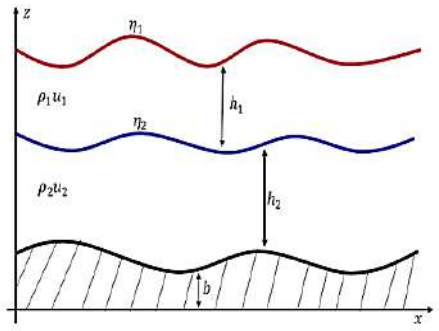


Figure 01: Two-layer shallow water in $x-t$ plane.

The constants ρ_1 and ρ_2 drop out of the conservation of mass equations for the upper layer and lower layer of equations (1a) and (1c), respectively, and the conservation of momentum equations for upper layer and lower layer of equations (1b) and (1d), respectively take the form of the gas dynamics equations (Jihwan Kim & Randall J. LeVeque).

By the momentum of two-layers being couples, the system contains non-conservative products. Using the initial and boundary conditions, a set of time-stepped numerical solutions can be calculated to predict the velocity and the height of the wave, as well as where the water will flow and the area impacted by the water.

Since the 1-D two-layer SWEs system depends only on the $x-$space and time-t variables so that we can numerically model it in the form:

$$\frac{\partial q(x,t)}{\partial t} + \frac{\partial\, f\big(q(x,t)\big)}{\partial x} = S(q)\ , \quad -----(2)$$

$$f\big(q(x,t)\big) = \begin{bmatrix} h_1u_1 \\ h_1u_1^2 + \frac{1}{2}gh_1^2 \\ h_2u_2 \\ h_2u_2^2 + \frac{1}{2}gh_2^2 \end{bmatrix}$$

$$S(q) = \begin{bmatrix} 0 \\ -gh_1\frac{\partial}{\partial x}[h_2 - b\,]^2_2 \\ 0 \\ -gh_2\frac{\partial}{\partial x}[\rho_0\, h_1 - b] \end{bmatrix}.$$

Since we need to expect to solve not only smooth but also shock waves, this source term $S(q)$ is difficult to handle, whose derivative is the delta function. So that the system in the quasi-linear form that can be written as

$$\frac{\partial q(x,t)}{\partial t} + A(q)\,\frac{\partial q}{\partial x} = \tilde{S}(q)\ . \quad -----(3)$$

Here, the Jacobian matrix $f'(q)$ is

$$A(q) = \begin{bmatrix} 0 & 1 & 0 & 0 \\ gh_1 - u_1^2 & 2u_1 & gh_1 & 0 \\ 0 & 0 & 0 & 1 \\ \rho_0 gh_2 & 0 & gh_{2-}u_2^2 & 2u_2 \end{bmatrix}$$

and

$$\tilde{S}(q) = \begin{bmatrix} 0 \\ -gh_1\left[\frac{\partial b}{\partial x}\right] \\ 0 \\ -gh_2\left[\frac{\partial b}{\partial x}\right] \end{bmatrix}.$$

2.2 Eigen structure

The explicit expression for the eigenvalues cannot be found for this matrix $A(q)$. Therefore, we find the approximation in order to analyze the given system.

Then, by (Mandli, 2013) , let the characteristic polynomial $f(\lambda)$ can be given as

$$f(\lambda) = [(\lambda - u_1)^2 - gh_1]\,[(\lambda - u_2)^2 - gh_2] = \rho_0 g^2 h_1 h_2 \,. \quad -----(4)$$

Now we can find that

$$f\left(\frac{u_1 + u_2}{2}\right) > 0\,, f\left(u_1 \pm \sqrt{gh_1}\right) < 0\,,$$

and

$$f\left(u_2 \pm \sqrt{gh_2}\right) > 0 \quad .$$

Thus, the hyperbolicity condition is

$$f\left(\frac{u_1 + u_2}{2}\right) = \left[\left(\left(\frac{u_1 + u_2}{2}\right) - u_1\right)^2 - gh_1\right].\left[\left(\left(\frac{u_1 + u_2}{2}\right) - u_2\right)^2 - gh_2\right] - \rho_0 g^2 h_1 h_2 \quad > 0\,. \quad -----(5)$$

Consider that the hyperbolicity condition depends on the value of $(u_1 - u_2)^2$ and when this value is small, the system remains hyperbolic. Also, if $|u_2 - u_1|$ and $(1 - \rho_0)$ are small, we can find the approximate expressions for the eigenvalues.

Therefore, using velocity difference expansion, real (external) and conditionally real (internal) eigenvalues are respectively given as

$$\lambda_{ext}^{\pm} = \frac{h_1 u_1 + h_2 u_2}{h_1 + h_2} \pm \sqrt{g(h_1 + h_2)} \quad -----(6a)$$

and

$$\lambda_{int}^{\pm} = \frac{h_1 u_2 + h_2 u_1}{h_1 + h_2} \pm \sqrt{g' \frac{h_1\, h_2}{(h_1 + h_2)}\left[1 - \frac{(u_1 - u_2)^2}{g'(h_1 + h_2)}\right]}.$$

$$----- (6b)$$

where $g' = (1 - \rho_0)g$ is the reduced gravity.

Then, assuming that we can accurately calculate the eigen-speeds λ_p, we can find the eigen-vectors by solving

$$\begin{bmatrix} 0 & 1 & 0 & 0 \\ gh_1 - u_1^2 & 2u_1 & gh_1 & 0 \\ 0 & 0 & 0 & 1 \\ \rho_0 gh_2 & 0 & gh_2 - u_2^2 & 2u_2 \end{bmatrix} \begin{bmatrix} 1 \\ \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{bmatrix} = \begin{bmatrix} \lambda_p \\ \alpha_1\lambda_p \\ \alpha_2\lambda_p \\ \alpha_3\lambda_p \end{bmatrix}$$

$$----- (7)$$

These equations imply that $\alpha_1 = \lambda_p$ and $\alpha_3 = \alpha_2\lambda_p$. So, we need to find the next unknown α_2 by the two equations 2nd and 4th in the system (7) simultaneously.

Solving each of the equations separately, we get

$$\alpha_{2,p} = \begin{cases} \dfrac{(\lambda_p - u_1)^2 - gh_1}{gh_1}, \\ \dfrac{\rho_0 gh_2}{(\lambda_p - u_2)^2 - gh_2}. \end{cases}$$

$$----- (8)$$

Where the subscript of p corresponds to the appropriate eigenvalue. We can use either form of the equation (8).

Hence, the final form of the eigen vectors is $[1, \lambda_p, \alpha_p, \alpha_p\lambda_p]^T$, here we have used one of the expressions of the equation (8) and dropped the subscript 2.

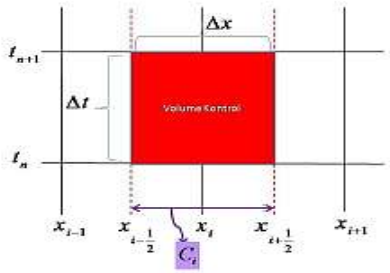
3. EXPERIMENTAL DESIGN

3.1 Finite Volume Method (FVM) with Godunov Scheme

The FVM resolves the PDEs through control volumes. It is discounted into a new equation by dividing the domain into many cells and taking the value of the average quantity approach in each cell.

Then these values are updated using an approach with flux through the interval at the end of each cell. (Arnasyita Yulianti Soelistya & Sumardi, Numerical solution of the two-layer shallow water equation using finite volume method, 2020).

Figure 02: The volume control of the SWEs



in the $x - t$ field.

The discretization of the x-space variable and the time-t variable is represented in Figure 02, taken $x \in [a, b]$ with $a, b \in \mathbb{R}$ and grid cells i given by $C_i = \left(x_{i-\frac{1}{2}}, x_{i+\frac{1}{2}}\right)$.

Consider the average value approach of q over the i^{th} interval at time t_n is given

by with the length of cell $\Delta x = x_{i+\frac{1}{2}} - x_{i-\frac{1}{2}}$,

$$Q_i^n \approx \frac{1}{\Delta x}\int_{x_{i-\frac{1}{2}}}^{x_{i+\frac{1}{2}}} q(x,t_n)\,dx \equiv \frac{1^2}{\Delta x}\int_{C_i} q(x,t_n)\,dx . \quad -----(9)$$

Integral to the x-space variable for the grid cell C_i from the conservation form equation (2) is given as

$$\int_{C_i}\frac{\partial q(x,t)}{\partial t}\,dx = -\int_{C_i}\frac{\partial f(q(x,t))}{\partial x}\,dx = f\left(q\left(x_{i-\frac{1}{2}},t\right)\right) - f\left(q\left(x_{i+\frac{1}{2}},t\right)\right) \quad -----(10)$$

Now integrate the equation (10) by the time variable from t_n and t_{n+1}

$$\int_{t_n}^{t_{n+1}}\left(\int_{C_i}\frac{\partial q(x,t)}{\partial t}\,dx\right)dt = \int_{t_n}^{t_{n+1}}\left(f\left(q\left(x_{i-\frac{1}{2}},t\right)\right) - f\left(q\left(x_{i+\frac{1}{2}},t\right)\right)\right)dt \quad -----(11)$$

Using the fundamental theorem of calculus for equation (11) we get

$$\int_{C_i} q(x,t_{n+1})\,dx - \int_{C_i} q(x,t_n)\,dx = \int_{t_n}^{t_{n+1}}\left(f\left(q\left(x_{i-\frac{1}{2}},t\right)\right) - f\left(q\left(x_{i+\frac{1}{2}},t\right)\right)\right)dt . \quad -----(12)$$

With the time step of length $\Delta t = t_{n+1} - t_n$, and Q_i^{n+1} the average value at time t_{n+1}, we can derive the equation by multiplying the equation (12) by $\frac{1}{\Delta x\,\Delta t}$, and based on the equation (9), we have

$$\frac{1}{\Delta t}\left(Q_i^{n+1} - Q_i^n\right) = \frac{1}{\Delta x\,\Delta t}\int_{t_n}^{t_{n+1}}\left(f\left(q\left(x_{i-\frac{1}{2}},t\right)\right) - f\left(q\left(x_{i+\frac{1}{2}},t\right)\right)\right)dt \quad ----(13)$$

Then the approximation to the average flux along the average cell of $x = x_{i\pm\frac{1}{2}}$ is denoted by $F_{i\pm\frac{1}{2}}^n$ and obtained from the value of $Q_i^{n+1^2}$ and Q_i^n is given as in equation (13), we can obtain

$$\frac{1}{\Delta t}\left(Q_i^{n+1} - Q_i^n\right) = \frac{1}{\Delta x}\left(F^n_{i-\frac{1}{2}} - F^n_{i+\frac{1}{2}}\right) \quad -----(14)$$

It can be written in the form of

$$Q_i^{n+1} = Q_i^n - \frac{\Delta t}{\Delta x}\left(F^n_{i+\frac{1}{2}} - F^n_{i-\frac{1}{2}}\right) \quad -----(15)$$

Then substitute the value of $F^n_{i-\frac{1}{2}}$ with the numerical flux $\mathcal{F}$, which based on the value of Q^n_{i-1} and Q^n_i as

$$F^n_{i-\frac{1}{2}} = \mathcal{F}\left(Q^n_{i-1}, Q^n_i\right).$$

So that the numerical form of the FVM of equation (15) is defined as

$$Q_i^{n+1} = Q_i^n - \frac{\Delta t}{\Delta x}[\mathcal{F}\left(Q_i^n, Q^n_{i+1}\right) - \mathcal{F}\left(Q^n_{i-1}, Q^n_i\right)] \quad ----(16)$$

To compute equation (2), we can implement the Godunov scheme. This scheme is used to calculate the half-index in discretion and simplifies the Riemann problem solution as a piecewise constant function defined in each grid cell.

Furthermore, (Arnasyita Yulianti Soelistya & Sumardi, Numerical solution of the two-layer shallow water equation using finite volume method, 2020) presented the integral of the conservation law with the source value of $S(q)$ to the volume of space control C_i and time step Δt.

So, the reduction of the FVM numerical method is obtained as

$$Q_i^{n+1} = Q_i^n - \frac{\Delta t}{\Delta x}\left[F^n_{i+\frac{1}{2}} - F^n_{i-\frac{1}{2}}\right] + \Delta t\,.\,\hat{S}(q)\ , \quad -----(17)$$

where

$$\hat{S}(q) = \frac{1}{\Delta x}\int_{t_n}^{t_{n+1}}\left(\int_{C_i} S\big(q(x,t)\big)\,dx\right)dt\,.$$

3.2 Riemann's problem solving by Roe's linearization:

The Riemann problem arises at the cell interface. In 1981, Roe invented the method that can be implemented to solve this problem. Roe's linearization must satisfy the condition of

$$\widehat{\mathrm{A}}_{\mathrm{i}-\frac{1}{2}}(\mathrm{Q_i} - \mathrm{Q_{i-1}}) = \mathrm{f(Q_i)} - \mathrm{f(Q_{i-1})} \quad -----(18)$$

The equation (17) applies to Euler's equation, which effectively calculates the function average $Q_{i-\frac{1}{2}}$.

Also, we can use this approach to solve the two-layer SWEs by selecting the vector parameter $z = \frac{q}{\sqrt{h_i'}}$ for $i = 1, 2$. So, the average Roe for the model of equations (1a) – (1d) gives

$$\overline{h}_1 = \frac{1}{2}[(h_{i-1})_1 + (h_i)_1\,],$$

$$\overline{h}_2 = \frac{1}{2}[(h_{i-1})_2 + (h_i)_2\,],$$

$$\hat{u}_1 = \frac{\sqrt{(h_i)_1}\;(u_i)_1 + \sqrt{(h_{i-1})_1}\,(u_{i-1})_1}{\sqrt{(h_i)_1 + \;(h_{i-1})_1}},$$

$$\hat{u}_2 = \frac{\sqrt{(h_i)_2}\;(u_i)_2 + \sqrt{(h_{i-1})_2}\,(u_{i-1})_2}{\sqrt{(h_i)_2 + \;(h_{i-1})_2}},$$

$$-\,-\,-\,-\,-\,(19)$$

4. RESULTS AND DISCUSSION

4.1. Test I: Flat bed and free boundary and initial conditions

The numerical results for the 1-D SWEs system have analyzed by the MATLAB software. At first, test this system with a flat bed $b(x) = 0$, free boundary, and periodic initial conditions:

$$h_1(x, 0) = 1 + 0.2\,sin\left(\frac{2\pi x}{L}\right)$$

and

$$h_2(x, 0) = 0.8 + 0.1\,sin\left(\frac{4\pi x}{L}\right)$$

gives the visual representation in Figure 03 for the time step $\Delta t = 0.4$, and total time $T = 2$.

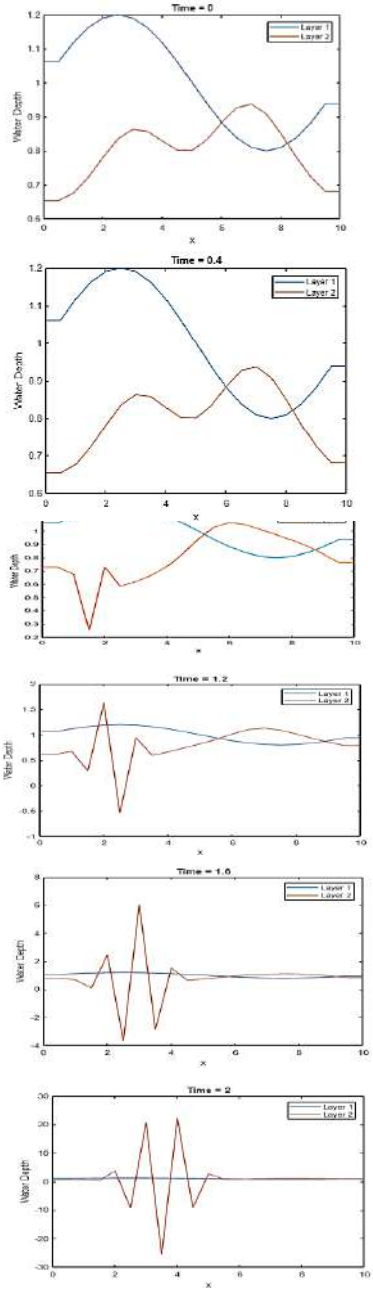


Figure 03: Simulation of wave perturbation of Test 1

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4.2 Test 2: Non-flat bed and free boundary and initial conditions

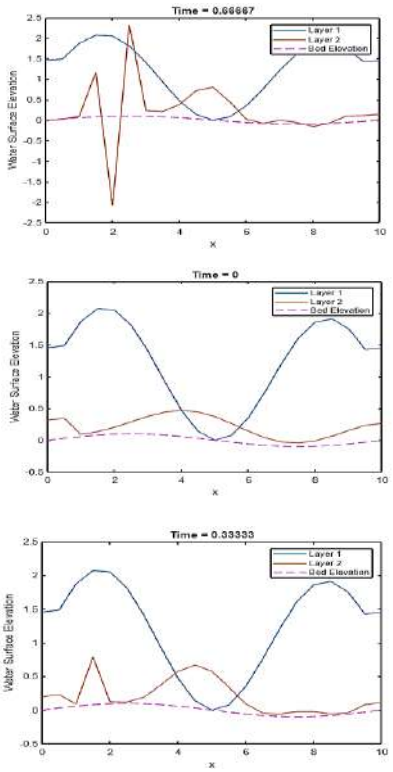
The simulation of the non-flat topography is taken as a function $b(x) = 0.1 * \sin(2\pi x/l)$, free boundary and periodic initial conditions:

$$h_1(x,0) = 1 + sin\left(\frac{3\pi x}{L}\right)$$

and

$$h_2(x,0) = 0.15 + 0.1sin\left(\frac{\pi x}{L}\right)$$

gives the visual representation in Figure 04 for the time step $\Delta t = 1/3$.



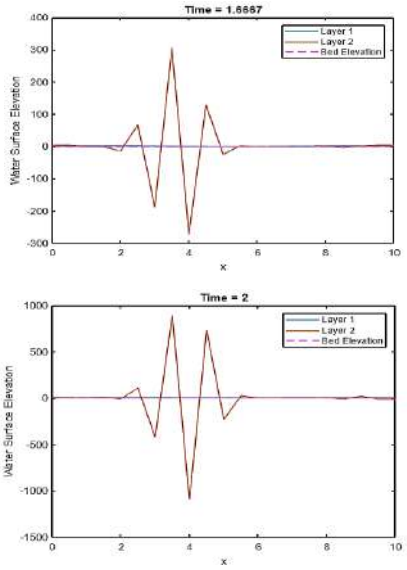


Figure 04: Simulation of wave perturbation of Test 2.

These results show that the topography of the shallow water system influences the wave propagation and the velocity changes with increasing time levels. The results show smooth variations when we choose the parameters properly.

5. CONCLUSION

In this research study, we have analyzed how the numerical solutions of the 1-D two-layer shallow water equations were evaluated with a set of fixed boundary conditions and initial conditions. The main focus of this research was on numerical solutions utilizing the finite volume method with Godunov schemes.

The numerical simulation of the test example results in the perturbation and velocity changes of the 1-D two-layer SWEs in the increasing time steps. Because of the wave spreading and interactions between the layers and the topography, the

lower layer velocity changes faster than the upper layer.

Furthermore, the study also used numerical simulations in MATLAB codes with different initial and boundary conditions to find the solutions, which are represented graphically.

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REFERENCES

Arnasyita Yulianti Soelistya, & Sumardi. (2020). Numerical solution of the two-layer shallow water equation using finite volume method. *JP Journal of Heat and Mass Transfer ·*, 57-71.

Arnasyita Yulianti Soelistya, & Sumardi. (2020). Numerical solution of the two-layer shallow water equation using finite volume method. *jP Journal of Heat and Mass Transfer*, 57-71.

Fayassal Benkhaldom, & Mohamed Seaid. (2010). A simple finite volume method for the shallow water equations. *Journal of Computational and Applied Mathematics*, 58-72.

Jaime Miguel Fe Marqu_es Introduction to the Finite Volumes Method.Application to the Shallow Water Equations. (n.d.).

Jihwan Kim, & Randall J. LeVeque. (n.d.). Two-layer shallow water system and its applications. *Symposia in Applied Mathematics.*

Mandli, K. T. (2013). A numerical method for the two-layer shallow water equations with dry state. *Ocean Modeling*, 80-91.

Roe, P. L. (1981). Approximate Riemann solvers, parameter vectors and difference schemes. *J. Comput. Phys.*, 357-372.

Performance Catalysts: A Comprehensive Study of Factors Influencing Research & Development Team's Performance

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ABSTRACT

Research and development organizations contribute towards the long-term growth of nations and even human civilization. This is where innovations are born and successfully scaled up to industry. R&D team performance directly influences the R&D organization's performance. R&D teams are made of employees with a wide variety of expertise and unique knowledge and experiences compared to well-established process teams in the industry. Studies carried out in Sri Lanka for the R&D team's performances are unavailable compared to other countries. In this research, elements that affect the R&D team's performance are studied in a local research organization. According to the literature, four independent variables are discovered: trust, knowledge sharing, group cohesiveness, and team efficacy, and the influence on the dependent variable R&D team performance is measured using a conceptual method. For study design, Saunder's research onion is used. Google questionnaire was used to gather data. Then Microsoft Excel and SPSS tools were used to analyze the data. To comprehend the characteristics of the acquired dataset, descriptive statistics were used. Furthermore, Pearson's correlation coefficient was employed to determine the relationship between variables. Correlation results indicated all predictors tested are linearly linked with the dependent variable. Three independent variables have shown a

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high positive correlation except for team efficacy which has shown a low positive correlation. Linear regression tests accept hypotheses developed based on the positive relationship between each independent variable and dependent variable. All independent variables showed high impact meanwhile team efficacy was at moderate impact. Multiple regression analyses showed the combined impact of independent variables was significant in combination and team efficacy wasn't significant in the combination. Then, results were used to suggest recommendations to improve R&D team performance.

Keywords **– R&D Team Performance, Group Cohesiveness, Trust, Knowledge Sharing, Team Efficacy**

1. INTRODUCTION

Generally, R&D organizations develop products or processes and transfer the technology to clients or governments so that they can commercialize it successfully. (Stoker et al., 2010) Investment in R&D contributes toward the economic growth of a nation. Many theoretical models (Grossman, G. and Helpman, 1991) (Aghion & Howitt, 1992) emphasize how R&D serves as a growth engine. In an R&D organization, commercialization from R&D to industrial application requires a long process chain (Figure 1).

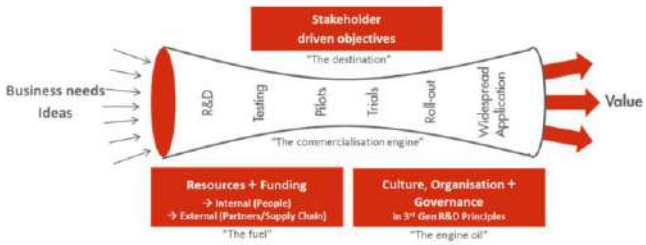

Figure 1. Commercialization of R&D products (Crispin Keanie, n.d.)

In an R&D organization research conducted by scientists results in new products, for which industrial engineers develop production processes, and for which marketing strategies are then established, responding to its rising demand in the market (Pessoa, 2007).

Therefore, understanding and improving the performance of a research and development organization is important. There are iinternal factors such as innovation culture, strategy, knowledge and competence, organizational structure, R&D activities and input, financial performance, and R&D team performance that contribute to R&D organization performance. (Dziallas & Blind, 2019)

R&D team performance is a critical fact among them. It is based on effective multidisciplinary teamwork across all functions of the organization. (Sawhney et al., 2000) So, it is challenging to manage R&D teams to get their best performance. (Tomkovick & Miller, 2000) Many types of research are conducted globally to understand these factors that affect the R&D team's performance. Locally, there are no such studies conducted in R&D

organizations. The target of this study is to identify and evaluate the contribution of factors that affect the research and development team performance of the ABC Institute.

ABC Institute is a research and development institute that has been involved in a wide variety of R&D work. Their research is primarily focused on six areas including energy, agriculture, textiles, polymers, and minerals. The organization has a structure with mainly science & engineering departments, management, and supportive services.

When a project starts in ABC organization, several departments need to work simultaneously to support the project. Mainly science team carries out the initial phase and the engineering team is involved in scaling up the process or providing any engineering support needed. During this time analytical department, procurement department, finance department, and technical service department provide support to the project.

The technology transfer department and business development departments direct the project to get the desired outcome according to client requirements and organizations' interests.

Therefore, the performance of the R&D team which consists of scientists, group leaders, senior scientists, and engineers is important to deliver the desired results. Also, optimal use of physical and human resources outside the project team is expected.

In this study, literature was studied to identify different variables that affect the R&D team's performance. Then, the effect of a selected set of variables against R&D team performance was tested in ABC organization and strategic suggestions were given to improve R&D team performance.

1.1 R&D Team Development Stages

There are different stages in team building. A strong model developed by American organizational psychologist Bruce Tuckman and still in use today was first presented in 1965. He proposed the "forming-storming-norming-performing" model (Figure 2), which is a map that includes four stages of any group's evolution based on his observations of group behavior in various contexts (Tuckman, 1965).

Constructs are present during the team buildup stages. building requires many shared mental model, and knowledge exchange. From these constructs, only a

Figure 2. Stages of the Group Development Model (Delice et al., 2019)

factors as shown below. During different stages of team building, these factors will affect the performance of the team significantly. The below figure shows how prominent these factors are in different stages of the team development life cycle (Delice et al., 2019).

According to Figure 3 main constructs related to the team life cycle are openness, trust, cohesion, team viability, collaboration, communication, conflict, cognition, transactive memory system, few are selected which are highly related to the R&D team performance.

1.2 Related Work: Studies about Factors That Influence R&D Team Performance

According to existing literature, various factors influencing R&D team performance have been assessed by researchers. Huang's (2009) study revealed connections between R&D team performance and trust, transactive memory system (TMS), knowledge sharing, network ties, collective mind, and group cohesiveness. His

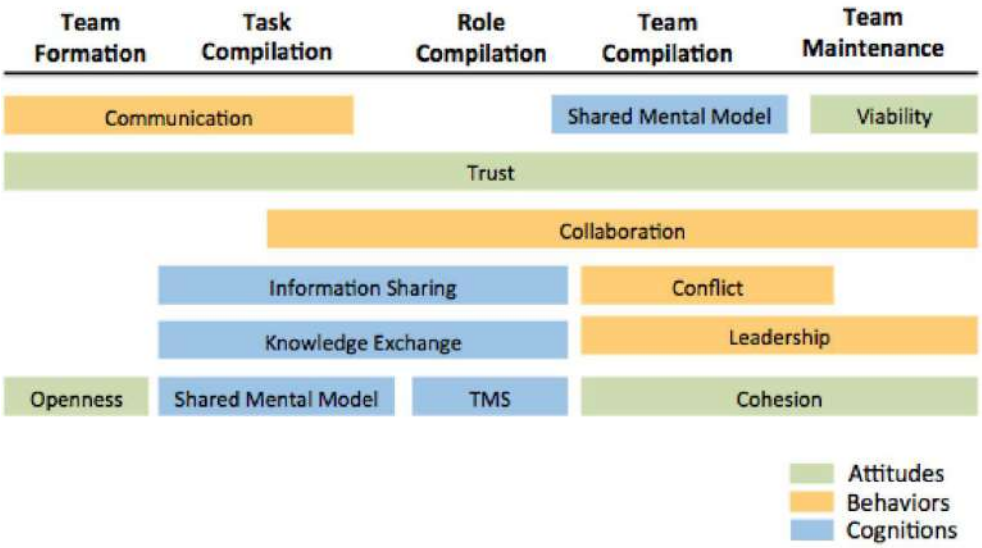

Figure 3. Model illustrating constructs present during team developmental stages (Delice et al., 2019)

study indicates that the Transactive Memory System (TMS) positively and significantly mediates the relationship between trust and knowledge sharing. Additionally, group cohesiveness exerts a positive and significant effect on team performance. Additionally, Jo & Park (2019) highlighted the impact of network, trust, shared vision, knowledge sharing, and team efficacy on R&D team performance. This study mentioned that in R&D teams, the network serves as social capital, encouraging shared vision and trust. This dynamic leads to the formation of common values and goals. Shared vision and trust drive knowledge sharing among team members, promoting effective communication and cooperation. Additionally, trust influences team efficacy and organizational development. Knowledge sharing positively impacts team efficacy and overall team performance. Finally, team efficacy contributes to improved team performance by encouraging cooperative behavior and joint decision-making.

Furthermore, Dailey (1978) investigated the correlation between task certainty, team interdependence, team cohesiveness, team size, team coordination, and R&D team performance. The findings of this study showed the connection between coordination in R&D teams and their performance. Additionally, all variables, except team size, were identified as factors influencing team coordination or performance.

In this research, the researcher investigates the influence of trust, knowledge sharing, group cohesiveness, and team efficacy on R&D team performance. These variables were selected due to their frequent consideration in the existing literature, reflecting their significance in impacting R&D team performance.

1.3 Trust vs the performance of R&D teams

Trust in teams has been defined by researchers in different ways. Many scholars researching trust in teams have collectively defined trust as a psychological state that is influenced by the complex interrelations between expectations, intentions, and dispositions. (Ashley Fulmer & Gelfand, 2012). It would appear that understanding exchanges requires trust. (Cropanzano & Mitchell, 2005). Research conducted throughout decades has unequivocally shown that trust in teams is vital for the effective functioning of work relationships (Costa et al., 2018).

Literature has demonstrated that trust improves team performance (Braun et al., 2013). Dirks (1999) suggested that team, trust helps team members to communicate more clearly, collaborate more effectively, and share resources in ways that improve team performance. This is explained by researchers as follows. trust helps team members suspend uncertainty and vulnerability toward their fellow teammates, thereby allowing them to interact as a team (De Jong & Elfring, 2010). Joshi et al. (2009) mentioned lack of trust causes team members to lose sight of the group's objectives in favor of their interests. Meta-analysis also supported the positive relationship between trust and team performance (Morrissette & Kisamore, 2020).

1.4 Knowledge sharing vs the performance of R&D teams

Research and development teams' participants come from multidisciplinary and a variety of expertise backgrounds. Project managers should coordinate the efforts of scientists and engineers from many disciplines to complete initiatives. (Katz & Allen, 1985). The performance of the Research and development team is impacted by task conflict in these interdisciplinary teams. The primary source of task conflict is operational background diversity, which also has a huge chance of hindering performance. (Pelled et al., 1999). Literature indicates different academic backgrounds lead to a lot of task-related confusion inside the research and development teams (Jehn et al. 1997). Knowledge sharing can reduce those conflicts and increase team performance.

R&D projects are complex. When information is not shared, different people dealing with the same problem may have to "reinvent the wheel" (Galletta et al., 2003). By sharing knowledge, a team can reduce duplication in the creation of new knowledge, promote the spread of best practices, and facilitate problem-solving by making relevant individual knowledge accessible to the process, regardless of where the knowledge was originally sourced and stored within the team. (Husted & Michailova, 2002) Furthermore, information sharing allows team members to learn from one another and to develop deeper abstractions and analogies between issues, as well as to employ experience-based abilities to tackle new challenges. (Zhuge et al., 1997).

Literature shows knowledge sharing has an important role in innovation processes (K. C. Lee et al., 2005). In another research, it is noted, that when shared perceptions are present, performance may improve. When shared information is absent, performance may decrease.

Researchers noted the presence of such shared knowledge, as opposed to the absence of shared knowledge, may improve group performance. (Nelson & Cooprider, 1996). In addition, Lee et al. (2007) suggested new product development team open information sharing has shown a positive association with team performance. Cehn said that to create a motivated team that can achieve greater new product development performance, promoting internal knowledge growth requires strong management backing, goal-setting communication, and cross-functional information sharing. (McAdam et al., 2008). For example, knowledge sharing can help university research units enhance their team effectiveness. (Numprasertchai & Igel, 2005). Similarly, Huang et al. (2009) promoted the theory that knowledge sharing aids in problem identification and solution-finding, enhancing product development. Furthermore, Love and Roper. (2009) promotes the theory that knowledge sharing aids in problem identification and solution-finding, enhancing product development. A study conducted in the wind turbine industry revealed that better communication and understanding enhanced team performance (Andersen & Drejer, 2009). Henriksen (2001) mentioned, that sharing expertise among project teams helps

engineers get the knowledge and abilities they need to handle real-world issues. As a result, it is speculated.

1.5 Group cohesiveness vs the performance of R&D teams

In the literature, the entire group social collectiveness includes the personal appraisal desire of the group they are selected, how satisfied they are within the group, and how many social interactions they like to do within the group are called group-cohesiveness which is a very significant factor (III et al., 1989). Throughout the literature, it has been demonstrated that teams may improve their performance by enhancing their cohesiveness. (Levine & Moreland, 1990). There are many advantages related to building group cohesiveness. It will encourage team members to connect and speak with one another regularly. Therefore, process-driven conflict among team members will be reduced (Jehn, 1995).

An increase in group cohesiveness will improve team members' mindfulness of the R&D process and their contribution. Because of this, their efforts are more likely to integrate and work together effectively in support of the baseline process, which will enhance the performance of the R&D team. (Huang, 2009). Some analytical examinations present in the literature have identified a direct correlation between group cohesiveness and R&D team performance. For example, Evans et al. (1991) stated that the correlation between group cohesiveness and performance was consistent and favorable. This research study was done regarding small R&D groups. Mullen et al. (1994) argued the effect of cohesiveness-performance is highly significant for smaller groups. Also, group cohesiveness is a robust predictor of R&D team performance regarding problem-solving and productivity Dailey (1978). Keller (1986) asserts that R&D project teams that were cohesive were able to complete projects on time and under budget. If the R&D teams are cohesive, they will perform stronger under financial constraints (Hoegl et al., 2008). In conclusion, group cohesion was favorably correlated with overall effectiveness in R&D teams(Yang & Tang, 2004).

1.6 Team efficiency vs the performance of R&D teams

Team efficacy is defined as a team's belief in the ability to perform specific tasks successfully (Lindsley et al., 1995). High team efficacy enables more ambitious and high-level goal setting, intense teamwork, high levels of trust and unity, and a propensity to actively participate in task structure, planning, and the adaptation process (DeRue et al., 2010). In addition, Team efficacy is important for fostering healthy interpersonal interactions, cooperation, and support among team members, all of which lead to improved team performance (Stajkovic et al., 2009). Literature confirms research and development teams' performance has been influenced by team efficacy in a conceptual analysis (Gully et al., 2002). Liu et al. (2015) argued that more cooperative behaviors and group decision-making are encouraged when the new product development team's collective efficacy

increases, which improves innovation performance.

2. METHODOLOGY

2.1 Development of the Hypotheses

According to the literature review, the following hypotheses were developed.

Hypothesis 1

H1.1: Trust is positively related to ABC Institutes' R&D team performance

H1.0: Trust is negatively related to ABC Institutes' R&D team performance

Hypothesis 2

H2.1: Knowledge-sharing positively related to ABC Institutes' R&D team performance

H2.0: Knowledge-sharing negatively related to ABC Institutes' R&D team performance

Hypothesis 3

H3.1: Group cohesiveness is positively related to ABC Institutes' R&D team performance

H3.0: Group cohesiveness is negatively related to ABC Institutes' R&D team performance

Hypothesis 4

H4.1: Team efficacy is positively related to ABC Institutes' R&D team performance

H4.1: Team efficacy is negatively related to ABC Institutes' R&D team performance

2.2 Conceptual Framework

The conceptual model given below in Figure 4 is designed using the above-described hypotheses.

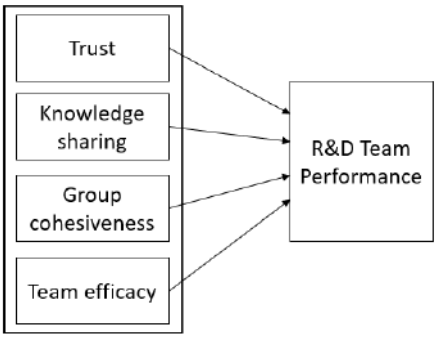

Figure 4. Research model (Developed by the researcher)

In this research model, trust, knowledge sharing, group cohesiveness, and team efficacy are taken as independent variables. The dependent variable that affects those selected variables is R&D team performance.

3. OPERATIONALIZATION

Table 1. Operationalization

Variable	Measuring Indicator
Section 1	
Demographic Information	Gender
	Age Group

	Level of Education
	Work Experience in R&D
Section 2 (Independent variables)	
Trust	Integrity between team members
	Reliability in one another
	Team spirit
	Confidence in one another
	Friendliness
	Sharing Methodologies and documents
	Productiveness of group meetings
	Communication without leaders' interference
	Avoiding duplication and awareness of other work
	Sharing educational expertise with members
Group cohesiveness	Sense of attachment toward the team
	Discussion of error without conflict
	Positive attitude towards the ultimate goal
	Review each other's work to prevent mistakes
	Extracting information from members
Team efficacy	Team confidence
	Faith in achieving goals
	Accepting challenges
	Self-initiation
	Enthusiasm to achieve team performance
Section 3 (Dependent variable)	
R&D team performance	Project Quality
	Project Success
	Time management within the team
	Complete work within the schedule
	Complete work within budget

3.1 Likert Scale

Five-point Likert scale was used to evaluate the responses given by the sample. The Likert scale measures how much they agree or disagree with a certain question as given below in Table 2.

Table 2. Likert scale and point table

Points of scale	Score
Very Satisfied	5
Satisfied	4
Neutral	3
Dissatisfied	2
Very dissatisfied	

4. RESULTS AND DISCUSSION

4.1 Preparation of Database

The population of the ABC organization's R&D employees is around 40. Therefore, according to Krejcie and Morgan's (1970) calculation, the sample of 36 employees is selected randomly to distribute the questionnaire and data is collected. Finally, 36 replies were evaluated for to experiment.

4.2 Studied Sample Profile

4.2.1 Gender

According to the demographic analysis of the sample, both genders have an equal contribution. Males have 53% contribution and females have 47% participation in questionnaire completion (Figure 5).

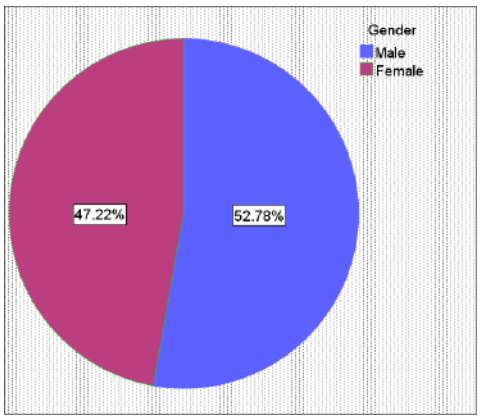

Figure 5. Gender (SPSS)

4.2.2 Age Group

The age distribution of the selected sample is shown in Figure 6. Therefore, the major contribution of the sample is from between the 21 – 30 age category (75%). Then, between 31 – 40 and between 41 – 50 categories have 22% and 3% distributions respectively. Other age categories, below 20 and above 50 have negligible percentage contributions.

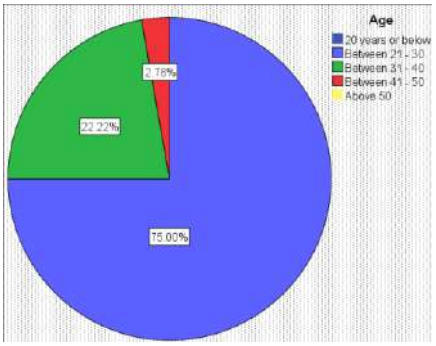

Figure 6. Age (SPSS)

4.2.3 Education level

Figure 7 gives the education level distribution of the selected sample. The majority of the sample have an education level of Masters/Ph.D. (53%). Then bachelor's degrees have 42%, Diplomas 3%, and Other 3% respectively. The percentage of vocational certificate education level is negligible.

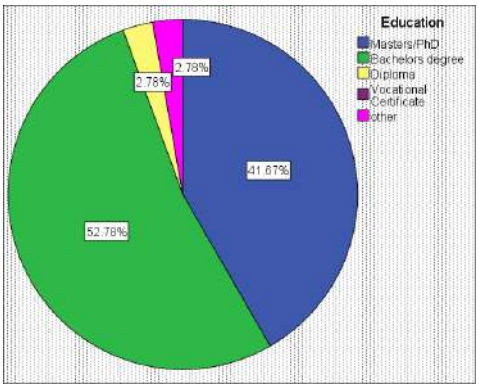

Figure 7. Education level (SPSS)

4.2.4 Carrier Experience in Research & Development Industry

Figure 8 indicates the experience in the R&D field of the selected sample. This variable has an equal distribution among all the categories. From 1 to 3 years have 36%, 6 months to 1 year have 19%, More than 5 years have 17%, 3 to 5 years have 14% and less than 6 months have 14% percentage experiences respectively.

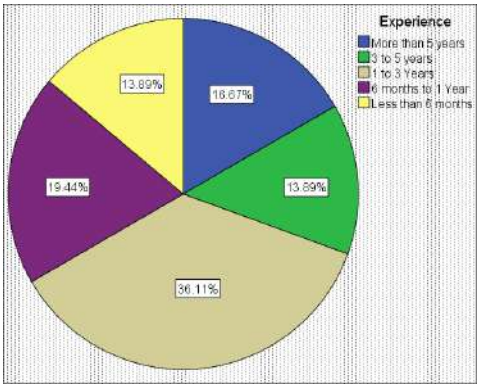

Figure 8. Experience in the R&D field (SPSS)

4.3 Reliability Test

Cronbach's alpha is used to evaluate the internal consistency of the developed questionnaire. Internal consistency compared to Cronbach's alpha value can be identified from the given Table 3.

Table 3. Cronbach's alpha internal consistency table (David L. Streiner, 2003)

Cronbach's alpha	**Internal consistency**
$\alpha \geq 0.9$	Excellent
$0.7 \geq \alpha \geq 0.9$	Good
$0.6 \geq \alpha \geq 0.7$	Acceptable
$0.5 \geq \alpha \geq 0.6$	Poor
$\alpha < 0.5$	Unacceptable

This questionnaire had 25 questions related to independent variables. The reported Cronbach's alpha score for all of these questions was 0.929 (Figure 9) which displays excellent internal consistency.

Reliability Statistics

Cronbach's Alpha	N of Items
.929	25

Figure 9. Reliability test all items (SPSS Output)

Operationalization has described there are 5 questions per independent variable in the questionnaire. The reliabilities of those independent variables are given in Figure 10-13.

Reliability Statistics

Cronbach's Alpha	N of Items
.802	5

Figure 10. Reliability Statistics of Trust (SPSS)

Reliability Statistics

Cronbach's Alpha	N of Items
.675	5

Figure 11. Reliability statistics of Knowledge sharing (SPSS)

Reliability Statistics

Cronbach's Alpha	N of Items
.785	5

Figure 12. Reliability statistics of Group cohesiveness (SPSS)

Reliability Statistics

Cronbach's Alpha	N of Items
.804	5

Figure 13. Reliability statistics of Team efficacy (SPSS)

The independent variables; trust, knowledge sharing, team cohesiveness, and team efficacy got reliability scores of 0.802, 0.675, 0.785, and 0.804 respectively. This emphasizes all the independent variables have a good internal consistency according to Table 3.

The reliability value reported for the dependent variable R&D team performance was 0.794 which gives a good internal consistency (Figure 14).

Reliability Statistics

Cronbach's Alpha	N of Items
.794	5

Figure 14. Reliability statistics of R&D team performance (SPSS)

In conclusion, reliability tests confirm the questions in the questionnaire are authentic.

4.4 Descriptive Statistics

4.4.1 Dependent variable – R&D team performance

According to the analysis, the majority of the sample agreed or stayed neutral with the questionnaire declarations. This can be proved by the mean, median, and mode had values of 3.8, 3.8, and 3.4. The standard deviation was 0.616 which means the spread around the mean value is 0.616 (Figure 15-16).

Statistics

RD team performance

N	Valid	36
	Missing	0
Mean		3.8278
Median		3.8000
Mode		3.40[a]
Std. Deviation		.61626
Skewness		-.330
Std. Error of Skewness		.393

a. Multiple modes exist. The smallest value is shown

Figure 15. R&D team performance statistics (SPSS Output)

Slightly less median compared to the mean is the reason for the negative skewness (-0.33). Therefore, a left distribution tail was created.

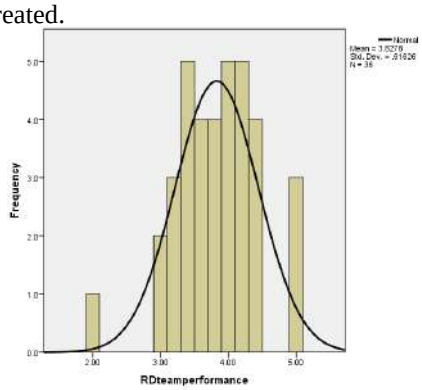

Figure 16. R&D team performance Histogram (SPSS Output)

Independent Variable 1 – Trust

According to the analysis Mean, median and mode gave values of 3.95, 4.00, and 4.00 indicating the sample agreed with the declarations made in the questionnaire. The standard deviation was 0.558 which means the spread around the mean value is 0.558 (Figure 17-18).

Statistics

Trust

N	Valid	36
	Missing	0
Mean		3.9556
Median		4.0000
Mode		4.00
Std. Deviation		.55777
Skewness		-.042
Std. Error of Skewness		.393

Figure 17. Trust Statistics (SPSS Output)

Slightly less median compared to the mean is the reason for the negative skewness (-0.042). Therefore, a left distribution tail was created.

In conclusion, the ABC Institute employees believe that trust is an important aspect of R&D team performance.

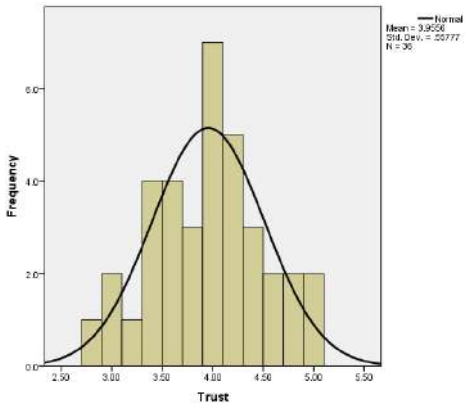

Figure 18. Trust Histogram (SPSS Output)

Independent Variable 2 – Knowledge Sharing

According to the analysis Mean, median and mode gave values of 3.90, 3.80, and 3.60 indicating the sample agreed or stayed neutral on the declarations made in the questionnaire. The standard deviation was 0.546 which means the spread around the mean value is 0.546 (Figure 19-20).

Statistics

Knowledge sharing

N	Valid	36
	Missing	0
Mean		3.9000
Median		3.8000
Mode		3.60
Std. Deviation		.54616
Skewness		-.900
Std. Error of Skewness		.393

Figure 19. Knowledge Sharing Statistics (SPSS Output)

Bit larger negative skewness (-0.900) was due to the mean being lesser than the median. Therefore, a left distribution tail was created.

In conclusion, the ABC Institute employees consider knowledge sharing as an influential factor for the R&D team's performance.

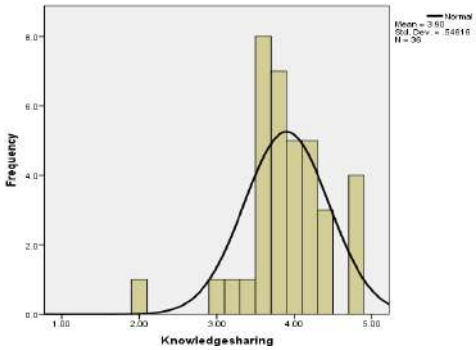

Figure 20. Knowledge Sharing Histogram (SPSS Output)

Independent Variable 3 – Group Cohesiveness

Results emphasize majority of the sample agreed or stayed neutral to the questionnaire declarations giving 3.93, 4.00, and 4.00 for the mean, median, and mode respectively. The standard deviation was 0.569 which means the spread around the mean value was 0.569 Figure 21-22).

Statistics

Group cohesiveness

N	Valid	36
	Missing	0
Mean		3.9333
Median		4.0000
Mode		4.00
Std. Deviation		.56971
Skewness		-.388
Std. Error of Skewness		.393

Figure 21. Group Cohesiveness Statistics (SPSS Output)

A slightly lesser mean than the median was the reason for low negative skewness (-0.388). Therefore, a left distribution tail was created.

In conclusion, the ABC Institute employees consider group cohesiveness as an influential factor for the R&D team's performance.

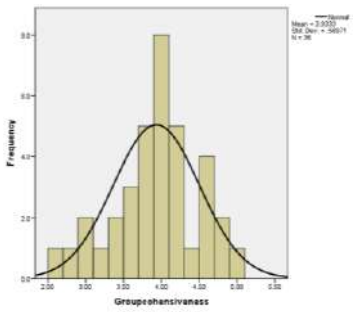

Figure 22. Group Cohesiveness Histogram (SPSS Output)

Independent Variable 4 – Team Efficacy

The mean median and mode have given values of 4.11, 4.10, and 4.00 respectively. This means the majority of the sample agreed with the declarations made in the questionnaire. The standard deviation was 0.577 which means the spread around the mean value was 0.577 (Figure 23 - 24).

Statistics

Team efficacy

N	Valid	36
	Missing	0
Mean		4.1056
Median		4.1000
Mode		4.00
Std. Deviation		.57666
Skewness		-.814
Std. Error of Skewness		.393

Figure 23. Team Efficacy Statistics (SPSS Output)

A slightly lesser mean than the median was the reason for the negative skewness

(-0.814) Therefore, a left distribution tail was created.

Table 4. Pearson correlation summary

		RD team performance
Trust	Pearson Correlation	.738**
	Sig. (2-tailed)	.000
	N	36
Knowledge sharing	Pearson Correlation	.874**
	Sig. (2-tailed)	.000
	N	36
Group cohesiveness	Pearson Correlation	.868**
	Sig. (2-tailed)	.000
	N	36
Team efficacy	Pearson Correlation	.461**
	Sig. (2-tailed)	.005
	N	36

In conclusion, the ABC Institute employees consider Team efficacy as an influential factor for the R&D team performance.

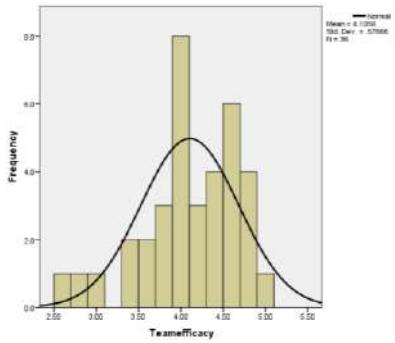

Figure 24. Team efficacy Histogram (SPSS Output)

4.5 Pearson Correlation

The strength of the linear relationship between two variables is measured from the Pearson correlation test in statistics. This correlation interpretation (Hinkle et al., 2003) is given below in Figure 25.

Size of Correlation	Interpretation
.90 to 1.00 (−.90 to −1.00)	Very high positive (negative) correlation
.70 to .90 (−.70 to −.90)	High positive (negative) correlation
.50 to .70 (−.50 to −.70)	Moderate positive (negative) correlation
.30 to .50 (−.30 to −.50)	Low positive (negative) correlation
.00 to .30 (.00 to −.30)	negligible correlation

Figure 25. Pearson Correlation interpretation (Hinkle et al., 2003)

From Pearson correlation results, trust, knowledge sharing, and group cohesiveness have values of 0.738, 0.874, and 0.868 indicating high positive correlations. Team efficacy was 0.461 indicating low positive correlation (Table 4).

4.6 Hypothesis Testing

In this research, the questionnaire responses are taken from a 5-point Likert scale. Then they were converted into values. Therefore, the dependent variables and the independent variable both are quantitative. The scatter plots for each dependent variable vs the independent variable drawn from SPSS are given below in Figure 26 - 29.

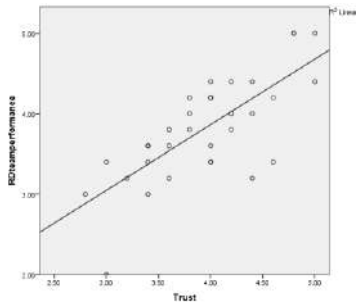

Figure 26. Trust vs R&D team performance

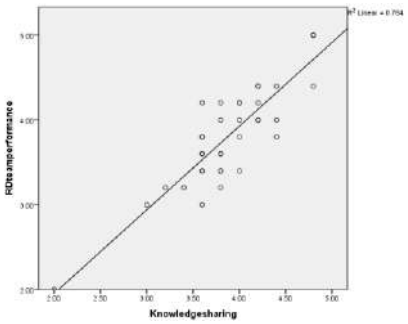

Figure 27. knowledge sharing vs R&D team performance

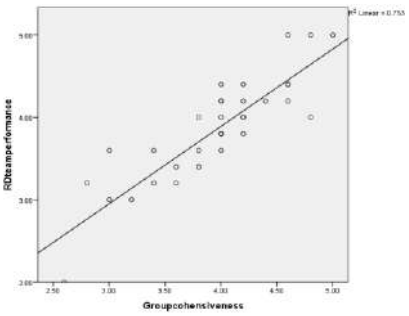

Figure 28. Group cohesiveness vs R&D team performance

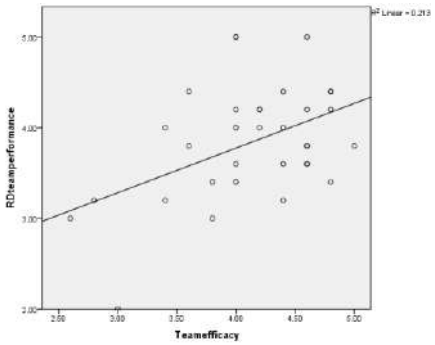

Figure 29. Team efficacy vs R&D team performance

Table 5. Hypothesis Test Summary

Variable	B value	P-value	Strength of Impact	Alternative Hypothesis	Null hypothesis
Trust	0.816	0.000	Strong	Accepted	Rejected
Knowledge sharing	0.987	0.000	Strong	Accepted	Rejected
Group cohesiveness	0.939	0.000	Strong	Accepted	Rejected
Team efficacy	0.493	0.005	Moderate	Accepted	Rejected

Then linear regression is used to test the hypotheses because of the quantitative nature of responses and simplicity of the study. The tests have given significance values less than 0.05 for all four variables. Therefore, hypotheses developed based on the positive relationship between independent variables and dependent variables were accepted (Table 5).

4.7 Multiple Regression

Multiple regression is used to evaluate the merged impact of the variables. Multiple regression results show trust ($0.032<P<0.05$), knowledge sharing ($0.00<P<0.05$), and group cohesiveness ($0.011<P<0.05$) have given statistical significance in combination. Team efficiency ($0.507>P<0.05$) was not significant in combination.

The results obtained align with existing literature. Huang (2009) identified a positive and significant effect of group cohesiveness on team performance, reinforcing this research's findings. Likewise, Jo & Park (2019) emphasized a relationship between trust, knowledge sharing, and team efficacy. Their study supports obtained results, indicating that trust drives knowledge sharing, and both knowledge sharing and team efficacy contribute positively to team performance.

4.8 Suggestions to Improve R&D Team Performance of ABC Organization.

4.8.1 Trust

Increasing the R&D team's communication and transparency, consistent decision-making, giving employees autonomy, and building accountability will improve trust within the team.

4.8.2 Knowledge sharing

There are two types of knowledge explicit knowledge and tacit knowledge (Figure

30). The main barrier to knowledge sharing in an R&D organization is the confidential issues and value of ideas in the research field. The main barrier to knowledge sharing in an R&D organization is the confidential issues and value of ideas in the research field.

Figure 30. Explicit knowledge and tacit knowledge (Lin, 2021)

Managers should encourage knowledge-sharing platforms, reward employees who share knowledge, conduct knowledge and experience-sharing workshops, accept mistakes, provide new employees mentors, develop documentation of knowledge, and introduce a professional culture with rules to discourage plagiarism and misuse of

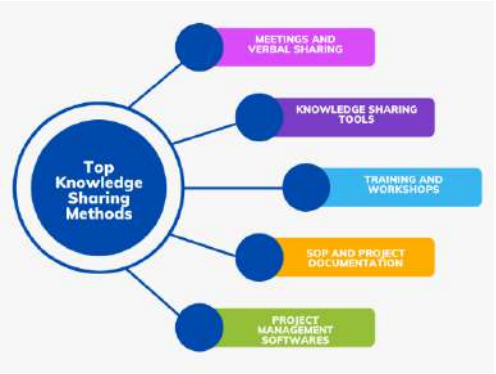

Figure 31. Knowledge sharing methods

4.8.3 Group cohesiveness

To increase group cohesiveness, managers should encourage communication, conduct team-building activities, encourage collaboration within teams, and show appreciation to team members.

4.8.4 Team efficacy

To improve team efficacy, managers should define clear deliverables and plan projects, promote team members' project ownership, and use project management tools.

5. CONCLUSION

R&D team performance is a major factor in successful innovations in R&D organizations. Studies have been done worldwide to find the variables that affect R&D team performance. In Sri Lanka, such studies are not found. In this research, variables such as trust, knowledge sharing, group cohesiveness, and team efficacy were selected from the literature and their effect on the R&D team performance of ABC organization was studied.

The study faced challenges due to the limited workforce in R&D organizations within the country reducing the analyzed sample size. A more extensive sample would enhance the understanding of the factors impacting R&D team performance.

Furthermore, this study was carried out as quantitative research. However, there is room for complementary qualitative studies to uncover new factors related to R&D team performance.

Additionally, the existing literature highlights numerous variables influencing team performance. however, this research was deliberately focused on studying the

influence of only four selected variables to manage the study's complexity. Further research can be carried out to measure the influence of these additional variables.

REFERENCES

Aghion, P., & Howitt, P. (1992). A Model of Growth Through Creative Destruction. *Econometrica*, *60*(2), 323. https://doi.org/10.2307/2951599

Andersen, P. H., & Drejer, I. (2009). Together we share? Competitive and collaborative supplier interests in product development. *Technovation*, *29*(10), 690–703. https://doi.org/10.1016/j.technovation.2008.12.003

Ashley Fulmer, C., & Gelfand, M. J. (2012). At What Level (and in Whom) We Trust: Trust Across Multiple Organizational Levels. In *Journal of Management* (Vol. 38, Issue 4). https://doi.org/10.1177/0149206312439327

Braun, S., Peus, C., Weisweiler, S., & Frey, D. (2013). Transformational leadership, job satisfaction, and team performance: A multilevel mediation model of trust. *Leadership Quarterly*, *24*(1), 270–283. https://doi.org/10.1016/j.leaqua.2012.11.006

Costa, A. C., Fulmer, C. A., & Anderson, N. R. (2018). Trust in work teams: An integrative review, multilevel model, and future directions. *Journal of Organizational Behavior*, *39*(2), 169–184. https://doi.org/10.1002/job.2213

Crispin Keanie, O. C. (n.d.). *Delivering Effective Commercialization, Hart Energy*. Retrieved November 18, 2023, from https://www.hartenergy.com/exclusives/delivering-effective-commercialization-175723

Cropanzano, R., & Mitchell, M. S. (2005). Social exchange theory: An Interdisciplinary review. *Journal of Management*, *31*(6), 874–900. https://doi.org/10.1177/0149206305279602

Dailey, R. C. (1978). Role of Team and Task Characteristics in R&D Team Collaborative Problem Solving and Productivity. *Manage Sci*, *24*(15), 1579–1588. https://doi.org/10.1287/mnsc.24.15.1579

David L. Streiner. (2003). Starting at the beginning: An introduction to coefficient alpha and internal consistency. *Journal of Personality Assessment*, *80*(1), 99–103.

De Jong, B. A., & Elfring, T. (2010). How does trust affect the performance of ongoing teams? the mediating role of reflexivity, monitoring, and effort. *Academy of Management Journal*, *53*(3), 535–549. https://doi.org/10.5465/amj.2010.51468649

Delice, F., Rousseau, M., & Feitosa, J. (2019). Advancing teams research: What, when, and how to measure team dynamics over time. *Frontiers in Psychology*, *10*(JUN), 1–20. https://doi.org/10.3389/fpsyg.2019.01324

DeRue, D. S., Hollenbeck, J., Ilgen, D., & Feltz, D. (2010). Efficacy dispersion in teams: Moving beyond agreement and aggregation. *Personnel Psychology*, *63*(1), 1–40. https://doi.org/10.1111/j.1744-6570.2009.01161.x

Dirks, K.T., 1999. (1999). *The effects of interpersonal trust on work group performance*. *455*, 445–455.

Dziallas, M., & Blind, K. (2019). Innovation indicators throughout the innovation process: An extensive literature analysis. *Technovation*, *80–81*(May), 3–29. https://doi.org/10.1016/j.technovation.2018.05.005

Evans, C. R., & Dion, K. L. (1991). Group Cohesion and Performance: A Meta-Analysis. *Small Group Research*, *22*(2), 175–186. https://doi.org/10.1177/1046496491222002

Grossman, G. and Helpman, E. (1991). *Innovation and growth in the world economy. Press, Cambridge.*

Gully, S. M., Incalcaterra, K. A., Joshi, A., & Beaubien, J. M. (2002). A meta-analysis of team-efficacy, potency, and performance: Interdependence and level of analysis as moderators of observed relationships. *Journal of Applied Psychology*, *87*(5), 819–832. https://doi.org/10.1037/0021-9010.87.5.819

Henriksen, L. B. (2001). Knowledge management and engineering practices: The case of knowledge management, problem-solving, and engineering practices. *Technovation*, *21*(9), 595–603. https://doi.org/10.1016/S0166-4972(01)00023-2

Hinkle, D.E., Wiersma, W. and Jurs, S. G. (2003). *Applied statistics for the behavioral sciences*. Houghton Mifflin College Division.

Hoegl, M., Gibbert, M., & Mazursky, D. (2008). Financial constraints in innovation projects: When is less more? *Research Policy*, *37*(8), 1382–1391. https://doi.org/10.1016/j.respol.2008.04.018

Huang, C. C. (2009). Knowledge sharing and group cohesiveness on performance: An empirical study of technology R&D teams in Taiwan. *Technovation*, *29*(11), 786–797. https://doi.org/10.1016/j.technovation.2009.04.003

Husted, K., & Michailova, S. (2002). Diagnosing and fighting knowledge-sharing hostility. *Organizational Dynamics*, *31*(1), 60–73. https://doi.org/10.1016/S0090-2616(02)00072-4

III, C. A. O., Caldwell, D. F., & Barnett, W. P. (1989). Work Group Demography, Social Integration, and Turnover. *Administrative Science Quarterly*, *34*(1), 21. https://doi.org/10.2307/2392984

Jehn, K. A. (1995). A Multimethod Examination of the Benefits and Detriments of Intragroup Conflict. *Administrative Science Quarterly*, *40*(2), 256.

https://doi.org/10.2307/2393638

Jehn, K. A., Chadwick, C., & Thatcher, S. M. B. (1997). To agree or not to agree: The effects of value congruence, individual demographic dissimilarity, and conflict on workgroup outcomes. *International Journal of Conflict Management*, *8*(4), 287–305. https://doi.org/10.1108/eb022799

Jo, D., & Park, J. (2019). Understanding the Success Factors of R&D Organization. In *Studies in Computational Intelligence* (Vol. 789). Springer International Publishing. https://doi.org/10.1007/978-3-319-98881-8_6

Joshi, A., Lazarova, M. B., & Liao, H. (2009). Getting everyone on board: The role of inspirational leadership in geographically dispersed teams. *Organization Science*, *20*(1), 240–252. https://doi.org/10.1287/Orsc.1080.0383

Katz, R., & Allen, T. J. (1985). Project Performance and the Locus of Influence in the R&D Matrix. *Academy of Management Journal*, *28*(1), 67–87. https://doi.org/10.2307/256062

Krejcie, R. V., & Morgan, D. W. (1970). Determining Sample Size for Research Activities. *Educational and Psychological Measurement*, *30*(3), 607–610. https://doi.org/10.1177/001316447003000308

Lee, C., & Chen, W. J. (2007). Cross-functionality and charged behavior of the new product development teams in Taiwan's information technology industries. *Technovation*, *27*(10), 605–615. https://doi.org/10.1016/j.technovation.2007.02.012

Lee, K. C., Lee, S., & Kang, I. W. (2005). KMPI: Measuring knowledge management performance. *Information and Management*, *42*(3), 469–482. https://doi.org/10.1016/j.im.2004.02.003

Levine, J. M., & Moreland, R. L. (1990). Progress in Small Group. *Annual Review of Psychology*, *1982*.

Lin, J. (2021). *Knowledge is power: why the future is not just about the tech | World Economic Forum*. World Economic Forum.

Lindsley, D. H., Brass, D. J., & Thomas, J. B. (1995). Efficacy-Performing Spirals: A Multilevel Perspective. *Academy of Management Review*, *20*(3), 645–678. https://doi.org/10.5465/amr.1995.9508080333

Liu, J., Chen, J., & Tao, Y. (2015). Innovation performance in new product development teams in China's technology ventures: The role of behavioral integration dimensions and collective efficacy. *Journal of Product Innovation Management*, *32*(1), 29–44. https://doi.org/10.1111/jpim.12177

Love, J. H., & Roper, S. (2009). Organizing innovation: Complementarities between cross-functional teams. *Technovation*, *29*(3), 192–203. https://doi.org/10.1016/j.technovation.2008.07.008

McAdam, R., O'Hare, T., & Moffett, S. (2008). Collaborative knowledge sharing in Composite New Product Development: An aerospace study. *Technovation*, *28*(5), 245–256. https://doi.org/10.1016/j.technovation.2007.07.003

Morrissette, A. M., & Kisamore, J. L. (2020). Trust and performance in business teams: a meta-analysis. *Team Performance Management*, *26*(5–6), 287–300. https://doi.org/10.1108/TPM-02-2020-0012

Mullen, B., & Copper, C. (1994). The Relation Between Group Cohesiveness and Performance: An Integration. *Psychological Bulletin*, *115*(2), 210–227. https://doi.org/10.1037//0033-2909.115.2.210

Nelson, K. M., & Cooprider, J. G. (1996). The contribution of shared knowledge to IS group performance. *MIS Quarterly: Management Information Systems*, *20*(4), 409–429. https://doi.org/10.2307/249562

Numprasertchai, S., & Igel, B. (2005). Managing knowledge through collaboration: Multiple case studies of managing research in university laboratories in Thailand. *Technovation*, *25*(10), 1173–1182. https://doi.org/10.1016/j.technovation.2004.03.001

Pelled, L. H., Eisenhardt, K. M., & Xin, K. R. (1999). Exploring the black box: An analysis of work group diversity, conflict, and performance. *Administrative Science Quarterly*, *44*(1), 1–28. https://doi.org/10.2307/2667029

Pessoa, A. (2007). Innovation and Economic Growth: What is the actual importance of R&D? *Managing Technology and Innovation: An Introduction*, *November 1994*, 1–384. https://doi.org/10.4324/9780203012567

Sawhney, M., Prandelli, E., & Series, R. (2000). *Communities of Creation: 42*(4).

Stajkovic, A. D., Lee, D., & Nyberg, A. J. (2009). Collective Efficacy, Group Potency, and Group Performance: Meta-Analyses of Their Relationships, and Test of a Mediation Model. *Journal of Applied Psychology*, *94*(3), 814–828. https://doi.org/10.1037/a0015659

Stoker, J. I., Looise, J. C., Fisscher, O. A. M., Jong, R. D. De, Looise, J. C., Fisscher, O. A. M., & Leadership, R. D. D. J. (2010). *Leadership and innovation : relations between leadership, individual characteristics and the functioning of R & D teams Leadership and innovation : relations between leadership, individual characteristics and the functioning of*. *5192*(January 2016), 37–41.

Tomkovick, C., & Miller, C. (2000). Perspective - riding the wind: Managing new product development in an age of change. In *Journal of Product Innovation Management* (Vol. 17, Issue 6, pp. 413–423). https://doi.org/10.1016/S0737-6782(00)00056-4

Tuckman, B. W. (1965). Developmental sequence in

small groups. *Psychological Bulletin*, *63*(6), 384–399. https://doi.org/10.1037/h0022100

Yang, H. L., & Tang, J. H. (2004). Team structure and team performance in IS development: A social network perspective. *Information and Management*, *41*(3), 335–349. https://doi.org/10.1016/S0378-7206(03)00078-8

Zhuge, H., Ma, J., & Shi, X. (1997). Abstraction and analogy in cognitive space: A software process model. *Information and Software Technology*, *39*(7), 463–468. https://doi.org/10.1016/S0950-5849(96)00008-0

The Impact of Multisensory Interior Design Factors in Shopping mall Regarding the Human Behavior Control in a Public Space Design

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ABSTRACT

A successful interior design is a space that can achieve user expectations while improving the aesthetic value and the functionality of the space. When concerning on interior design of public spaces their major objective is provide comfort, convenience, pleasure, recognition, and the curiosity. In a public space people can choose to become user, customer, or patron. The interior design should be able to design the space with the suitable control in order to pursue the expected functionality of the public space. This research conducts to understand human behavior factors, and humans respond to different design factors. Commonly design factors are determined by only the eye detective element, but design has ambient factors which impact human sensors and can change their response to the built environment. in this study those design factors are going to study under the multisensory factors and the research has narrow the study area by

selecting the shopping malls as public space. This research structure has built on a theoretical framework which is covers the areas of public spaces and shopping mall design, multisensory design theories and their interconnection with human behavior factors.

After based on the factors that collect through the theoretical framework the public survey has conduct through the google forms and collect the data on user experience and selected two case studies to analyze the application of multisensory factors and Insite interview has conducted analyze user behavior. As the findings of the research, it explained the application of multisensory factors has ability to impact on human behavior control in the public spaces as it's required.

Keywords **- Human Behaviour Control, shopping malls, Multisensory Interior Design, Built Environment.**

1. INTRODUCTION

Human behaviour and the experience of the space result by their mind and different features in the space. These mindsets can affect by their social and cultural background, sexuality, and age factors. Those features may affect on human

behaviour and the same time human behaviour can affected on space function. Considering on that, to create more functionally successful space their need to provide required control over user by the space design.

To create more suitable space upon all the factors that mention above designer can follows some studies and theoretical factors. One of major fact is multisensory design. Multisensory design can make huge effect on the human comfort and required control over the space. This study also focusses on the impact of multisensory design upon human behaviour factors.

The aim of this study is identifying the design strategies which able to design a public space effectively without make a conflict with the natural behavioural reaction of human and how to provide the required control over space by using identify theoretical factors. This study has based on the research question of how Do multisensory interior design factors can do impact on the effectiveness of shopping mall function and how human behaviour control achieves through multi-sensory design in shopping malls?

The framework of the study has based on the related literature and the theorical factors related to multisensory design, human behaviour, and the public space design. Second segment will explain the addressing human interaction regarding the cognitive and human perception theories and the application of the multisensory design factors. The final segment it will discuss how the collected data and the research methods have been proven the hypothesis.

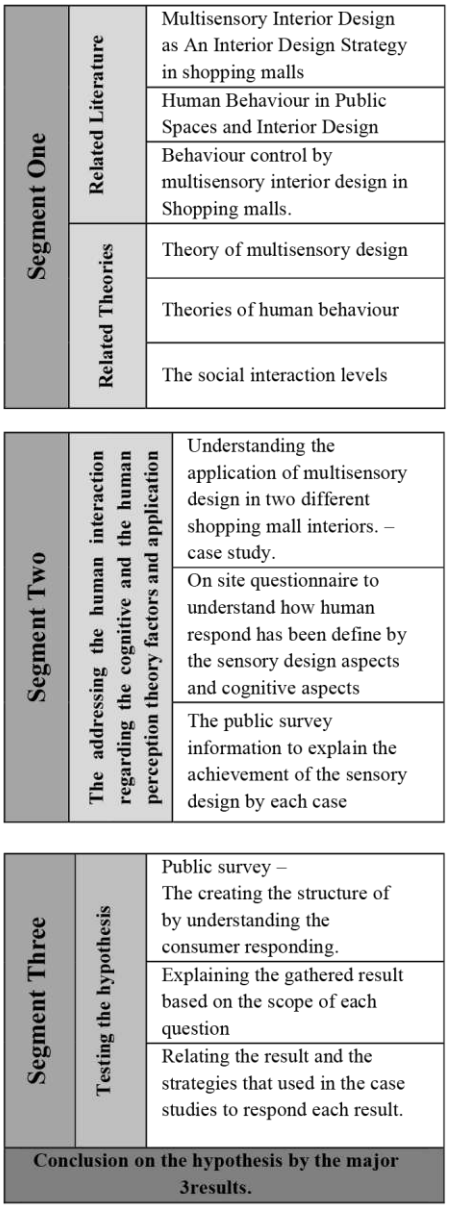

Figure 1. Framework of the research

3. RELATED LITERATURE AND THEORIES

3.1 Nature of The Shopping Mall

According to the (Richard A. Feinberg, 1989) the shopping malls was not just happened. The first planners have studied people who lived in suburban. They observe the people with virtually no social life and stimuli. They regularly watch TV, read and they are gone for a two-week trip for every year. They were needed a place to cruise without cars. The pioneer of shopping malls; entrepreneur Victor Gruen (Richard A. Feinberg, 1989) explain the major objectives of shopping mall were.

• Create a space for the suburban people to serve the deficiency of local retail provide.

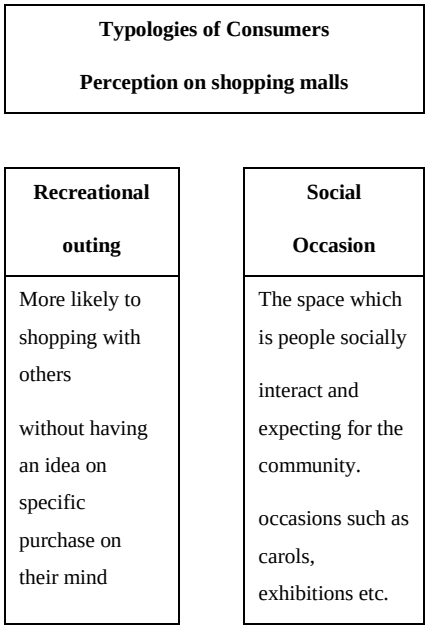

Figure 2. Types of consumer perception on social nature

• Create community Centre where the residence was converged for cultural activities and social interaction

According (Richard A. Feinberg, 1989) the consumer of shopping mall can be divided to two groups under the social nature of the shopping malls.

The positive atmosphere for the social occasion that is providing by the shopping mall has more ability to effect on retail traffic. (Richard A. Feinberg, 1989)

Proper parking facilities

Large atrium with seating

Entertainment and the aesthetically pleasing environment

Temperature control

can determine as positive atmospheric fact which is able to create more effectiveness on retails.

3.2. Theory of Multisensory Design

“Multisensory design has been developed from the idea that humans experience a space or environment in numerous ways – more than just visually. Sight is what people tend to think of first when it comes to engineering and architecture, we respond just as strongly to noises, aromas, temperature, humidity, textures, flavors.” Explain (Wellbeing Design Consultants, 2018) (Spence, 2020) describes human are visually dominant people. This is the reason people tend to think and imagine visually. It says humans are mainly processing the information which is visually detected more than the other sensers.

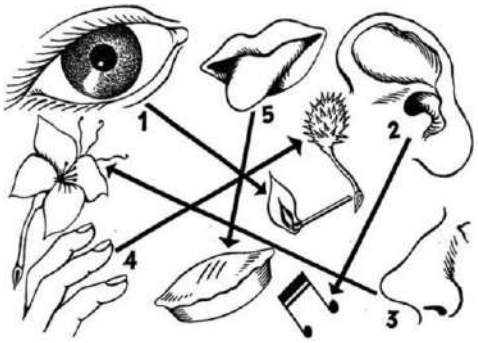

Figure 3. ranked the order of attention to be captured by the various senses (Spence, 2020)

3.2.1 Effect of Visual Factors.

Variable	Quality Of the Variable	Impact On Human Behavior
Lighting (Environment, 2007)	Dimly dark light (Environment, 2007)	Tend to release their social inhabitance. (Environment, 2007)
	Brightly lit setting (Environment, 2007)	Engaging in act of intimacy, aggression of impulse behavior (Environment, 2007)
Color (zhuang, 2012)	Color's ability emphasizes the space. (zhuang, 2012)	Large space creates more discomfort for humans than the small space.
	Create space seem warm/ cold. (zhuang, 2012)	Colors that clash with each other may produce a feeling of irritation or uneasiness. Ability to change the mood. (zhuang, 2012)
Form / Shape (Sibel S. Dazkir, 2012)	Curvier shapes /form (Sibel S. Dazkir, 2012)	More comfortable
	Clear visualizing of Edges of the spaces / spaces near by the edges (French, 1978)	creates psychological protection and comfort. It's creating a sense of space by expressing the scale of the space. It isn't mean the enclosed wall is directing user on activities but proper ambient and of the space such as lighting and the space arrangement. (French, 1978)

Table 1. the variables of vision and their effects on human behavior / response.

3.2.1 Effect of Sound Factors

(Mehrabian, 1974) describes that the underlying theory of the influence of music is that environment will influence an individual's emotional reactions; this, in affects an individual's behavioral responses to either approach or avoid the environment.

Approach	The Behavior State	The Result of The Behavior State
Pleasant	The music which is related to the function	Ability on increase time spend on purchasing.
	The slow music	Ability to decrease the work speed of consumers. Buy more items because not feeling of

		rush.
Unpleasant	Pleasure creates Positive engagement	Tend to spend extra time in unpleasant purchasing.
	Arousal creates Negative engagement	Predict less spending in unpleasant store environments
Speed / fast music		Feeling of rushed. Increase the walking speed. Less social interaction.

Table 2. The variables of sound and their effects on human behavior / response.

3.2.1 Effect of Touch / Tactile Factors

According to the (Spence, 2020) the touch and the texture of the built environment create a physical contact when we entering to a space and also when leaving the space, it further describes that when human enter to a space, they create some sort of interact with the all the materials and finishes such as flooring eventually. The imagination and mentality about the texture on their stimuli can do a huge effect.

(Rybczynski, 2001) explain two factors that impact on tactile.

Texture

Temperature

3.2.1 Effect of Smell

Scents influence emotions and purchase behavior: and pleasant scents have shown to, (Mehrabian, 1974)

- Enhance brand memory.
- Risk-taking
- Variety seeking
- In retailing
- Curiosity and consumer attention

3.2.1 Effect of Architectural Taste.

The oral taste in a built environment can be insane. However, polished, and coloured stone as well as colors in general, and finely crafted wood details, for instance, often evoke an awareness of mouth and taste.

The colors could evoke the taste.

People are defined some taste with colors “colors in general … often evoke … taste” seemingly linking to the widespread literature on the cross-modal correspondences that have increasingly been documented between color”. (Spence, 2020)

Identifying multisensory factors through the related literature and the theories above will be taken as the dependent variables in the survey to collect data on user experience and the impact of the multisensory design factors on user perception.

3.3. Theories of Human Behavior

According to (Environment, 2007) all the behavioral patterns can be explained under major 6 segments. Here it’s explained the different theories and their major impact on human behavioral reactions.

	Effect on Behavioral Performance.
The Arousal Theory	• The behavior performance increases with the psychological arousal (stress) but only up to a certain point. • When the level of Arousal (stress) becomes higher, the performance level decreases. (Paul A. Bell, 2001)
The Stimulus Load Theory	• In an unfamiliar public space with a towering and buildings, the attempt of finding the way is disturbance by stimuli such as, colors streets patterns, symbols, and people. • In a situation like that finding the way rather than concern about the crowd getting important and central nervous system ignores the other stimulus. (Environment, 2007)
The Adaptation Level Theory	• Adaptation People changing their respond and adapting with the stimulation of the environment. • Adjustment People changing the environment in the way they are. (Paul A. Bell, 2001)
The Behavior Constraint Theory	• According to this theory the environment is capable of preventing or controlling human behavior. • According to (Paul A. Bell, 2001) when humans feel they lost required control over their environment, they feel discomfort and leads them to reassert their control. Ex- in a crowded situation humans try to create physical or social barrier to let out others. • When they perceived the reassessing is unsuccessful, they feel the thing happened around them are out of their control. • In the opposite way, when people feel the control over their environment research shows, (Environment, 2007) the problems like littering and graffiti are reduced.
The Environment Stress Theory	• According to (Environment, 2007) when humans identify a certain stimulation as a threat to them ones, the behavioral reaction began with the automatically alarm. • These reactions may affect on person physiological and psychological behaviors.

The Perception or Cognition theory	• According to this theory it's supports to identify the situation or the environment through the experience of the cognition we felt rather than totally depends on environmental stimuli. • From perception it's make connection between environment and the human body. (Environment, 2007)

Table 3. human behavior theories and their effect on behavior performance

3.4. The social Interaction and the Human Respond to the Environment

Social interaction factors and human respond are important to understand user expected level of privacy and the interaction.

According to the (zhuang, 2012) there are major 3 factors will be affected on

human interaction with the environment.

Social interaction

Physiological interaction

Psychological interaction

3.4.1 Social Interaction

Personal interaction level

Privacy is a ***c***entral regulatory human process by which people make themselves more or less accessible. (Hall, 1982)

There's manly 4 levels of interpersonal interaction (Hall, 1982)

Intimate-This is the most immediate surrounding of person body. This space may affect both physical and emotional interaction.

Personal Space-The area which is person allows for some selected people (ex. Friends, fellow workers) for whom personal conversations is mandatory.

Social Space-Which person interest to make purely social contact on temporary basis.

Public Space-Area which is person don't need to have a direct contact with others.

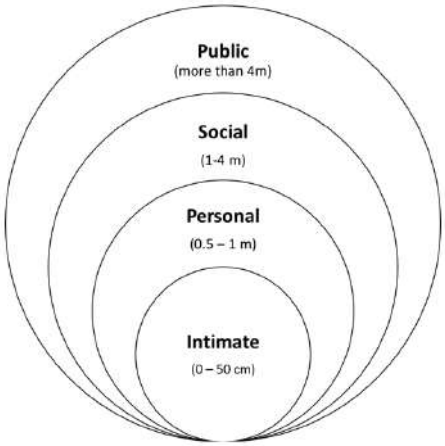

Figure 4. The levels of interpersonal interaction

Territoriality

Territoriality means the achieving desire level of privacy in certain environments and involving exclusive control in that certain area. Individuals and groups both support to create identity and the security they required. And may can follow aggressive

actions to defend each territoriality. (zhuang, 2012)

Crowding

Unsuccessfulness of personal space and territoriality creates crowding. It may cause to exceed undesired social contact.in sociologically crowding may affect on human with the environment condition.

Group Dynamics

Group dynamic are depend with the social factors such as culture, religion, age etc.. It's important to determine the physical arrangement of the interior. They need to consider interaction distance between groups. That can affect the function of the environment. (zhuang, 2012)

Communication

People's tendency to behaves when communicating with another person is vary. The factors of the space arrangement can impact on their communication.

3.4.2 Physiological Interaction.

Visual Control

When concerned about public spaces and its needs to determine human comfortability by understanding their reactions. Human natural behavior is tent to avoid situations which are being watched by another person without their awareness. (zhuang, 2012)

Acoustic Control

High quality of acoustic control able to improve social interaction and desirable level of communication. Creating acoustic privacy by creating acoustic separation makes a more suitable interior which people tend to interact with each other.

Aesthetics

Aesthetics is always determined by the environment and the functional needs of space. Aesthetics is something Beyond the constructional determinations. Through aesthetics the designer is able to communicate certain kind of control or a massage to the user.

3.4.2 Psychological Interaction.

Functional efficiency

Functional efficiency will be determined by how space interact with the human body requirements. Those are hearing, vision, mobility and stability. (zhuang, 2012)

Ergonomic efficiency

Each aspect of interior design should be interconnected with human body measurement information (anthropometrics) if there's a conflict between these two it may affect human response towards the space. (zhuang, 2012)

Life safety and health concern

These factors mainly concern how human react to the negative stimulation. In an emergency or dangerous situation individual didn't able identifying the abstract symbolisms for the safety

guides. In interior design it should be clearly and straightly indicate the meaning. (zhuang, 2012)

4.METHADOLOGY AND DATA COLLECTION

Three methods have been used to collect data. Each data collection method has been based on one major factor. The link and the interconnection of those data have been

able to explore the findings of the study and to prove the hypothesis.

01. Case study

Aim –

Examine the application of multisensory factors and expected control based on the literature factors**.**

Selected Site		**One Galle face shopping mall**	**Crescat shopping mall**
Multisensory design factors	**Vision**	Has more visual variant of textures with similar, natural, neutral color pallet	Overall gloss textured finish with warm color pallet with few primary colors
	Touch	Matt and gloss finish with more wooden finish for the interacting surfaces.	Gloss finish and painted finish
	Sound	Calm music all over the space with gradually changes according to certain areas (fast music has used for the food court)	Radio channels have been played throughout the whole space.
	Taste	Low heigh partition, different textures and the different ambient has used accordingly in the food court	Floor to floor partition with same ambient through the space in the food court
	Smell	Has significant fragrant	Hasn't unique fragrant few retail spaces had their ow fragrant.

02.In site interviews

Aim –

The impact of design factors on user behavior.

More positive arrangement with One Galle Face shopping mall factors.

Based on the related literature factors the One Galle Face shopping mall has applied multisensory design factors in order to create well controlled space.

03.Public Survey

Aim – Proving the required behavior control have been achieve through the well application of multisensory factors without direct impact on human behavior.	
General questions	Understand the impact of sociological group dynamics
Overall perception base questions	Taking entrance to term of multisensory and understand overall experience with the shopping malls.
Multisensory factors base questions	Understand and data on the perception on design factors.
Conclusion questions	Design factors and their experience of the space questioning on hypothesis.

Testing the Hypothesis → **Survey questions analyses the result**

Hypothesis –

Multi-sensory design factors can influence people on use the space as it's required → **based on three factors and proven the hypothesis.**

Major three factors are,

- **ser comfortability**
- **ser psychological determination and the perception.**
- **chieving the functional requirements of the space.**

5.FINDINGS

5.1. Sociological Factors and Their Impact

Survey has analysed gender, age, work status and the cultural background.

Result shows 75% are belongs to the age of 20- 30 and cultural variant was less since majority was Sinhalese. The work status showcases there's similar weight among employed and the students which describes their reason for visit.

The shopping mall has achieved the major objective of providing a recreational space.

Survey result showcases most of the time people are visited to hang out with their family and friends whereas the secondary priority with purchasing some target items.

5.2. Experiencing shopping mall

Survey has conduct among 112 participants. And from that 95.8% has visit to a any kind of shopping mall. This question will filter the people with shopping mall experience into the next questions.

The frequency of using the shopping mall can determine their interaction. Majority of people are visiting to the space ones or few times a month. Its' describes people will answer on design concern related question depending on their memory of the experience.

The choice of the best shopping mall has been determined on the following hierarchy of factors.

Quality of the retail

Quality of the food

Freedom of the space.

Aesthetic and the attractiveness of the space.

The target design objectives of a shopping mall have able to attract the consumers.

Majority select One Galle Face as their favourite shopping mall even survey question gives the freedom to mention their favourite shopping mall.

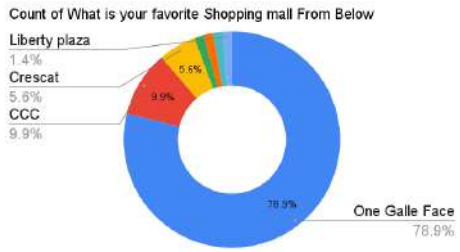

Figure 5. What is your favorite shopping mall From Below?

The sensory comfort space achieves their functional requirement.

Majority select the food court as their favourite space to send time. The One Galle Face Shopping mall food court has no common seating arrangement all the seating has arrange for each food stall, that aspect encourage consumers to move through the space or purchase something from a shop. Survey shows that didn't damage the user comfortability. They are still choosing the food court of One Galle Face Shopping mall because it's overall sensory comfort.

5.3. Multisensory experience and Impact on Behavioural Factors

The third segment of the questionary determined on how people experience the sensory experience, and it describes how it has impact on their behavior.

The perception of space can be defined with sensory experience.

The majority agreed that sensory factors have the ability to determine the perception of space. The previous findings and the proven information of the case study show case how the different sensory design aspects create a successful space.

The user comfort can depend on the sensory experience.

- The survey result shows all the participants somehow agreed on the fact of multi-sensory design comfortability.

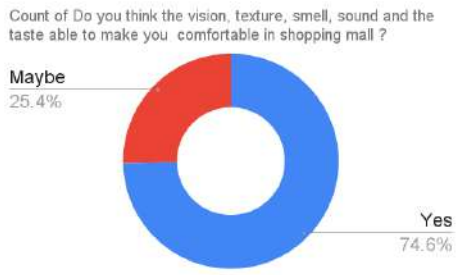

Figure 6. Do you think the vision, texture, smell, sound and the taste are able to make you comfortable in shopping mall?

Sensory design can determine space identification.

The survey question is expected to understand how the consumers interact with the sensory design aspect on identifying the differences of spaces and functionality. The result shows that consumers are aware and accept that the sensory design factors guide over them and support them to identify the functional differences of the space.

6.CONCLUSION

This research is establishing to study on how the human behaviour can be variable with the interior design approaches. As the interior design approach this research specifically studied on how the multisensory design factors impact the human behaviour in public environment. By the section of public environment this research conduct related to the shopping malls.

Related Literature proves there's need of certain control over the shopping mall environment in order to achieve the major functional objectives. It further describes what type of control it's needed. The literature on that subject area revealed the shopping malls are not just catering the audience who are coming to by certain product, but also, they are catering the consumers who came to the space to spend quality time and purchasing something besides of that. And to create those environment as they expected there has ability to use the multisensory design aspects to communicate and interact the consumers indirectly. The literature review next goes through the concept of multi-sensory design. The multisensory design is the design aspect which is trying to indulge the human sensors by creating the pleasing environment for them. Under those multisensory aspects, the sense of vision, hearing, smell, touch, and taste can be taken. The taste and the smell are the sensers which is hard to cater through the interior design. But literature shows that the visual sensation of certain aspect can imaginably stimulate the sense of taste and the smell.by that this literature will explain how the small design changes can be able to effect on how consumers are reacting to the space. this guides the survey questionaries to identify the answers area. The later literature will cover the all the theoretical information which is important for understand in human behaviour to create more suitable shopping mall space. In those theoretical aspect. the cognitive and the perception theory has more connection with the multisensory since that theory is depending on how the ambient element can interact and effect the human behaviour.

The research methodology has design to understand how the actual shopping malls has used the multimemory aspects and how much those shopping malls able to achieve

their consumers perception through that. There used three research methods. The case study, in site questions/ interview and the public survey. Case study has conduct in two shopping malls which is located nearby and with several differences. Both sites have located with the competitive urban environment which have diversity of consumers. Both has so both has followed the same overall aspects with the totally different approaches on detailing. The first part of the research methodology has conduct by combining the several research methods, first it's discussed how the space has design in each sensory aspect in a comparing in a table. Then it will discuss how user responded related to those certain sensory aspect. Later, it will show the survey result that has been got from the public survey and discuss how some aspect been successful compared to the other design aspect. The second part of the methodology will survey the hypothesis of "multi-sensory design influence people on use the space as it's required" to do that the understanding the human response is more important. The questionnaire has design in a proper structure which is easily cater to the participants. The term of multisensory not familiar for the consumers or most people, based on that the proper structure of the questionnaire support to participant to easily answered to the questions without get bothered. By the questionary it will discuss the reason to ask the certain questions and how consumer respond can be explained under the case study information.

The discussion on findings have explain how the hypothetical statement has been proven by analysing the collected data.

REFERENCES

Aghostin-sangar, v. (2007). Human behaviour. Faculty of the built environment .

Environment, F. o. (2007). HUMAN BEHAVIOUR. Sydney: The University of New South Wales, .

French, J. S. (1978). urban space . Kendall/Hunt Publishing Company, .

Hall, E. (1982). The Hidden Dimension . New York: United States by Anchor Books, adivision of Random House, Inc.

Mehrabian, A. R. (1974). An approach to environmental psychology. The MIT Press.

Paul A. Bell, T. C. (2001). Envirnmental psychology. Lawrence Erlbaum, Mahwah,.

Richard A. Feinberg, B. S. (1989). There's something social happening at the mall. Journal of Business and Psychology , 49-63.

Rybczynski, W. (2001). The Look of Architecture. Oxford University Press.

Sibel S. Dazkir, M. A. (2012, September). Furniture Forms and Their Influence on Our Emotional Responses towards Interior. pp. 722-732.

Spence, C. (2020). Senses of place: architectural design for the multisensory mind. Cognitive Research: Principles and Implications, 46.

Wellbeing design consultants. (2018). Biofilico wellness interior . Retrieved from greentherapyplace.com.

Zafar U. Ahmed (Texas A&M University at Commerce, C. T. (2007, october 9). Malaysian shopping mall behavior: an exploratory study. Asia Pacific Journal of Marketing and Logistics, 331-348.

zhuang, s. (2012). Human Behavior and the Interior Environment Sociological Human Need 2.1 Psychological Human Response 2.3 Perception and Aesthetic 2.3 Human Response to the Interior Environment. Wiley.

Narrate 'Transformed Worker' in Architecture: Specific Reference to Post Conflict Reconstruction

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ABSTRACT

Over the past several years, local and global atmospheres have revealed many internal crises that headed towards the conflicts which influenced the social, economic, political and environmental backdrops. Architecture re-defines itself as a collaborative practice in the territory of infrastructure development which is affected by the specific conflict and identified worker as an effective component in the building process. By adopting a process specific approach, it has perceived considerable transformation in workers practices influenced by economic re-growth, societal needs, technological advancement and changing design philosophies. This paper examines the transformative facets of architectural worker evolving in the upshot conflict focusing on the changing role, practices and professional rebuilt efforts on the identified context.

The research methodology involves a comprehensive analysis of case studies and investigative theoretical frameworks. Data will be gathered through the combination of interviews, onsite observations and document analysis.

The paper further explores the construction site as a training ground and a broad realm to discuss which is to be implemented more as a design and construction phase in the building process. Understanding and adapting to the changing nature of workforce composition to socially responsible built environment. Additionally, it provides insights into the human capital transformations impact on reconstruction process, organizations and the society. The discussion composes vital repercussions for policy makers to uplift building industry towards sustainable regrowth seeking to direct the challenges and opportunities by transformed workers in the contemporary built fabric.

Keywords **- Transformed worker, post-conflict reconstruction, Process- specific approach, Interdisciplinary collaboration, Professional roles,**

1. INTRODUCTION

The architecture and building industry have long been a keystone of economic and infrastructure development, contributing not only to the physical landscape but also to the livelihoods of millions of skilled professionals worldwide. However, in recent years,

this industry has faced significant challenges, including economic downturns, regulatory changes, and, most notably, the unprecedented disruptions caused by conflicts and geopolitical tensions. In times of significant conflict and geopolitical turmoil, the transformation of soldiers into civilian workers within the architecture and building industry represents a unique and critical aspect of workforce adaptation. This comprehensive research aims to investigate the multifaceted process of military personnel transitioning into civilian roles, particularly in the architecture and building sector, amid widespread conflict exploring established theoretical framework. By delving into the motivations, challenges, and outcomes of such transformations, this research seeks to shed light on a crucial but understudied dimension of both military and civilian life.

This comprehensive research aims to investigate the transformative journey of workers within the architecture and building industry who have been compelled to shift their skills and expertise into entirely different occupations due to the profound conflicts affecting their sector. The primary objective of this research is to shed light on the complexities, opportunities, and barriers that individuals encounter when navigating such a transition.

2. LITERATURE REVIEW

The purpose of this literature review is twofold: firstly, to provide a comprehensive overview of the existing body of knowledge on factors that contribute to the successful transformation of workers in the face of technological and labor market shifts; and secondly, to identify gaps or areas of contention within this literature. By synthesizing and critically analyzing the findings of previous case studies, it is to collaborate future research endeavors and contribute to a deeper understanding of the factors that influence the success of labor training programs in transforming workers.

2.1 Worker Transformation in Architecture

2.1.1 Worker: as a commodity

The concept of viewing workers as commodities in construction projects has been often considered the work force as a resource to be acquired and utilized efficiently to maximize project outcomes. It provides critical insights into the ways in which worker is classified within the building profession, and it contributes to the broader discourse on worker issues in architecture. It highlights the need for a more comprehensive understanding of the economic and social dynamics at play in architectural practice and the importance of addressing these issues for the well-being of the quality of work (Deamer, 2000).

2.1.2 Human capital as an asset (skilled workers/unskilled workers)

Human capital in construction refers to the collective knowledge, skills, expertise, and experience of individuals within the construction industry. This includes architects, engineers, project managers, construction workers, and other professionals involved in building projects. Human capital is a critical asset in construction, as it directly influences project outcomes, safety, efficiency, and innovation. Skilled and knowledgeable professionals are essential for planning, designing, managing, and executing construction projects effectively and sustainably (Becker, 1993). The construction industry relies on a

combination of skilled and unskilled workers to complete projects successfully. Skilled workers provide expertise and specialized knowledge, while unskilled workers perform essential labour-intensive tasks. Together, they form a diverse and interconnected workforce that is essential for the construction of buildings, infrastructure, and other structures.

2.1.3 Transformed worker in the building Industry.

The concept of "transformed workers" encompasses individuals who have successfully navigated the challenges posed by technological disruptions and have effectively transitioned to new roles or adapted their existing skills to remain competitive in the labor market. (Ke & Bian, 2023). Labor training plays a pivotal role in facilitating this transition, equipping workers with the knowledge and skills required to meet

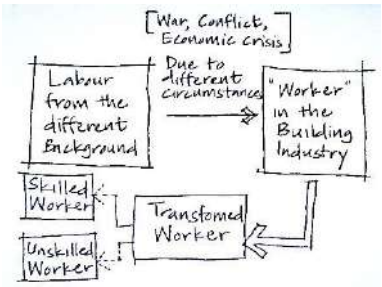


Figure 1: Labor Structure

the demands of emerging industries and job profiles.

2.2 Post-conflict Reconstructions

2.2.1 Reconstruction as a strategic change

Strategic change considers as multifaceted process aimed at rebuilding and revitalizing societies and regions in the aftermath of conflict or war. It goes beyond physical infrastructure repair to encompass broader socio-economic and political transformation. This strategic change involves establishing stability, promoting reconciliation, and fostering sustainable development (Hasic, 2004). It requires collaboration between working professionals and the communities, with an emphasis on addressing root causes of conflict and creating inclusive built environment.

2.2.2 Collaboration and Integrative Learning

In the aftermath of conflict, addressing multifaceted challenges requires the concerted effort of various stakeholders, including government agencies, local communities, and academic institutions. Interdisciplinary learning encourages professionals from diverse backgrounds, to work together, fostering a holistic understanding of complex issues and innovative solutions. Collaborative approaches, combining local knowledge, facilitate the development of sustainable strategies that encompass the composition of socio-cultural, socio- political and knowledge-based infrastructure. Integrative learning and collaboration not only promote effective reconstruction but also contribute to

long-term sustainable regrowth.

2.2.3 Build in practice

Building in practice through on-site labor training is a transformative approach that equips workers with practical skills while directly engaging them in reconstruction efforts. In post- conflict scenarios, it empowers individuals by offering hands-on experience in construction, infrastructure development, and related fields (Pathiraja, 2010). This approach not only enhances the employability of workers but also fosters self-reliance and confidence. Transformed workers, armed with newfound skills, become active contributors to rebuilding theircommunities. On-site training not only addresses the shortage of skilled labor but also serves as a catalyst for local economic growth. As transformed workers gain experience and proficiency, they play an essential role in the long-term sustainability and resilience of post-conflict regions, ultimately driving positive change and progress.

3. RESEARCH DESIGN

3.1 Methodology

The research design aimed at identifying an established theoretical framework from a single-case study and subsequently applying it to a new design project, incorporating project observation and individual interviews as key methodologies. To achieve this, the study embarked on a systematic and multi-faceted approach. Firstly, an exhaustive literature review was conducted to identify the case study, which contained the foundational theoretical framework. Once selected, the case study was examined in-depth, extracting the key theoretical underpinnings that had proven successful. Subsequently, the new design project was observed, integrating the identified theoretical framework. To refine this integration, project observation was employed, allowing for real-time data collection on how the framework manifested in practical design processes.

Additionally, individual interviews with project stakeholders provided invaluable insights into their perceptions and experiences related to the framework's application. This comprehensive research design facilitated the transfer of established theoretical knowledge into actionable design strategies, ensuring the new project's alignment with proven principles while allowing for the adaptation necessary to address specific contextual factors and stakeholder needs.

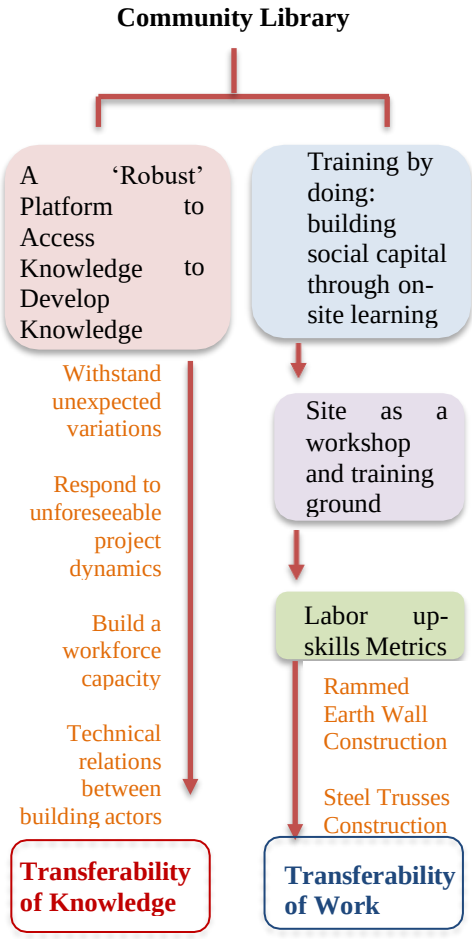
3.2 Defining Theoretical Framework

Figure 2: Ambepussa Community Library

According to the fourth Holcim Award publication in 2014/2015, Community Library at Ambepussa Srilanka by

Robust Architecture Workshop has highlighted how soldiers strategically transformed into the construction labor force in the community scale library building construction.

The project explores the possibility of using real building projects as training grounds for skill development. Planned training tasks are built into the design, an approach that can be extended across building industry as a policy to build workforce capacity establishing following parameters.



Flow chart 1: Theoretical Framework

4. CASE STUDY

4.1 Introduction to the Project

The Defense Head Quarters Complex Project is the second largest project in Sri Lanka in the recent past. The ex- armed forces are motivated, well- disciplined workforce and eventually they are utilizing their regular behaviour, values, skills and experience to the construction sector. Besides the project is the massive opportunity to make a training ground to former military workforces as they are transitioning to the industry.

Figure 3 DHQC project Site, Akuregoda

The project consists with Main Building (B1, B2, B3, B4, B6, B7 and Auditorium-B5), Services Buildings (Generator house, Pump House and Treatment Plant) and Landscape Design.

A. *B6, B7 as phase 01 Development and B8 is as phase 02 Development are selected for analyse as a training ground for young military transitions.*

B. *Aluminium fabrication workshop and Melamine Fabrication workshop is identifying as start-up construction elements.*

4.1 Aluminium Fabrication- Case 01

Aluminium fabricated items like doors, windows, ceiling sheets and pantry cupboards etc. have become the standard accepted feature in building complex. The many advantages of aluminium such as being lightweight, strength, corrosion resistance, durability, ease in fabrication, attractive appearance and easy maintenance make it a popular construction and finishing material usage in building construction.

Figure 4: Aluminium Workshop

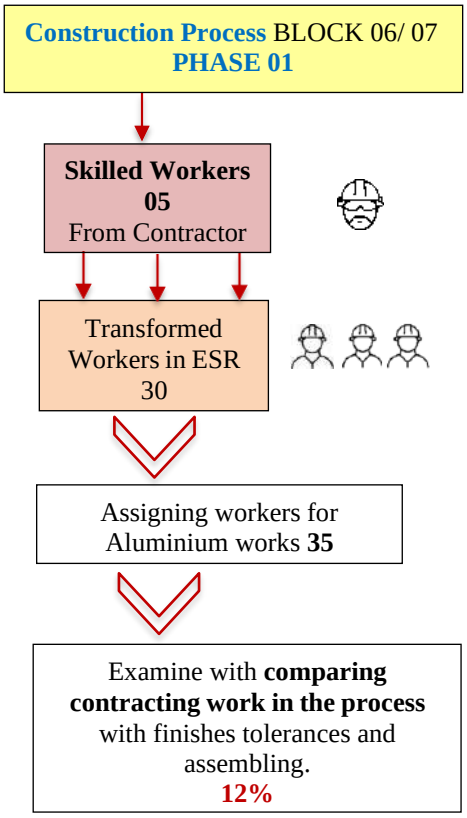
4.2 Melamine Fabrication – Case 02

The design and production process of furniture prototype with the use of reconstituted wood sheets and emphasison application of fabrication in product development including general office furniture and wall cupboards. The materials used to produce furniture were MDF (Medium Density Fibreboards) boards 18mm of thickness with melamine covering. Application of assembling prefabricated furniture components and designing the required furniture item can be seen as major work in the production and finishing stage.

Figure 5 Melamine Workshop

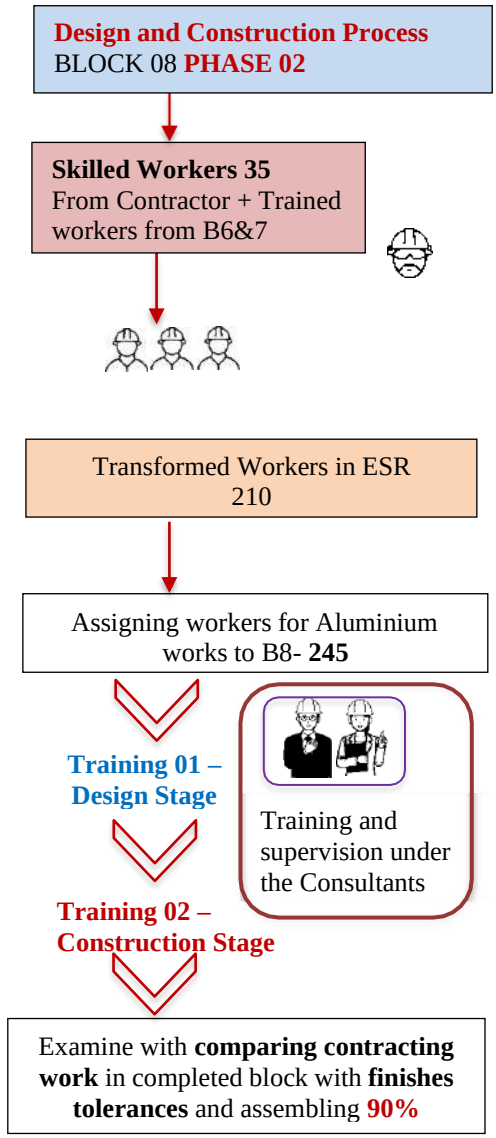
5. RESULTS AND DISCUSSION

5.1 Aluminium Fabrication- Case 01



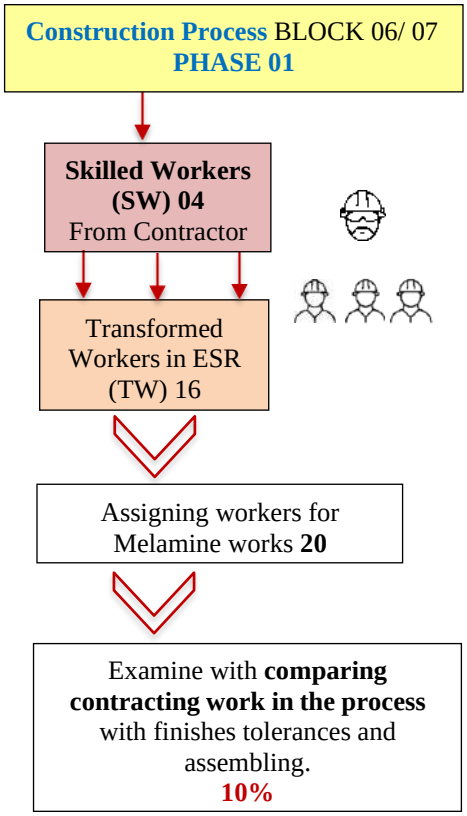
Flow chart 2: Labor structure in B6&B7 in Aluminium workshop

The workshop presents a uniqueopportunity to bridge the gap between military training and valuable vocational skills. By collaborating with professionals, this initiative can ensure that the workshop is designed andequipped to meet both military training requirements and the practical needs of a modern workforce.



Flow chart 03: Labor structure in B8 in Aluminium workshop

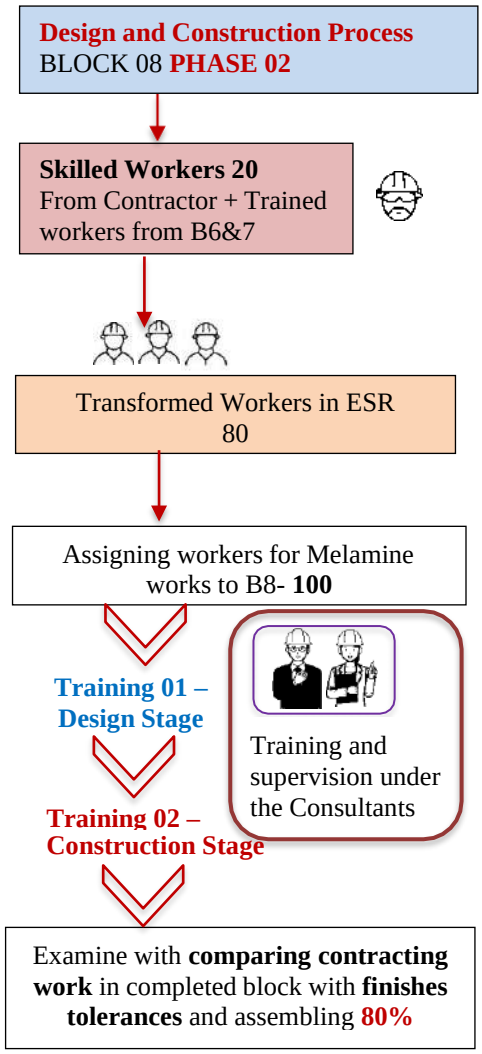
5.2 Melamine Fabrication- Case



Flow chart 4: Labor structure in B6&B7 Melamine workshop

In such a setting shown in Figure XX, project architects can play a crucial role in not only teaching technical skills but also fostering creativity and problem- solving abilities. By combining hands- on experience in a melamine workshop with architectural expertise, young soldiers can gain practical skills in woodworking, craftsmanship, and design. This interdisciplinary training approach not only equips them with valuable trade skills but also encourages them to think critically and apply their learning in various contexts. Moreover,

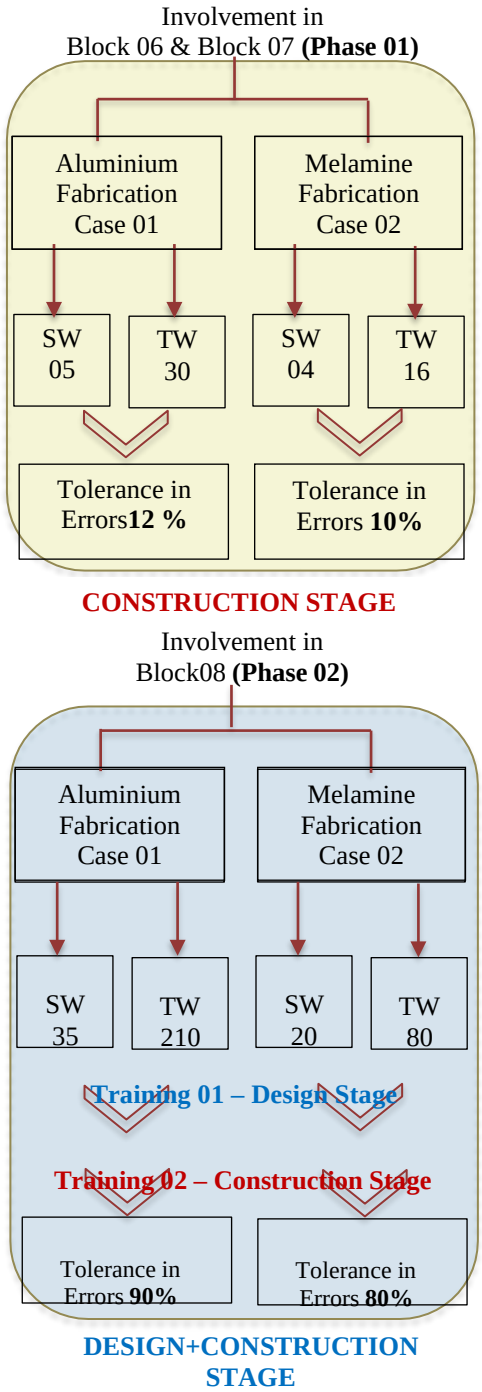
it demonstrates the potential for unconventional training grounds to adaptation for the individuals.



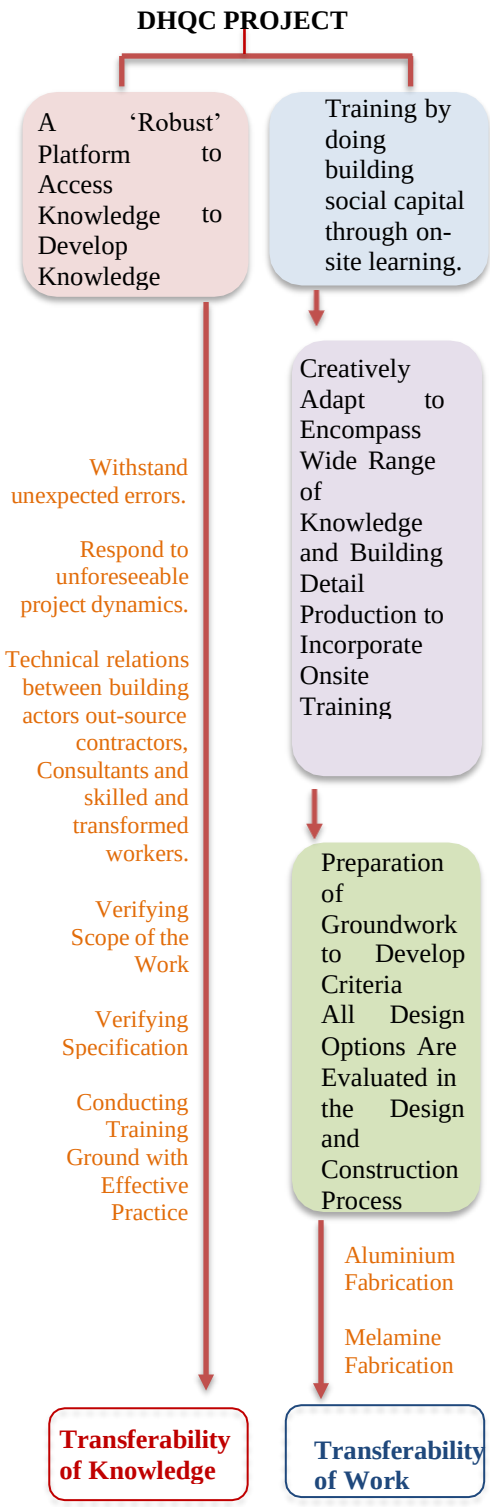
Flow chart 5: Labor structure in B8 in Melamine workshop

5.3 Cross Project Analysis Case 01 & Case 02

Cross-project analysis of the aluminium workshop and melamine workshop, both serving as training grounds for young soldiers, offers a unique opportunity to assess the effectiveness of vocationaltraining programs within a military context.



Flow chart 6: Cross analysis of Labor structure building stages



Flow chart 7: Research Findings

By comparing the skill acquisition, learning outcomes, and long-term career prospects of participants in these two workshops, valuable insights can be gained regarding the suitability of vocational training pathways for military personnel, helping to inform future training strategies and resource allocation. It depicts that 78% upsurge for tolerance to Aluminim fabrication and 70% rise for tolerance to Melamine fabrication under the supervision of Design consultants. By leveraging the experiences and best practices from both workshops, military personnel can gain valuable skills and insights during the process of transformed worker to skilled worker. This collaborative approach enhances the soldiers' proficiency and adaptability, ultimately bolstering their effectiveness in the field.

6. CONCLUSION

In most of the developed countries only the professionally qualified and certified labour is allowed to do any building construction works and that is how the quality of workmanship and final product are assured. Sri Lanka still cannot afford to have such systems but there are many positive steps that have been taken by the relevant authorities to train and improve the required skills. Therefore, training of transformed workers at any level would be complementary to the local construction industry.

Training of transformed labour for construction of buildings for themselves and their communities and has been

successfully carried out in several projects handled by the architects in Sri Lanaka. However, training of transformed worker in large scale projects like DHQC and using them directly in the project is not very common in the local construction industry.

Ultimately, the paper conveyed how acute skill shortages, poaching, traditional skill demarcations, and professional/ technical skills, lack of training and low productivity impacted on building production. Indeed, the solution to skill shortages focuses on training and importing the necessary skilled labour through restructuring the project phases and programme. Further it is needed to look to understand the 'social capital' which people are embedded within the working terrain and on sites.

REFERENCES

Deamer, P. (Ed.). (2000). Architecture and Labor. Routledge.

Becker, G. (1993). Human Capital: A Theoretical and Empirical Analysis with Special Reference to Education. Economic and Industrial Democracy, 27 (2), 240

Ke, Y., Bian, J. (2023). Systematic Training to Improve the Transformation of Migrant Workers into Industrial Workers within the Construction Sector in China. Buildings 2023, 13(8), 1948.

Thomas, D., Kapplman, A., & Richards,
(1996). Training empowerment & creating a culture for change, Empowerment in organization, 4, 3, 26-29

Hasic, T. (2004). "Reconstruction planning in post-conflict zones: Bosnia and Herzegovina and the international community" (PhD dissertation, Infrastructure).

Pathiraja. M. (2011). Architecture of a 'Third-World': Design, Technology and Architectural Education. South Asia Journal for Culture, 5&6, 137-151

Karakhan. A., Nnaji. A., Gambetese. A., Simmons. R. (20023). Best Practice Strategies for Workforce Development and Sustainability in Construction. Practice Periodical on Structural Design and Construction, 28(1)

Pathiraja. M. (2015). Strategic Resourcing, Holcim Award for Sustainable Construction, (A15)

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Impact of Workplace Layout designed to foster Collaboration on Employee Workplace Satisfaction.

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ABSTRACT

The office is found to be the place where employees spend most time of the day secondly to home which sums up to an average of eight hours. The work environment is ultimately important as it has a great effect upon their general wellbeing. Workplace design that facilitates and promotes collaboration and knowledge sharing between employees has now been a major requirement to all offices along with its high concern in employee comfortability and satisfaction of workers. Employee satisfaction is as result of a worker's psychological comfort. Thereby the workplace layout determines a properly designed office with a well thought and planned layout that could support work flow and collaboration among fellow members thus increase productivity while creating a satisfying work environment.

The chief purpose of this study is to find out whether there is a relationship between an office that designs their layout in order to foster collaboration among workers and employee satisfaction and to identify what factors causes its impact. The study analyses scenarios of three private organizations of different fields of working under three layout typologies of open space layout, enclosed shared layout and enclosed private layout. The study conducts on the layout determinants of circulation, accessibility, privacy, spatial progression and furniture arrangement.

Keywords **– workplace layout, collaboration, workspace satisfaction**

1. INTRODUCTION

With the global environment being highly competitive technological and fast-moving productivity has been a key factor to create nourished working environments. Companies constantly focus on teamworking, collaborating, resource sharing flexibility and productivity. Psychology and mental well-being are playing a significant role in impacting employee workability, job performance and satisfaction. Companies have realized that in order to foster productivity, employee

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comfort and satisfaction is important to retain the employees. Collaboration is important with the trends in business to reduce cost of electrical communication, globalized practices along with the specialized knowledge related work. It is a challenging task to create a background that inspires knowledge while achieving collaboration. Fruitful collaboration among the employees are the foundation for a company's competitive advantage.

Office interior design influences the employee's way of work by creating an environment that support quality working, quantity of working and the style of working. Through this it identifies how important it is to have the working environments designed to fulfil employees physical and emotional needs for them to become productive at work. (Proper, 1998) The research discusses facts on how a workplace design its importance and types of layouts followed by current offices. It intends to discuss how employees view their workplace and whether they find it to be a productive environment. Companies are now focusing on how well they can achieve job satisfaction and how collaboration between employees can be improved through maximizing the various factors that are included in office interior design. With the problem being identified, on improving employee job satisfaction while maintaining collaboration among employees in the work place, the problem on how it can be done in terms of the office spatial arrangement and layout, is raised up. This study specifically provides answers to the impact of office layout on employee job satisfaction in an environment that supports collaboration. It is performed by analysing office layouts of three private firms, of different fields under three different layout typologies. Accordingly, the following research objectives are being set, which will be achieved through the findings.

Primary Objective

1. To identify the relationship between collaborating workplace layout and employee satisfaction.

Secondary Objective

1. To identify what determinants of layout, affect to employee satisfaction in terms of collaboration.
2. To provide solutions to the company problems of employee job satisfaction in terms of office interior layouts and seating arrangements.
3. To identify whether a collaborating workplace layout leads to productivity.

2. LITERATURE REVIEW

2.1 Workplace Design

An office building's main function is to provide a suitable working environment that facilitates, planning, supervising, analysing, decision making and communicating. Staff members of the organization are assigned with portions of the office space along with desks, computers and other necessary machines and equipment in order to carry out these activities. An office design is the arrangement of these components, facilitating a favourable environment for people to work, research perform team work and create documents and

information. (Hassanain, 2010) Therefore, it is important that the workplace environment is planned, designed and equipped carefully in order to maximize worker efficiency. Workplace design has a direct relationship with job performance and that businesses ignoring workplace designs and layouts are unsuccessful to gain the maximum capacity out of their human resources. (Gutnick, 2007)

2.1.1 Workplace Layout Typology

Hicks and Place explains an office layout in a more definitive format as "the problem of layout relates to the arrangement in the space involved so that all equipment, supplies, procedures and personal can function at maximum efficiency" The space arrangement should happen through a proper allocation of space to each office section or department while interlinking with other departments to ease coordination and communication. An office space defectively arranged lead employees to wastage of time and energy, losing productivity and rising operational expenses. At present we see the offices changing from their conventional layouts to new forms of layout typologies, such as open office layout. With the pandemic situation in hand to support distant but open layouts, the post-COVID era of today will bring in varying trends of layout typologies and floor plan designs. An open plan office defines itself as "absence of interior partitions and rooms" (P. N. A. Muzaffar, 2020) A conference room or a formal meeting room may be available in order to facilitate private meetings but the day-to-day office functions happen in open spaces. All-managerial levels of the organizational hierarchy are seated in an open space which is believed to motivate all other employees and develop transparency and equality. Although, this may cause employees job performance to drain as they lack control of their workspace. (Lee, 2015) it increase level of stress which makes the employees to withdraw from social interactions. In the modern business world, we see that open plan layouts dominates among other layouts, claiming that it endorses an interaction and collaboration among employees. However, lack of privacy and personal space for an employee caused a major decline in worker's social interaction and work effectiveness. Therefore, employees expressed dissatisfaction in working in an open space office mainly due to the fact of overhearing conversations and thermal conditions which disturbed them to perform their work. Through this they saw the need in employees to feel comfortable within boundaries to make maximum use of their working environment. (Bernstein, 2018) While it is confirmed that there is also a capability for open office plans to boost social interaction and cooperation, enhanced feedback and knowledge sharing, it is suggested that there should be flexibility within the space which enables them to use when needed. (Shafaghat, 2014)

A closed office is where spaces are allocated to employees individually through separations of walls, cubicles or panels. This generates maximum concentration levels and boost efficiency for those employees because of an allocation of a separate personal space. However, certain employees would experience boredom and oppression by being restricted to a defined

space for several hours per day. (Naish, 2018). There are higher costs associated with closed offices as it does not support much of physical communication and employees need to heavily depend upon electronic modes. Thus, social interactions and collaboration among staff members are reduced. Enclosed work environment inhibits job supervision, since it takes a long time for a supervisor to visit from one cubicle to another. This may lead to higher level of employee privacy where they may deviate from office work and involve in personal and office unrelated tasks or engage in negative behaviour which might actually affect the employee's job performance affecting overall productivity level.

As discussed above, the various type of layouts can lead towards making the employee comfortable to work in the respective work environment impacting the employee satisfaction level to increase however the level of work productivity and efficiency is questionable.

2.1.2 Spatial Variables of Workplace Layout

A. Spatial Progression

According to (El-Zeiny, 2011) spatial arrangement in an office categorizes to a "good workplace interior design" which can make a significant variance in the job performance. the space planning should mainly concern to fit in user's requirements to improve user-environment quality, so that it would enable them to carry out their tasks efficiently and safely and this will in return gain their satisfaction.

Spatial connectedness could either connect and create working spaces interacting or can detach them. (Wolfeld, 2010) Spaces also depict the hierarchy of the organization, through the way of arrangement. Most employees are in the perception the better the office space, the better the position in the office. It usually refers to the office space assigned to the highest managerial position of the company.

B. Circulation

The main criteria that influence the interior layout and the typology of space also lies with the selection of appropriate circulation patterns. Circulation through and around a building could be categorized into direction, the type of use, the frequency and the time of use. Smith et al. shows in his research the importance between the office layout and building destinations which may influence the users walking time and sitting time, such as print and meeting rooms. (Lee Smith, 2013) (as cited in Mustafa,2021) Sloan et al Once the environment is complex in planning it affects to the people's traveling ability in unfamiliar environments where users tend to be misled more and take longer to reach to their destinations in a connected environment. These have proved that an influential factor in determining the office layout formation is the circulation pattern, and they had also declared that there is a strong relationship between the circulation patterns, and spatial formation which could greatly affect the user's work environment and behaviour patterns in a direct or indirect manner.

C. Accessibility within the layout

Accessibility is another important spatial variability that influences on a workplace layout. Oldham and Rotchford describe accessibility as "the extent to which an employee's individual workspace is accessible to the external intrusions of others". The ease of accessibility defers only based on the level of enclosure in an office or workstation by a door. Mustafa et al., they investigated the accessibility within office spaces differing on various layouts based on the relationship between space and time and they found out that proper space layout designed according to the functional aspects of spaces can reduce distance an employee travels in the office save their productive time and also achieve user satisfaction and comfort levels. (Faris Ali Mustafa, 2021)

Penn et al in their research found that spaces which are easily accessible draws interaction between employees which proves that spatial configuration has a positive influence with interactions. With a high availability of spaces to collaborate and interact there is a higher density of interactions. This may possibly be the cause to improve employee satisfaction with the ease of accessibility to such locations. It is also seen that the factors of spatial progression and accessibility are hand in hand. (A. Penn, 1999) Research found that employees tend to collaborate, communicate or interact less when the distance from an employee to another is high. Therefore, the length of the pathways available for employees to access locations impacted on their frequency and likability for communication. (Allen,1970, as cited in (Wolfeld, 2010)

Wolfeld, in the research defines accessibility as "the proximity of one employee to another and the frequency of which an employee passes another" Accordingly it was found that the extent of accessibility is positively correlated with the frequency of an induvial to engage in informal or unprepared communications. This further proved that when the level of incorporation is high along with less distance between employees it increases tendency of unprepared communications.

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2.1.3 Furniture Arrangement within a workplace layout

Placement of furniture determines employee movements and circulation throughout their working period. The location and orientation of seating heavily

depends upon their well-being, satisfaction and finally productivity. Therefore, in order to derive a better outcome arrangement of the furniture should target upon achieving work efficiency and make the employee comfortable at work. It is crucial in creating a user centred design which employees can adopt where, a well-balanced open-close ratio should be supported while giving the freedom to move. (Hazan and Tuncel, 2012 as cited by (Neslihan Top, 2019) In a research by Kruger et al, the use of orientation during a collaboration activity between students on a tabletop, was examined. Their findings came across with 3 important roles that impacted orientation, Understanding of information, Activity Coordination and Communication among participants. (Kruger, 2003) the furniture arrangement plays a vital role in achieving comfortability to all members. (Stacey D. Scott, 2004) Tang during his investigations identified that during a collaborative work activity, employees orient and partition their workspace to coordinate the activities. He also identified during another investigation that, during the task of designing a product, employees used various orientations of seating, where the new drawings were aligned to existing drawings oriented towards a specific person and to develop a new audience when explaining. However, during tasks included loosely coupled collaborations the participants partition the workspace based on their seating positions. (Tang, 1991)

2.1.4 Privacy within the workplace layout

In a workplace layout Privacy is referred to as the "ability to regulate the incoming and outgoing information flow and social contact.

Various privacy types apply to space design. Architectural privacy refers to "The visual and acoustical isolation supplied by the physical design of the environment." Acoustical privacy refers to the "measure of sound insulation between internal and external spaces" whereas Visual privacy refers to "the ability of residents to carry out private functions within private rooms or open spaces without compromising views, ventilation, sunlight access or other internal and external space functions" (NSW Department of Planning and Infrastructure, 2011) Visual and acoustical distractions in a space which create a lack of privacy of an employee tend to decrease productivity of work, which proves that there is a positive relationship between privacy and employee performance. One of the most important aspects of acoustic privacy is achieving speech privacy in a workplace.

This extends to being an expense for the employer while trying to choose between the dilemma of collaboration and conversational privacy. It is believed that certain employees require a higher level of privacy in a workspace which is important in the decision-making process and to bring a feeling of secureness. Lack of privacy causes an employee feel uncomfortable to concentrate and focus on the task due to the lack of visual and sound privacy. (Bernstein, 2018) It was found in researches that the lack of confidentiality due to high noise levels was a major complaint in open plan offices. (Gabor Nagy, 2004)

2.2. Employee Collaboration

With the current practical and managerial approaches being implemented, the workspace requirements need to be studied and addressed on how employee collaboration and interaction has an influence on it. Spatial organizations allow individuals not only for informal communications but also in collaborative experiences which are essential in team working in an extreme creative manner. It is also believed that good office designs are likely to create casual or unexpected encounters by the use of spaces which are in between individual work terminals and collaborative spaces such as separated meeting areas, spaces shared for common use of office equipment, coffee stations, recreational areas, break out rooms, circulating spaces etc. (McCoy 2000) Collaboration zones in offices are in on the trend for most workplace designs, where featured furniture items such as modular pieces allow employees to adapt the space according to their preference and with the users as required.

2.3. Workplace design and employee Satisfaction

Generally, it was found that the elements such as noise, lighting, temperature and windows are having an impact on behaviours attitudes and satisfaction of employees. (Crouch, 1989)

According to Jae Vanden Berghe 2011, it was identified that the physical work environment is having a larger impact on the satisfaction levels of the employees whereas aspects of comfort, communication, access and functional efficiency were considered more than three times more important than the working hours, compensation and benefits of management. (Berghe, 2011) A good office design can also make a great impact to staff satisfaction, motivation attraction and retention according to the research conducted by Limor Gutnick in 2007, Followers of open plan office designs also says that a good design can help good communication and interaction among employees and thus it increases morale, productivity and finally satisfaction. (Bach, 1965)

According to Adedayo et al (2016), at many instances the users of the space are forced to adapt to the offices provided and these affect their productivity levels very often. Building designers should aim to evaluate what users consider as comfortable enough for them and incorporate high level of user comfort in order to increase work productivity.

3. APPROACH

With the conducted literature review, certain variables and indicators serving as determinants of layout and space were identified. Thereby, it is intended to identify the impact of independent variables of Circulation, Accessibility, Privacy, Spatial Progression and Furniture Arrangement, on the Dependant Variable Employee Workplace Satisfaction. Accordingly, the below hypothesis will be tested based on the identified independent variables against the dependent variable for the three each type of layouts discussed.

$H1_1$ - Employees are satisfied when circulation paths allow them for

collaboration and communication with their co-workers.

$H1_0$ - Employees are not satisfied when circulation paths allow them for collaboration and communication with their co-workers.

$H2_1$ - Employees are satisfied with the level of accessibility to shared spaces.

$H2_0$ - Employees are satisfied with the level of accessibility to shared spaces.

$H3_1$ - Employees are satisfied with the level of privacy at their workstation in a layout of collaborative working.

$H3_0$ - Employees are not satisfied with the level of privacy at their workstation in a layout of collaborative working.

$H4_1$ - There is an impact of spatial progression on employee satisfaction.

$H4_0$ - There is no impact of spatial progression on employee satisfaction.

$H5_1$ - There is an impact of collaborative furniture arrangement on employee satisfaction

$H5_0$ - There is no impact of collaborative furniture arrangement on employee satisfaction

3.1 Case Study

The layout typologies for the case were selected as "Open plan offices with limited partitions, Enclosed Shared Offices and Enclosed Private offices."

Open plan offices are the types of layouts which includes less or no cubicles or partitioning. Enclosed Shared Offices are the types of layouts which are partitioned but shared spaces between them. Enclosed private offices are where each employee is in a closed environment.

A. Company A

This office is in an open plan layout, where employees are seated in 4 gang workstations and 6 gang workstations. Each of these gangs are with a plant trough separation at the middle. Each table includes space for personal storage. The employees have a dedicated worktable where they are seated according to their department. The 4 managers are in separated by open partitions. The meeting room, Managing Director's office and pantry are in partitioned private spaces. The printing area is between 2 manager stations which is accessed and shared by all employees. The gang workstations create a hub where employees access other common areas through this space. Visitors for the managers access the respective manager workstation from the reception through the gang workstation.

Figure 1. Layout and Zoning plan of

Company B

The company is an enclosed shared office. There is a higher need for inter-departmental communication, and heavy amount of hard copy document and file preparation, thus printing area commonly used by all departments. Departments are separated and each department comprise of teams which are seated together with a specific team leader. Further, employees work in inter-departmental teams for each design project. Employees are seated at 2 and 4 Gang workstations without any separation. Departments are enclosed with a door. The design department and the quantity surveying department is seen to have higher visits due to the higher communication and collaborative working processes hence material sample storage and sample board preparation is located between these departments.

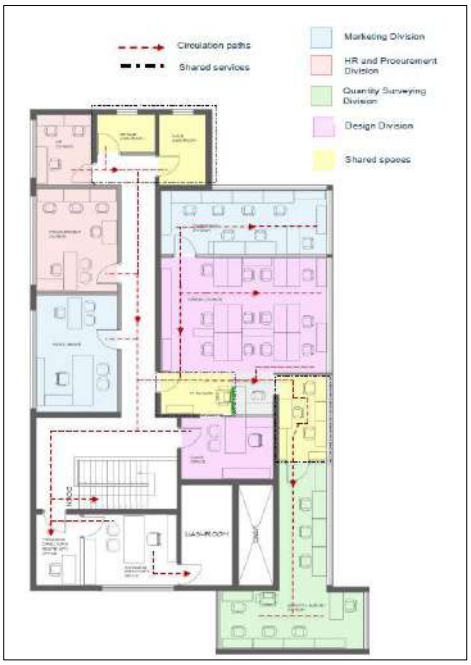
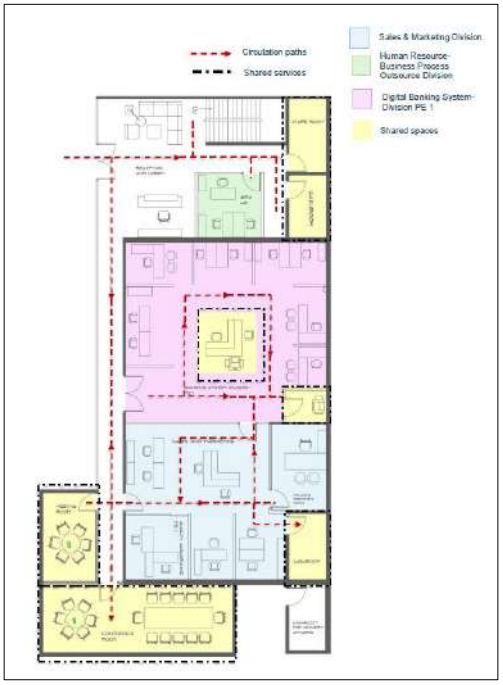


Figure 2. Layout and Zoning plan of Company B

B. Company C

This is an enclosed private office which maintains a high degree of software confidentiality within the office. The departments are separated through partitions and groups are further subdivided by function allocating a group manager for each. Printers and scanning services are allocated to each group along with file storage spaces. The space consists of reception area, and a conference room. Employees need to access the 1st floor which consists of an open dining and pantry space. Departments and sub departmental separations are enclosed with a door. There is a heavy amount of confidential printing and scanning performed thus printing services are common. Inter-departmental communication is high.

Figure 3. Layout and Zoning plan of Company C



4. DATA ANALYSIS

Data Collection was conducted through a questionnaire. The sample includes 75 employees 25 each from the 3 offices. Questions relating to indicators under each of the identified variables were measured using a 5 point Likert Scale where 1 = Strongly Disagree,
2 = Disagree, 3 = Neutral, 4 = Agree,
5 = Strongly Agree. Open ended questions were also included which allowed the participants to input descriptions on how they felt about their workplace. Therefore data was analysed both quantitatively and qualitatively.

Statistics

		Circulation	Accessibility	Privacy	Spatial Progression	Furniture Arrangement	Productivity
N	Valid	75	75	75	75	75	75
	Missing	0	0	0	0	0	0
Mean		3.6267	4.0400	3.8000	3.6333	3.6267	3.1800
Median		4.0000	4.0000	4.0000	4.0000	4.0000	3.0000
Mode		4.00	4.00	4.00	4.00	4.00	3.00
Std. Deviation		.96944	.77877	.92998	.90170	.95540	1.16143
Variance		.940	.606	.865	.813	.913	1.349
Minimum		1.00	1.00	2.00	1.50	1.00	1.00
Maximum		5.00	5.00	5.00	5.00	5.00	5.00

a. Multiple modes exist. The smallest value is shown

Table 1. Descriptive Statistics

The mean value for circulation is at 3.6, median and mode values are at 4 Employees are satisfied with circulation pathways supporting for collaboration. Mean, median and mode for accessibility too stands at 4.0 where most of the employees are satisfied with the level of accessibility to shared spaces within their workplace layouts. A mean value of 3.8 and mode and median values of 4 for Privacy means employees are satisfied with the level of privacy available in a collaborative work environment. Spatial progression gives a mean value of 3.6 and mode and median values at 4 where most of the employees are agreeing to a collaborative space layout. Furniture arrangement too stands at the same level. agreeing for a collaborative arrangement. Productivity indicators draw the attention here where the mean value records to be at 3.18 and mode and median at 3 which shows that the respondents have neutrally answered, neither agreed nor disagreed.

However, Overall satisfaction with work environment indicators are at an agreeable level.

When analyzing the Mean values across all types of layouts, we see that employees of the enclosed shared offices showed the highest satisfaction level for collaborative circulation pathways with a mean value of 3.88 while employees in private offices showed the least satisfaction.

Table 2. Overall Mean Score of Workplace Satisfaction Across Three Layout Types

	Mean		
Variable	Open Plan Layout	Enclosed Shared Office	Enclosed Private Office
Circulation	3.60	3.88	3.49
Accessibility	3.73	4.29	3.90
Privacy	2.94	3.06	3.58
Spatial Progression	3.59	3.75	3.60
Furniture Arrangement	3.33	3.76	3.69
Total Mean Score	3.44	3.75	3.65

Satisfaction level with Privacy in an open plan layout is the lowest and dissatisfied with a score of 2.9, where enclosed private offices has the highest.

Thus, privacy has the strongest relationship with the satisfaction level. Enclosed shared offices show a higher satisfaction with spatial progression, with a mean value of 3.75 and open layouts show the lesser. Enclosed shared offices recorded the highest value at 3.76 of furniture arrangement affecting satisfaction.

Table 3. Correlation between variables in Open Plan Office Layout

Correlations

			Employee Workplace Satisfaction in Open Plan Layout	Circulation in Open Plan Layouts	Accessibility in Open Plan Layout	Privacy in Open Plan Layout	Spatial Progression in Open Plan Layout	Furniture Arrangement in Open Plan Layout
Spearman's rho	Employee Workplace Satisfaction in Open Plan Layout	Correlation Coefficient	1.000	.255	.698**	.354	.400*	.543**
		Sig. (2-tailed)	.	.219	.000	.082	.047	.005
		N	25	25	25	25	25	25
	Circulation in Open Plan Layouts	Correlation Coefficient	.255	1.000	.083	.425*	.366	.636**
		Sig. (2-tailed)	.219	.	.693	.034	.072	.001
		N	25	25	25	25	25	25
	Accessibility in Open Plan Layout	Correlation Coefficient	.698**	.083	1.000	.117	.344	.524**
		Sig. (2-tailed)	.000	.693	.	.577	.092	.007
		N	25	25	25	25	25	25
	Privacy in Open Plan Layout	Correlation Coefficient	.354	.425*	.117	1.000	.456*	.556**
		Sig. (2-tailed)	.082	.034	.577	.	.022	.004
		N	25	25	25	25	25	25
	Spatial Progression in Open Plan Layout	Correlation Coefficient	.400*	.366	.344	.456*	1.000	.687**
		Sig. (2-tailed)	.047	.072	.092	.022	.	.000
		N	25	25	25	25	25	25
	Furniture Arrangement in Open Plan Layout	Correlation Coefficient	.543**	.636**	.524**	.556**	.687**	1.000
		Sig. (2-tailed)	.005	.001	.007	.004	.000	.
		N	25	25	25	25	25	25

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

In order to test the developed hypothesis for each layout typology, bivariate correlation was conducted for each type of layout separately. Here the Spearman's coefficient is used measure the correlation between the independent variables and employee satisfaction.

A. Open plan Office Layout

The significant value for circulation records at 0.219 which is higher than the statistically significant value of 0.05. The collaborative circulation in open plan offices does not significantly correlate with employee workplace satisfaction, hence the null hypothesis is accepted.

$H1_0$ - Employees are not satisfied when circulation paths allow them for collaboration and communication with their co-workers.

The significant value for accessibility records at 0.000 which is statistically significant. This explains that the accessibility level to shared spaces in an open plan office significantly correlates with employee workplace satisfaction, hence the hypothesis is accepted.

$H2_1$ - Employees are satisfied with the level of accessibility to shared spaces.

The significant value for privacy records at 0.082 which is statistically insignificant, the privacy level at an open plan office does not significantly correlate with employee workplace satisfaction, hence the null hypothesis is accepted.

$H3_0$ - Employees are not satisfied with the level of privacy at their workstation in a layout of collaborative working.

The relationship existing between spatial progression and employee workplace satisfaction is recorded to be statistically significant at a level of 0.047, hence the hypothesis is accepted.

$H4_1$ - There is an impact of spatial progression on employee satisfaction.

With the Sig value recording at 0.05 it shows a statistically significant value of collaborative furniture arrangement in an open plan office which is impacting upon employee workplace satisfaction an

$H5_1$ - There is an impact of collaborative furniture arrangement on employee satisfaction and hence accepts the hypothesis.

Table 4: Correlation between variables in Enclosed Shared Office Layout

Correlations

			Employee Workplace Satisfaction	Circulation in Enclosed Shared Office	Accessibility in Enclosed Shared Office	Privacy in Enclosed Shared Office	Spatial Progression in Enclosed Shared Office	Furniture Arrangement in Enclosed Shared Office
Spearman's rho	Employee Workplace Satisfaction	Correlation Coefficient	1.000	.415*	.537**	.495*	.517**	.496*
		Sig. (2-tailed)	.	.039	.006	.014	.008	.012
		N	25	25	25	25	25	25
	Circulation in Enclosed Shared Office	Correlation Coefficient	.415*	1.000	.449*	.233	.621**	.421*
		Sig. (2-tailed)	.039	.	.024	.261	.001	.036
		N	25	25	25	25	25	25
	Accessibility in Enclosed Shared Office	Correlation Coefficient	.537**	.449*	1.000	.395	.550**	.599**
		Sig. (2-tailed)	.006	.024	.	.051	.004	.002
		N	25	25	25	25	25	25
	Privacy in Enclosed Shared Office	Correlation Coefficient	.495*	.233	.395	1.000	.602**	.163
		Sig. (2-tailed)	.014	.261	.051	.	.001	.435
		N	25	25	25	25	25	25
	Spatial Progression in Enclosed Shared Office	Correlation Coefficient	.517**	.621**	.550**	.602**	1.000	.220
		Sig. (2-tailed)	.008	.001	.004	.001	.	.291
		N	25	25	25	25	25	25
	Furniture Arrangement in Enclosed Shared Office	Correlation Coefficient	.496*	.421*	.599**	.163	.220	1.000
		Sig. (2-tailed)	.012	.036	.002	.435	.291	.
		N	25	25	25	25	25	25

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

B. Enclosed Shared Office Layout

The significant value for circulation records at 0.039 and is statistically significant. The

collaborative circulation in enclosed shared offices significantly correlate with employee workplace satisfaction, hence the hypothesis is accepted for this layout.

$H1_1$ - Employees are satisfied when circulation paths allow them for collaboration and communication with their co-workers.

The significant value for accessibility records at 0.006 which is statistically significant. the accessibility level to shared spaces in an enclosed shared office strongly correlates with employee workplace satisfaction, hence the hypothesis is accepted.

$H2_1$ - Employees are satisfied with the level of accessibility to shared spaces.

Significant value for privacy records at 0.014. the privacy level at an enclosed shared office does correlate with employee workplace satisfaction, hence the hypothesis is accepted.

$H3_1$ - Employees are satisfied with the level of privacy at their workstation in a layout of collaborative working.

The relationship existing between spatial progression and employee workplace satisfaction is recorded to be statistically significant at a level of 0.008, hence the hypothesis is accepted.

$H4_1$ - There is an impact of spatial progression on employee satisfaction.

A collaborative furniture arrangement in an enclosed shared office is impacting upon .

employee workplace satisfaction and it depicts a strong relationship and with the Sig value recording at 0.012 it shows a statistically significant value and hence accepts the hypothesis.

$H5_1$ - There is an impact of collaborative furniture arrangement on employee satisfaction.

C. Enclosed Private Office Layout.

The significant value for circulation records at 0.075 and is statistically insignificant. The collaborative circulation in enclosed shared offices does not correlate with employee workplace satisfaction, hence the null hypothesis is accepted for this layout.

$H1_0$ - Employees are not satisfied when circulation paths allow them for collaboration and communication with their co-workers.

The significant value for accessibility records at 0.048 which is statistically significant. The accessibility level to shared spaces in an enclosed shared office strongly correlates with employee workplace satisfaction, hence the hypothesis is accepted.

$H2_1$ - Employees are satisfied with the level of accessibility to shared spaces.

Significant value for privacy records at 0.030. the privacy level at an enclosed shared office does correlate with employee workplace satisfaction, hence the hypothesis is accepted

Table 5: Correlation between variables in Enclosed Private Office Layout

Correlations

			Employee Workplace Satisfaction in Enclosed Private Office Layout	Circulation in Enclosed Private Office Layout	Accessibility in Enclosed Private Office Layout	Privacy in Enclosed Private Office Layout	Spatial Progression in Enclosed Private Office Layout	Furniture Arrangement in Enclosed Private Office Layout
Spearman's rho	Employee Workplace Satisfaction in Enclosed Private Office Layout	Correlation Coefficient	1.000	.362	.400*	.435*	.408*	.454*
		Sig. (2-tailed)	.	.075	.048	.030	.043	.023
		N	25	25	25	25	25	25
	Circulation in Enclosed Private Office Layout	Correlation Coefficient	.362	1.000	.186	.062	.298	-.009
		Sig. (2-tailed)	.075	.	.374	.767	.148	.965
		N	25	25	25	25	25	25
	Accessibility in Enclosed Private Office Layout	Correlation Coefficient	.400*	.186	1.000	-.033	.048	.175
		Sig. (2-tailed)	.048	.374	.	.874	.821	.402
		N	25	25	25	25	25	25
	Privacy in Enclosed Private Office Layout	Correlation Coefficient	.435*	.062	-.033	1.000	.689**	.336
		Sig. (2-tailed)	.030	.767	.874	.	.000	.101
		N	25	25	25	25	25	25
	Spatial Progression in Enclosed Private Office Layout	Correlation Coefficient	.408*	.298	.048	.689**	1.000	.202
		Sig. (2-tailed)	.043	.148	.821	.000	.	.332
		N	25	25	25	25	25	25
	Furniture Arrangement in Enclosed Private Office Layout	Correlation Coefficient	.454*	-.009	.175	.336	.202	1.000
		Sig. (2-tailed)	.023	.965	.402	.101	.332	.
		N	25	25	25	25	25	25

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

$H3_1$ - Employees are satisfied with the level of privacy at their workstation in a layout of collaborative working.

The relationship existing between spatial progression and employee workplace satisfaction is recorded to be statistically significant at a level of 0.043, hence the hypothesis is accepted. However, productivity as a whole is questionable when there is availability of individual space with high privacy. (Reddy, 2019)

$H4_1$ - There is an impact of spatial progression on employee satisfaction.

A collaborative furniture arrangement in an enclosed shared office is impacting upon employee workplace satisfaction and it depicts a strong relationship and with the Sig value recording at 0.023 it shows a statistically significant value and hence accepts the hypothesis.

$H5_1$ - There is an impact of collaborative furniture arrangement on employee satisfaction.

4.1 Qualitative analysis

As discussed in the literature review, satisfaction is a pleasurable or emotional state that is resulting from job aspects and a widely investigated concept under organizational psychology (Iresearchnet, 2020) hence their real state of responses is depicted in open ended questions. Employees prefer to exchange ideas however, they view the open space to have no personal control over it. Since circulation by the workspace happens more this tend to increase n open spaces tend to

have low privacy both in terms of visual and acoustic. Respondents depict this through answers such as "people's conversations may distract the work", "Excessive noises at site". it was seen that the spatial progression actually matters to the employees although it is not in an open space plan. which describes that circulation pathways could also bring in less privacy and personal space. Studies have proved team working and collaboration can lead to higher productivity strongly supporting the notion the more the individuals share information, the higher the group performance and productivity (Wolfeld, 2010) where an employees believe that Open office environment gives more space and I think it will give more opportunities." And that "Technology company should have open space and friendly environment to innovate and bring our creative ideas to work." However, to some collaborative capacity is not necessarily seen to satisfy the employees, where some respondents of enclosed shared office prefer individual space in being productive. On the other hand, there are also some that would prefer more social interaction in enclosed private offices since they tend to have "Fixed working space" oise levels disturbing to focus on work.

5. FINDINGS AND CONCLUSION

Deriving at overall findings, it was identified that in a nutshell despite of the type of layout Privacy had the most impactable determinant of a collaborative layout on Employee workplace satisfaction, while circulation was the least and weakest, meaning that in a layout which is designed to collaborate Privacy levels need to be of higher concern with regard to creating a satisfactory workplace for employees.

It was seen that in open plan layouts, having collaborative Circulation paths did not satisfy the employees. When collaborative capacity increased, within circulation pathways, employees found that they have less control over their workplaces and that the noise levels were too high, this made them to less focus on work. However, employees of enclosed shared layout spaces and enclosed private layout spaces are found to be satisfied when collaboration happens during the circulation. On a positive note, it was identified that the level of accessibility to shared spaces were satisfactory with employees of all types of layouts. Employees of enclosed layouts were satisfied with the level of privacy even in a collaborative work environment.

The results of Spatial Progression inform that the employees of all types of layouts were concerned about the arrangement and progression of spaces, departments and offices. impacting their workability and productivity.

Furniture arrangement in all three types of layouts also showed that they have a positive impact on employee workplace satisfaction while in a collaborative setting.

However, it may be contradictory to find that the employees of open layouts are lacking personal space within their workstation in an open setting while the furniture arrangement is satisfactory. It may possibly be due to fact that the average response rate of furniture arrangement satisfaction is being viewed here, and the study does not necessarily examine the

seating positions within the layout. Therefore, it could differ from position to position as in findings of other studies where employees at end of the row achieves more privacy than those positioned at the middle or front.

The research only considers 3 layout typologies only among three fields of employment. Results may differ from various other layout typologies and other fields of working, and the study in concern looks over only the median values of a significant portion of employees in the company.

The results supported concepts that were not predicted under the hypothesis. Another significant finding was the relationship between overall employee workplace satisfaction in terms of satisfaction derived from independent variables and Productivity. This recorded a strong relationship which cleared the questionable area of whether an employee is essentially productive although he/she achieves satisfaction from the workspace.

REFERENCES

A. Penn, J. D. (1999). The space of Innovation: Interaction and Communication in the Work Environment. Environment and Planning B: Planning and Design, 193-218.

Hajdukova, A., & J. K. (2014). The job satisfaction as a regulator of the working behavior. Procedia - Social and Behavioral Sciences, 190, 471–476.

Bach, F. W. (1965). The whys and wherefores of the open-plan office. . Kommunikation, 103-106.

Berghe, J. V. (2011). Job Satisfaction and Job Performance at the Workplace.

Bernstein, S. T. (2018). The Impact of The Open Workspace on Human Collaboration.

Brill, M. M. (1984). Using Office Design to Increase Productivity. . Workplace Design and Productivity.

Cambridge Sound Management. (2015). Solving the Workplace Speech Privacy Crisis. https://cambridgesound.com/wp-content/uploads/2015/09/CSM-WP-The-Workplace-Speech-Privacy-Crisis_Web.pdf: WhitePaper.

Crouch, A. &. (1989). Perceived facilitators and inhibitors of work performance in an office environment. 206–226.

Danielsson, C. B. (2010). Architectural Design's Impact on Health, Job Satisfaction & Well-being. Sweden: KTH School of Architecture and Built Environment.

De Croon, E. S.-D. (2005). The effect of office concepts on worker health and performance: A systematic review of the literature. . Ergonomics, 119–134.

El-Zeiny, R. M. (2011). The Interior Design of Workplace and its Impact on Employees' Performance: A Case Study of the Private Sector Corporations in Egypt. Procedia - Social and Behavioral Sciences, 35, 746-756.

Faris Ali Mustafa, S. A. (2021). Role of office layout typology in saving time and distance spent by users: Case of office buildings in Erbil city. Ain Shams Engineering Journal.

Gabor Nagy, K. F. (2004). Office LAyout and Workplace Enclosure as mediators to workers' privacy and Communication affecting Productivity. Journal of Architecture and Planning, 55-63.

Gutnick, L. (2007). A workplace design that reduces employee stress. Master's Theses and Doctoral Dissertations, 151.

Ha, M. K.-K.-H. (2002). Office Environmental Satisfaction Focusing on Persona and Common Spaces . Journal of Asian Architecture and Building Engineering, 165-170.

Hassanain, M. A. (2010). Analysis of factors influencing office workplace planning and design in corporate facilities. Journal of Building Appraisal, 183-197.

Hughes, V. S. (1973). Why Employees Stay. Employee Retention. Retrieved from Harvard Business Review.

Inamizu, N. (2014). Two densities for successful non-territorial offices: A case of Microsoft Japan. Annals of Business Administrative Science,, 05–127.

Inkpen, A. C. (1996). Creating Knowledge through Collaboration. California management review, 123-140.

Iresearchnet. (2020). Psychology . Retrieved from Iresearchnet.

Lee Smith, M. U. (2013). Active buildings: modelling physical activity and movement in office buildings: An observational study protocol. BMJ Journals.

Lee, P. L. (2015). Impact of Noise on Self-rated Job Satisfaction and Health in Open-Plan Offices: A Structural Equation Modeling Approach. Impact of Noise on Job Satisfaction and Health.

Luparello, D. (2004). Office design trends. Interiors & Sources, 12(20).

M. Potkany, G. (2013). Statistical prognosis of basic business performance indicators in the wood

processing industry of the Slovac Republic. In: Markets for wood and wooden products. Zagreb : WoodEMA, 31-56.

Mark Saunders, P. L. (2018). Research Methods for Business Students (Fifteenth ed.). India: Pearson.

Mital, A. M. (1992). Noise in multiple-workstation open-plan computer rooms: measurements. Journal of Human Ergology, 69-82.

Monroe, L. (1999). The 'new' workplace: Emerging and packaged technology assure flexibility and connectivity. Building, 84(2).

N. Kamarulzaman, A. A.-G. (2011). An Overview of the Influence of Physical Office Environments towards Employees. Procedia Engineering, 262-268.

Naish, S. (2018, December 11). Open Office Vs Closed Office. Retrieved from TC&D: https://tcdconstruction.co.uk/open-office-vs-closed-office-which-is-best/

Neog, B. B., & Barua, M. (2014). factors influencing employee's job satisfaction. The SIJ Transactions on Industrial, Financial & Business Management (IFBM).

NSW Department of Planning and Infrastructure. (2011). SEPP 65 & Residential Flat Design Code Review: State Environmental Planning Policy No 65. New South Wales: Department of Planning and Infrastructure.

P. N. A. Muzaffar, N. M. (2020). A comparative Study on the impacts of open plan and closed office layout towards employees' perceived productivity. Jurnal Penyelidikan Sains Sosial (JOSSR), 49 - 58.

Proper, E. (1998). Surroundings affect worker productivity; office design is more than cosmetics. Industry week, 247(11).

Rashid, M. K. (2006). Spatial layout and face-to-face interaction in office study of the mechanisms of spatial effects on face-to-face interaction. Environment and Planning B: Planning, 825-844.

Ray, L. (2019, March 06). What Are the Causes of Job Satisfaction in the Workplace? Retrieved from Chron.com: https://smallbusiness.chron.com/causes-job-satisfaction-workplace-21851.html

Reddy, C. (2019). Closed Office Layout: Advantages and Disadvantages. Retrieved from WiseStep: https://content.wisestep.com/advantages-disadvantages-closed-office-layout/

Robert L. Cross, R. D. (2006, August 1). Mapping the Value of Employee Collaboration. Retrieved from McKinsey Quarterly: https://www.mckinsey.com/business-functions/people-and-organizational-performance/our-insights/mapping-the-value-of-employee-collaboration

Shafaghat, A. (2014). Open Plan Office Design Features Affecting Staff's Health and Well-being. .

hilpa Kochar, J. W. (2019). Network Ties and Their Effect on Employee Collaboration in Enterprise Social Networks: A Review and Research Agenda. Australasian Conference on Information Systems, 711-717.

Soltani, S. (2016). Analyzing Legibility of Space in Office Buildings:Case Studies in Kerman Iran. 2016;6(7):28–37. International Journal Eng Res Appl, 28-37.

Staff, C. S. (2021). Corporate Suites. Retrieved March 27, 2022, from https://www.corporatesuites.com/how-office-layout-affects-productivity/#Ergonomics_Reduce_Distractions

Sundstrom. E., T. J. (1982). Physical enclosure, type of job and privacy in the office. Environment and Behaviour , 543-559.

The concept of Spatial Progression in Architecture. (2019). The concept of Spatial Progression in Architecture.

Wolfeld, L. R. (2010). Effects of Offiffice Layout on Job Satisfaction, Productivity and Organizational Commitment as Transmitted through Face-to-Face Interactions. Colonial Academic Alliance Undergraduate Research Journal, 1.

Ying Hua, V. L. (2010). Workplace Collaborative Space Layout Typology and Occupant Perception of Collaboration Environment. Environment and Planning B: Urban Analytics and City Science, 37(3), 429-448.persons by their posts/positions. You may acknowledge funding organizations, research institutes, and those who have supported your research work.

Moving to Online Design Learning
Exploring the Design Process Adopted in Online Design Studio

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ABSTRACT

Design studio education is an established pedagogic mode throughout last many decades. During the pandemic period, the entire design education moved to online platform without any prior testing on learning outcomes. This study aims on understanding the influences made on the natural design process of students due to the movement made from conventional design studio to online design studio. for this study 25 students were selected adopting convenient sampling technique. The design process of students was observed through naturalistic observation and focus group interviews were conducted additionally. The results were analyzed through the thematic analysis.

Keywords— **Design process, online design studio, collaboration**

1. INTRODUCTION

The design studio eduction is placed at the heart of the design pedagogy. The design studio addops a uniques and dynamic teaching and learning mechanism where the students are learnng by doing (Abdelmonem 2016). The design studio context is having its own characterictics and learning mechanisums (Bashier 2014). Design students are usually getting design tasks and they are developing design proposals colobaratively or individually while working in design studio context (Schön 2016). This model of teaching and learning was not changed much and got modified time to time.

However the outbreak of COVID-19 in

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early 2020 brought about a drastic shift in the field of education, and architectural design studio learning was no exception. The conventional design studio, known for its collaborative, hands-on, and in-person nature, faced unprecedented challenges. This study explores the profound impact of moving to online design studio for architectural design learning, revealing not only the challenges it posed but also the changes made on design process adopted.

2. ONLINE DESIGN STUDIO

In conventional design studios, students and design tutors/ lecturers work together in a physical space, fostering a sense of community and collaboration (Al-Qawasmi 2005). The physicality of this environment allows for spontaneous conversations, immediate feedback, and the sharing of physical models and sketches. It encourages students to engage in face-to-face discussions, exchange ideas, and physically manipulate design elements. With the transition to virtual studios, this essential aspect of architectural education was disrupted (ADIGÜZEL ÖZBEK et al. 2018). The collaboration has been made through a digital platform where face-to-face interaction was limited .

In conventional design studio context, the face-to-face interaction has been placed at a higher level and students are learning from peer reflections and feedback. Not only that, but the conventional design studio also practices the master apprentice model where the student get direct guidance and reflections form the design tutors at the design studio.

Replicating the collaborative nature of the conventional design studio context in virtual environments is undoubtedly challenging. Video conferences and online platforms, while valuable for communication, could not entirely replicate the dynamic interactions that occur in a physical studio. Collaborative activities, such as group design charrettes, pin-up reviews, and model-making sessions, lost some of their immediacy and spontaneity cannot be replicate as it is and the online platform will create a different mode of collaboration than what they experienced in conventional design studio.

Not only that, architectural education places a strong emphasis on tactile learning, where students physically construct models, manipulate materials, and experience the three-dimensional nature of design. In virtual settings, this hands-on approach was compromised. Students missed the opportunity to create physical models, study material textures, and experience the haptic qualities of their designs.

2.1 Design Process in online design studio

The design process of students has got influenced due to this movement. The shift to virtual studios exposed disparities in students' technical skills and access to digital tools. Some students were proficient in using design software and comfortable with online collaboration, while others faced technical challenges and required additional support. Connectivity issues and unreliable internet access added another layer of complexity.

The rapid adoption of digital tools, such as 3D modeling software and virtual reality

platforms, became a necessity. While these tools offered new opportunities for design exploration, students had to acquire and master these skills in a short timeframe, which added another challenging barrier to their learning curve.

3. PROBLEM STATEMENT

There are many literature which had discussed the positive impacts on online learning. However, when it comes to architectural education, discussions on the influences made by online learning to the students' design process was not much addressed and discussed. The design process is indeed influence, once they change the mode of designed. In conventional design studio students adopt a face-to-face peer learning and collaborative problem-solving process. How this could be varied once the studio function moved to online platform was needed to be explored.

3.1 Research Questions

1. What is the design process adopted in online design studio?

2. What are the influences made on the design process?

3.2 Research Methodology

For this study 25 students were selected by adopting convenient sampling technique. Students were divided in to 5 random groups ,consisting 5 students in one group. The grouping was done virtually after introducing the project by the design facilitator. For this online design studio, we utilized MS teams facility along with MURAL mutual collaborative platform.

The students were assigned with a design task and their group engagement was separately monitored by adopting naturalistic observation technique. Naturalistic observation is a qualitative data collection technique , which does not disturb to the participant and collect the data as a fly on wall. This technique helps on reporting natural incidents and occasions from a third party point of view. The data collected was recorded in researcher's own field diary as descriptive notes.

Other than the naturalistic observation , we adopted focus group interviews technique to increase the credibility and the trustworthiness of the study. The interviews were audio recorded and transcribed for data analysis.

3.4 Data Analysis

The data analysis was done by adopting six phased thematic analysis. The observer narrative samples which are extracted form the field diary were firstly coded. Before coding , a through screening and scanning process was adopted to identify potential codes. Data gathered from focus group interviews and observer narrative samplings were coded separately and amalgamated meaningful phrases, quates together when developing categories. Meaningful categories were again clustered in to themes which could answer the research questions generated.

4. RESULTS

Figure 1: Thematic map of results

As per the results, we noticed the students have started their design process from a collaborative brainstorming.

- Real time design discussions
- Tool enhanced teamwork
- Assumption based user requirements.
- Collaborative idea generation
- Collobarative design development
- Testing them with the team

The design process adopted by students in an online design studio has been significantly influenced by the key strategies of real-time design discussions, tool-enhanced teamwork, assumption-based user requirements, collaborative idea generation, collaborative design development, and testing with the team. These themes generated by thematic analysis have reshaped the traditional design process, leading to a more dynamic and collaborative approach tailored to the online learning environment. We identified below factors (themes) have made significant impact on reshaping the design process in online design studio.

Real-Time Design Discussions:

Real-time design discussions have override the typical inception phase of the design process. Students were actively engaged with peers and instructors to exchanged ideas, seek feedback, and addressed design challenges promptly. This influence has made the design process more iterative and responsive, with a continuous flow of ideas and insights. Plus , seeing everyone collaborative and active on the digital platform made them motivated on collaboration.

Tool-Enhanced Teamwork:

We witnessed the design process has been heavily relied on digital tools for collaboration. Students used these tools for seamless communication, resource sharing, and for the task management. This influence has streamlined the design process, making it more efficient and enhancing students' ability to work together as a team.

Assumption-Based User Requirements:

Students have incorporated assumption-based user requirements by relying on their intuition and creativity to understand user needs. This influence has led to reduce the intuitive and empathetic approach of the design process. Plus it encouraged students to anticipate user preferences and

challenges without any logical grounding. We identified this as a negative influence made on the design process of students.

Collaborative Idea Generation:

Collaborative idea generation has become a cornerstone of the design process. Students work collectively to brainstorm and generate a wide array of creative solutions. This influence promotes a diverse range of ideas, fostering innovation and exploration during the early stages of design. We noticed , they have collaborated externally by using other platforms such as WhatsApp and other chat mediums.

We noticed the empathizing phases was not addressed much in online design studio. Instead of in-depth empathizing acts , they have assumed the user and contextual requirements. This made them hypothetically bias on their own needs than addressing to complex user requirements.

The design process has shown increased collaboration. Students worked together, leveraging their unique skills and viewpoints to refine design solutions. The online platform kept them engaged , plus, seeing how the others are working parallelly was a heavy motivation for the active engagement. They kept themselves busy by writing on the wall, sharing their ideas, making sketches, plus doing individual research and share the outcome by using the online platform.

Testing with the Team:

The design process includes collaborative testing, where the team provides insights and feedback. This influence guarantees that design choices are rigorously evaluated and refined based on collective knowledge. The design process is more informed and grounded in a team-oriented approach to validation.

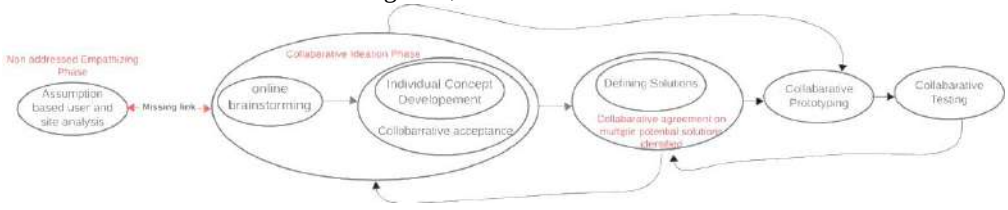

Figure 2: Design Process adopted in online design studio (developed by author)

5. DISCUSSION

Incorporating these influences into the design process has transformed it into a dynamic and collaborative journey. It encourages students to engage actively with their peers, embrace digital tools, think creatively, and test rigorously. As a result, the design process in online design studios now mirrors the iterative and teamwork-driven approach seen in the contemporary design industry. It prepares students not only for the design challenges they face in the online environment but also for the

evolving demands of the professional design world.

REFERENCES

Abdelmonem, M. G. (2016). From Propagation to Negotiation of Ideologies in the Architectural Design Studio: Critical Insights in Student-Centered Strategies for Interactive Learning. Journal of Design Research, 14(1), 1–21. doi: 10.1504/JDR.2016.074781.

Adigüzel Özbek, D., Melikoğlu Eke, A. S., Yücesan, E., & Ozar, B. (2018). Vertical Design Studio Experience in Interior Architecture Education. Online Journal of Art & Design, 6(2), 159.

Al-Qawasmi, J. (2005). Digital Media in Architectural Design Education: Reflections on the e-Studio Pedagogy. Art, Design & Communication in Higher Education, 4(3), 205–22.

Bashier, F. (2014). Reflections on Architectural Design Education: The Return of Rationalism in the Studio. Frontiers of Architectural Research, 3(4), 424–30. doi: 10.1016/j.foar.2014.08.004.

Schön, D. A. (2016). The Reflective Practitioner: How Professionals Think in Action. London: Routledge.

Design, Development, and Efficacy of Learning Devices for Enhancing Cognitive Skills in Intellectually Disabled Early Childhood: A Review

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ABSTRACT

Intellectual disabilities in early childhood present significant challenges for the affected individuals, their families, and society. Cognitive skill development is crucial during these formative years and a growing need for innovative approaches to enhance their cognitive abilities. This study explores the design, development, and efficacy of learning devices as a potential solution to address this pressing issue. In this research, the first phase investigates the cognitive deficits commonly observed in intellectually disabled early childhood, including challenges and sequential processing. Then discuss the theoretical foundations of sequential learning and its potential to support cognitive skill development. The study outlines the iterative design and development process of a novel learning device specifically tailored for intellectually disabled early childhood. This incorporates adaptive technology, interactive interfaces, and gamification elements to create an engaging and supportive learning environment. To assess the efficacy of the learning device, an experiment design involving intellectually disabled early childhood participants is structured. The study identifies the measures that impact the device on cognitive skill development, focusing on improvements in memory, attention, problem-solving abilities, and sequential processing skills. Literature endorses both Quantitative and qualitative data analysis is employed to evaluate the device's effectiveness. Preliminary literature shows promising outcomes, with significant enhancements observed in the cognitive skills of intellectually disabled early childhood participants after engaging with the sequential learning device.

This research provides potential insights

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into developing learning devices as innovative tools for enhancing the cognitive skills of these individuals. The findings underscore the importance of personalized and engaging learning approaches in addressing the unique needs of this population, with broader implications for special education and inclusive learning strategies. The study concludes by discussing the future directions and implications of these findings for the field of cognitive skill development in intellectually disabled early childhood.

Keywords **- Intellectually Disability, Early childhood, Learning Devices, Cognitive Skill development.**

1. INTRODUCTION

Intellectual disability or mentally retarded is a category with brain development defaults. Since anomalies in brain structure or function cause major impairments in cognitive and adaptive development, intellectual disability (ID) is a lifelong disorder. ID is a broad sign of neuronal malfunction rather than a singular condition (Shea, 2012). This disability cannot be cured forever but according to the medical reports the conditions can be maintained to a considerable amount as soon as the treatments are provided during the early stage. During the first years of life, children's brains grow faster than at any other time of life(Thompson, 2001). By using methods to encourage movement-based activities the brain-developing speed of mentally disabled children can be brought to a better condition.

Early childhood stage is the initial stage of human development according to psychological terms, early childhood is usually defined as the period from the age of two years until the age of six or seven years(Valentine, 2015). There are three simultaneous development stages. Neurological research shows that the early years play a key role in children's brain development. Special education was a state and instructed program for children (ages 3-5) who met state eligibility criteria because they were a category who were experiencing developmental delays(Farmer-Dougan & Alferink, 2013).

This research is yet to be a foundation stage to implement a project to Design a Psychological and Physical Elaborative Learning Device for the Educational space of Intellectually disabled early childhood children. The project will end up with a product to encourage "intellectually disabled" Preschool Kids, Physically and mentally, through a set of activities to improve gross motor skills within their educational space. Utterly the project will make the physically fit child which proportionately creates a considerable development intellectual impairment that leads them to live in a society.

Designing and developing learning devices to enhance cognitive skills in intellectually disabled early childhood is a multifaceted process that requires a combination of educational expertise, technology, and an understanding of the unique needs of this population(Terras et al., 2018). A comprehensive guide on how to approach this task is an inclusive requirement. Therefore this research aims to conduct a comprehensive review combined with the concept of "A Drive through Desire".

Creating effective learning devices for intellectually disabled early childhood is a complex process that requires ongoing collaboration, research, and sensitivity to the unique needs of this population. It's essential to prioritize the well-being and development of these children and to create technology that empowers them to reach their full potential.

2. SCOPE AND OBJECTIVES

The objective of the invention caters to the following,

1. To investigate how to deliver the optimum benefit of a curriculum with in the educational space
2. To investigate on the importance of gross motor skills towards the intellectually disable category
3. To develop a device with Passive therapy, Active therapy, Active-assist therapy
4. To develop a model to develop the product relevant to the educational space.

2.1 Methodology

To achieve the above objectives, this study first examined relevant keywords in (a) electronic databases; (b) reference lists of journals; and (c) specialist websites. Then a rigorous screening procedure was to select research for further analysis to develop a model. Each study was then reviewed to gain a full understanding of the major segments. Theoretical Frameworks were reviewed. Based on the literature review a sample model for product development was lined up for the further projects.

3. THEORETICAL FRAMEWORK

Theoretical frameworks in design serve as foundational concepts and principles that guide designers in their work(Stolterman & Wiberg, 2010). These frameworks help designers understand the problem they are trying to solve, make informed decisions, and create more effective and meaningful designs.

C. Cognitive Development in Early Childhood

Cognitive development in early childhood is a crucial phase in a child's life, marked by rapid and foundational changes in their cognitive abilities and skills(Kohlberg, 1968). Understanding the cognitive development of typically developing children is essential for designing effective interventions and learning devices for intellectually disabled early childhood populations.

This section of the theoretical framework delves into the key aspects of cognitive development during early childhood. By incorporating these theoretical perspectives into the framework, researchers and practitioners can gain a deeper understanding of the cognitive development processes in early childhood. This understanding serves as a foundation for developing effective strategies and learning devices that are tailored to the individual needs of intellectually disabled children, promoting their cognitive growth and overall well-being.

Table 1. The theoretical framework delves into the key aspects of cognitive development.

Frameworks	Reference
Piaget's Theory of Cognitive Development	(Kohlberg, 1968)
Vygotsky's Sociocultural Theory	(Jaramillo, 1996)
Information Processing Theory	(Swanson, 1987)
Neuroscientific Perspectives	(Reeve & Lee, 2019)
Socioemotional Development	(Thompson, 1993)
Implications for Children with Intellectual Disabilities	(Hronis et al., 2017)

D. Intellectual Disabilities (ID)

ID is a developmental disorder that first manifests in infancy or the early years of childhood, while it may not always be recognized until the child is older than 5 years old when standardized tests of developmental abilities are more valid and reliable(Eisenhower et al., 2005). The American Association on Intellectual and Developmental Disability uses three domains of measurement to describe intellectual and developmental disability (ID): intelligence (IQ), adaptive behavior, and support systems available to the person. Therefore, it is impossible to define ID purely based on IQ testing. The term ID has lately been proposed to take the place of "mental retardation." The American Association on Intellectual and Developmental Disability's definition of intellectual disability is used for this clinical report. ID is a disability characterized by significant limitations both in intellectual functioning and in adaptive behavior as expressed in conceptual, social, and practical adaptive skills(CARULLA et al., 2011). The impairment began before the age of 18. Between 1% and 3% of people are thought to have ID.

The below table 2 presents a general overview of the typical difficulties experienced by individuals with mild, moderate, severe, and profound ID.

E. Assistive Technology in Special Education

Assistive technology (AT) in special education denotes a wide range of tools, devices, software, and equipment designed to support individuals with disabilities in their educational endeavors. These technologies aim to enhance the independence, communication, learning, and overall quality of life for students with special needs. Table 3 e refers to assistive technologies which implemented.

F. Design and Development of Learning Devices

Design and development of learning devices involve the creation of educational tools and technologies that facilitate and enhance the learning process. The goal is to create effective and engaging tools that promote learning, adapt to individual needs, an leverage the latest advances in technology. Enhancing cognitive skills in individuals with intellectual disabilities require specialized approaches and learning devices that can cater to their unique needs.

Table 2. A general overview of the typical difficulties experienced by individuals with mild, moderate, severe, and profound ID

	Mild	Moderate	Severe	Profound
Conceptual Skills	some learning difficulties; might require some support in academic skills	slow in learning with difficulties using language might require more support in academic skills	limited understanding of language and concept	unable to understand conceptual skills or follow instructions
Social Skills	some difficulties perceiving social cues; some social immaturity with some difficulties regulating emotions and behaviors; might be at risk of being manipulated by others	some difficulties with communication; perceiving and interpreting social cues; limited ability to participate in social activities and might be at a higher risk of being manipulated by	limited communication skills; might use single words or phrases with gestures; limited ability to perceive and interpret social cues and might not	Rudimentary communication skills; might use non-verbal communication; unable to perceive or interpret social cues; and participate in social activities
Practical Skills	might be fully independent with early intervention; might require some support with complex daily living tasks;	might not be fully independent might be able to get around to familiar places	unable to be fully independent; need regular support and supervision for daily activities and motor impairments	unable to be fully independent; need constant help and supervision at all times and may be incontinent or immobile

Table 3. Assistive Technology

Assistive technology				
Communication Aids	Learning Aids	Mobility and Environmental Aids	Sensory Aids	Educational Software
Devices and software that help individuals with speech and communication	Assist with reading, writing, and learning, such as screen readers, text-to-speech and speech-to-text software, word prediction software, and electronic magnifiers.	Controlling their environment and mobility. Examples include power wheelchairs, environmental control systems, and adaptive switches.	Screen readers, screen magnifiers, hearing aids, and Braille displays.	There are programs designed to teach math, reading, and other subjects in an accessible and interactive manner.

These learning devices should be designed to be accessible, engaging, and supportive of individualized learning goals. Sensory integrations, Assistive

Technology, visual aids, and support are leading strategies that can be helpful in this context. The choice of learning devices should be based on an individual's specific needs and abilities, and a comprehensive assessment by a healthcare professional or therapist is often required to determine the most suitable options. Moreover, involving caregivers, educators, and therapists in the selection and implementation of these devices is crucial to ensure that they align with the individual's goals and provide a supportive learning environment(Jackman et al., 2022).

G. Adaptive Learning Technologies

Adaptive learning technologies are educational tools and platforms that use data-driven, personalized approaches to tailor instruction to the unique needs of individual learners. These technologies leverage algorithms, analytics, and assessment data to continuously adjust the content, pace, and learning pathways for each student, optimizing their learning experience. Developing a device with passive therapy, active therapy, and active-assist therapy capabilities requires a multidisciplinary approach and careful consideration of the device's design, functionality, and intended therapeutic outcomes.

H. Accessibility and Inclusivity Considerations

Human-centered design (HCD) is an approach to design that focuses on understanding the needs, behaviors, and preferences of the end-users to create more effective and user-friendly products, services, or systems. The Below facts are taken into consideration with different weights of attention.

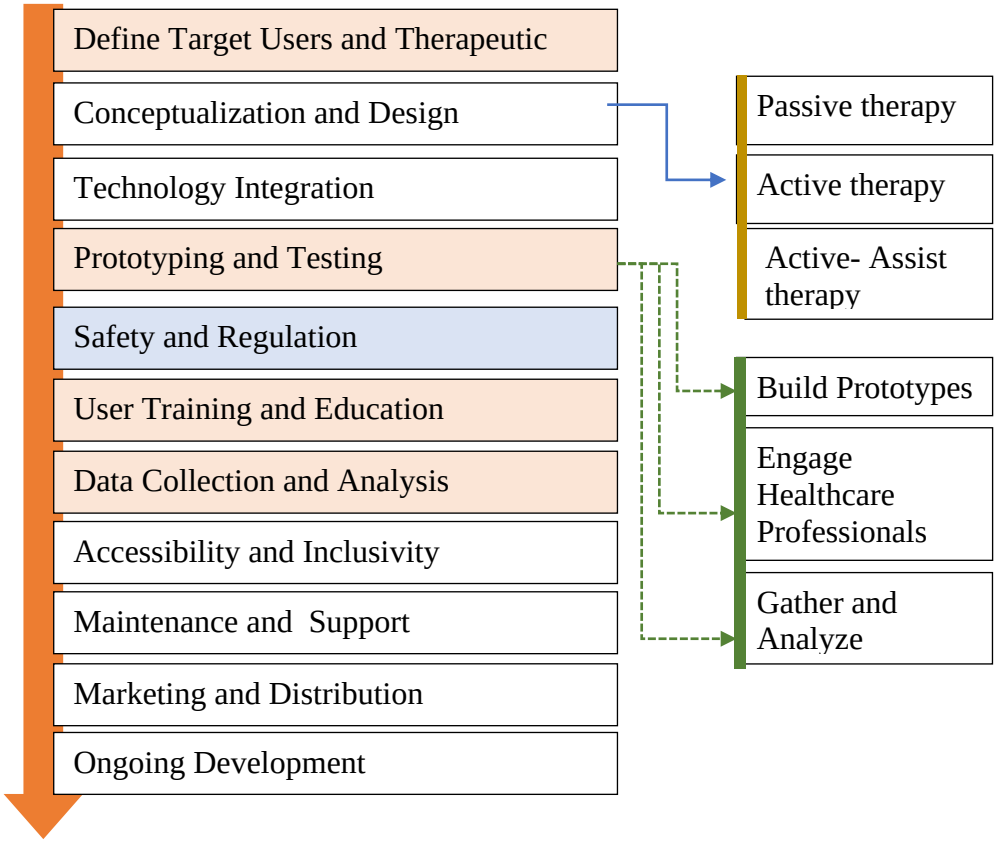
Table 3- Classified different weights of attention.

• Empathy
• User-Centered
• Iterative
• Collaborative
• Holistic
• Prototype and Test
• Visual and Interactive Design
• Simplicity
• Feedback-Driven
• Ethical Considerations
• Sustainability
• Aesthetics
• Flexibility
• User Education
• Continuous Learning

I. Collaborative Development Approaches

Collaborative development approaches are critical when creating products and services for individuals with intellectual disabilities. Collaborative methods involve working closely with various stakeholders, including individuals with intellectual disabilities, their families, caregivers, and professionals in the field.

Figure.1 Conceptual flow of the Adaptive



Learning Technologies.

4. COGNITIVE SKILLS ENHANCEMENT TECHNIQUES

Cognitive skills enhancement techniques are strategies and activities aimed at improving various cognitive functions, such as memory, attention, problem-solving, and critical thinking(Medina et al., 2017). These techniques are valuable for individuals of all ages, including children, adults, and the elderly. Before the enhancement, the assessment of detecting the level of each individual is so important. Major Domains of Young Children's Behavior and Tests Utilizable for Assessments of These Domains should be considered. Based on that Criteria for Evaluating Technical Characteristics of Early Childhood Cognitive Competence Assessment Devices should be implemented.

The primary goal of assessment is to conduct children formal examinations to gather and compile information about their level of functioning.

The most important sorts of data when working with young children are those gathered from direct evaluation, observation, and caregiver interviews (reports). There are specialist instruments

that focus on a particular type of data, but most developmental examinations use some mix of all three of these forms of data. The three different sorts of data each have advantages and disadvantages.

Based on them the Test construction, format, and administration should be completed. The appropriateness and appeal of the testing material for young children, the opportunities for teaching the tasks being tested, the thoroughness of the instructions, the suitability of the test for multicultural populations, and the testing environment are some examples of the qualitative characteristics of tests for young children (test construction, format, and administration)(Bostrom & Sandberg, 2009).

Language and Communication

Language and communication development for the intellectually disabled in early childhood is a critical aspect of their overall growth and quality of life(Ogletree et al., 2022). For children with intellectual disabilities, speech therapy is frequently a crucial component of communication development. It can treat issues with articulation, fluency, and language.

Motor Skills and Coordination

Motor skills and coordination are essential for the overall development and daily functioning of intellectually disabled individuals. These skills encompass both fine motor skills (small, precise movements) and gross motor skills (larger, whole-body movements). Sensitive strategies and considerations should be followed for enhancing motor skills and coordination in individuals with intellectual disabilities. Many activities depend on the coordination of broad and fine motor skills, motor skills typically develop concurrently. The development of gross motor abilities happens over a brief period. The majority of development happens in childhood(Altinkök, 2016).

Gross motor skills- which are the larger movements of arms, legs, feet, or the entire body (crawling, running, and jumping)

Fine motor skills- which are smaller actions, such as grasping an object between the thumb and a finger or using the lips and tongue to taste objects. Gross motor skills development is governed by two principles that also control physical growth.

1. Head-to-toe development refers to the way the upper parts of the body develop, beginning with the head, before the lower ones.

2. The second principle of development is trunk to extremities. Head control is gained first, followed by the shoulders, upper arms, and hands. Upper body control is developed next, followed by the hips, pelvis, and leg.

Head to Toe Development reflects the fact that in the early stages of development, children tend to gain control over their head and neck muscles before they develop control over their lower body. It's a top-down progression, starting with head movements and gradually extending to the lower parts of the body.

Social and Emotional Development

Social and emotional development in individuals with intellectual disabilities is an essential and often complex aspect of their overall well-being. While these

individuals may face unique challenges and barriers, they possess the same fundamental human need for social connection, emotional expression, and personal growth. A well-rounded approach to their development involves recognizing and valuing their strengths and abilities while providing tailored support and intervention to address their specific requirements. Early intervention programs, social skills training, and emotional regulation techniques are essential components of fostering positive social and emotional development (Vandevelde et al., 2016).

Problem Solving and Critical Thinking

Promoting problem-solving and critical thinking skills in individuals with intellectual disabilities is an essential part of their cognitive and personal development. These skills empower them to analyze situations, make informed decisions, and overcome challenges effectively. Through tailored educational and therapeutic interventions, individuals with intellectual disabilities can enhance their problem-solving abilities, learn to approach issues from multiple angles and build confidence in their decision-making. Encouraging a supportive environment that values their unique perspectives and fosters independent thinking is key to their growth, enabling them to navigate life's complexities(Herrington & Oliver, 2000).

Efficacy Assessment and Case Studies

In the context of individuals with intellectual disabilities play a critical role in evaluating the impact of interventions and support systems(Gómez et al., 2020). These assessments involve examining the effectiveness of various strategies, therapies, and programs designed to enhance the well-being and development of individuals with intellectual disabilities. Case studies provide valuable insights into the unique journeys of specific individuals, shedding light on their progress, challenges, and successes within the context of their intellectual disability. By analyzing and documenting these cases, researchers, educators, and caregivers can gain a deeper understanding of what works best findividuals with intellectual disabilities and refine interventions and support to maximize their quality of life and potential for growth.

Quantitative and Qualitative Methods

To design, the development, and efficacy of learning devices for enhancing cognitive skills in intellectually disabled early childhood, a combination of quantitative and qualitative research methods is often employed. These methods help gather both numerical data and rich descriptive information. When conducting the Quantitative Methods Surveys and Questionnaires, Standardized Cognitive Assessments, Usage and Performance Metrics, and Pre-Post Comparisons could be incorporated.

When conducting Qualitative Methods the study could implement Interviews, Observation, Content Analysis, Case Studies, and Thematic Analysis.

Based on the above facts the individualized lesson plans will be drawn to attention tailoring the interventions to specific major disability categories (examples – autism, Down Syndrome, etc.)Individualized Learning Plans should Tailor Interventions

to Specific Disabilities while adopting towards Multidisciplinary Collaboration.

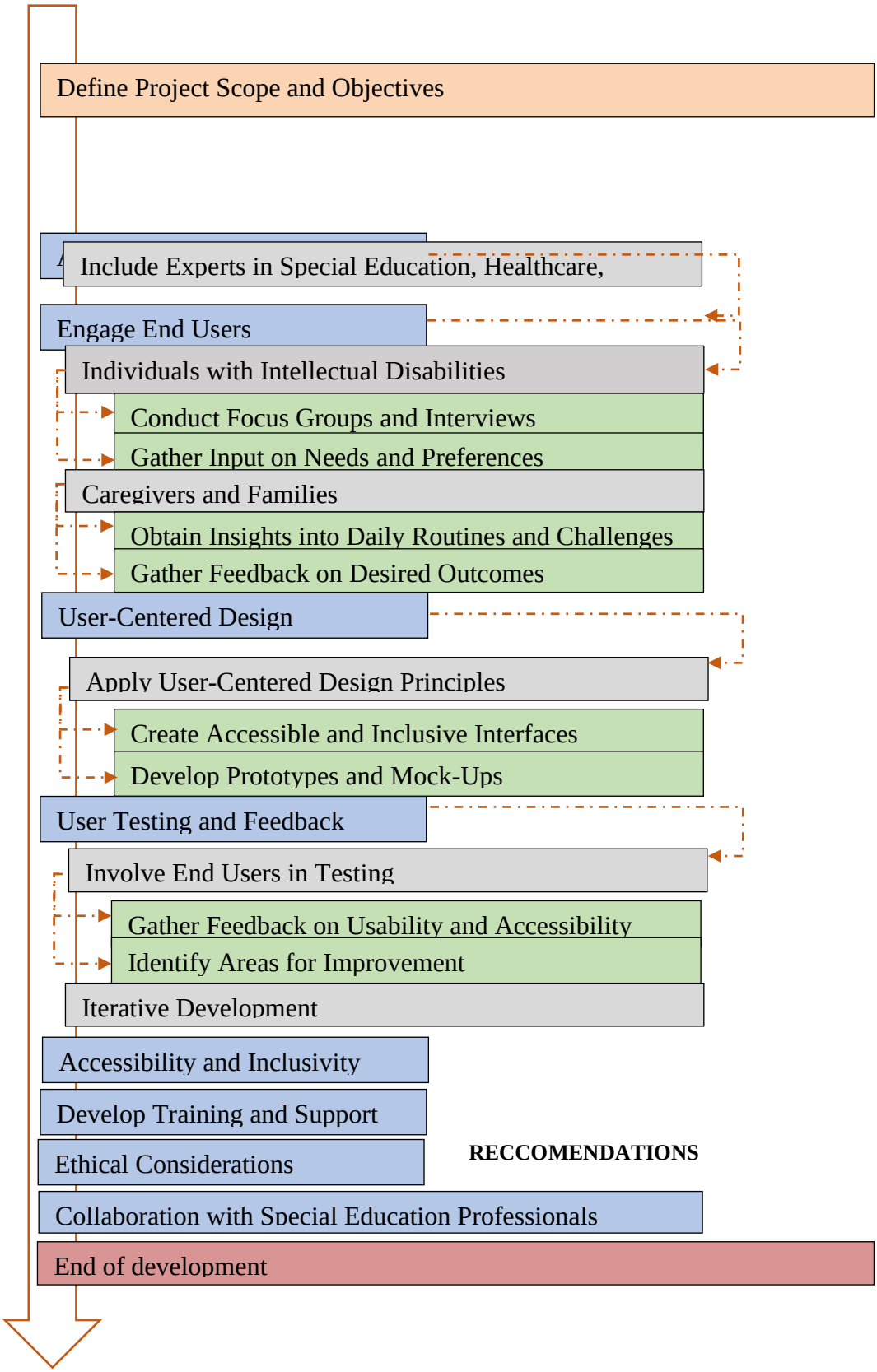
5. CONCLUSION

Key Findings and Insights

A tangible third party for intellectually disabled Pre preschool children has to develop and improve gross motor skills in their Educational Space.

When considering this user category their physical age was different from their mental age. However physical age was taken into consideration in this project to retain a proper size range and proportion to the product. Begin by conducting a needs assessment to understand the specific cognitive challenges that intellectually disabled children face. Identify the age group, cognitive domains (e.g., memory, attention, problem-solving), and individual variations in abilities. Assemble a multidisciplinary team that includes educators, child psychologists, special education experts, speech and language therapists, and technology developers. Review existing research and theories on cognitive development in intellectually disabled children. Deliberate established educational and therapeutic approaches. Define clear learning objectives for the cognitive skills you aim to enhance. Incorporate principles of universal design to ensure accessibility for a wide range of disabilities. Implement gamification and interactive elements to engage and motivate learners. Consider a multisensory approach to accommodate various learning styles. Choose an appropriate technology platform. Ensure the device is durable, portable, and user-friendly.Develop both software and hardware components to work seamlessly. Implement adaptive learning algorithms that adjust the difficulty level based on a child's progress. Enhancing motor skills and coordination in intellectually disabled individuals can significantly improve their quality of life, independence, and participation in various activities. Customized interventions and a supportive, encouraging environment are key to their development. Develop a variety of interactive activities, including games, puzzles, quizzes, and simulations. Personalize the learning experience to accommodate individual needs and learning profiles. Include features such as text-to-speech, speech recognition, and auditory feedback to cater to a range of abilities. Conduct user testing with intellectually disabled children to gather feedback and make necessary improvements. Involve parents, caregivers, and educators in the testing process. Implement a data collection system to track and analyze a child's progress. Assess the efficacy of the learning devices through controlled studies or clinical trials.

Flowchart 1- Conceptual flow of the proposed model



This study recommends the following model to follow when approaching the project, this would minimize the mistakes that may highly influence this particular domain. The model should be significant.

Flowchart 2 denotes the concepytual flow of the porposed model to implement during real application abnd development of the proposed porject.

Needs Assessment -> Collaborative Team-> Research and Theory->Learning Objectives -> implementing design Principles – Technology and materials ->Adaptive Learning -> Content Creation -> Assistive Technology ->User Testing -> Data Collection and Analysis ->Efficacy Evaluation -> Continues Improbvemnts -> Training ->Ethics and Sustainability .

REFERENCES

Altinkök, M. (2016). The Effects of Coordination and Movement Education on Pre-School Children's Basic Motor Skills Improvement. Universal Journal of Educational Research, 4(5), 1050–1058. https://eric.ed.gov/?id=EJ1099772

Bostrom, N., & Sandberg, A. (2009). Cognitive Enhancement: Methods, Ethics, Regulatory Challenges. Science and Engineering Ethics, 15(3), 311–341. https://doi.org/10.1007/s11948-009-9142-5

Carulla, L. S., Reed, G. M., Vaez-Azizi, L. M., Cooper, S.-A., Leal, R. M., Bertelli, M., Adnams, C., Cooray, S., Deb, S., Dirani, L. A., Girimaji, S. C., Katz, G., Kwok, H., Luckasson, R., Simeonsson, R., Walsh, C., Munir, K., & Saxena, S. (2011). Intellectual developmental disorders: Towards a new name, definition, and framework for "mental retardation/intellectual disability" in ICD-11. World Psychiatry, 10(3), 175–180. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3188762/

Eisenhower, A. S., Baker, B. L., & Blacher, J. (2005). Preschool children with intellectual disability: Syndrome specificity, behavior problems, and maternal well-being. Journal of Intellectual Disability Research, 49(9), 657–671. https://doi.org/10.1111/j.1365-2788.2005.00699.x

Farmer-Dougan, V., & Alferink, L. A. (2013). Brain Development, Early Childhood, and Brain-Based Education: A Critical Analysis. In L. H. Wasserman & D. Zambo (Eds.), Early Childhood and Neuroscience—Links to Development and Learning (pp. 55–76). Springer Netherlands. https://doi.org/10.1007/978-94-007-6671-6_5

Gómez, L. E., Schalock, R. L., & Verdugo, M. A. (2020). The Role of Moderators and Mediators in Implementing and Evaluating Intellectual and Developmental Disabilities-Related Policies and Practices. Journal of Developmental and Physical Disabilities, 32(3), 375–393. https://doi.org/10.1007/s10882-019-09702-3

Herrington, J., & Oliver, R. (2000). An instructional design framework for authentic learning environments. Educational Technology Research and Development, 48(3), 23–48. https://doi.org/10.1007/BF02319856

Hronis, A., Roberts, L., & Kneebone, I. (2017). A review of cognitive impairments in children with intellectual disabilities: Implications for cognitive behavior therapy. British Journal of Clinical Psychology, 56(2), 189–207. https://doi.org/10.1111/bjc.12133

Jackman, M., Sakzewski, L., Morgan, C., Boyd, R. N., Brennan, S. E., Langdon, K., Toovey, R. A. M., Greaves, S., Thorley, M., & Novak, I. (2022). Interventions to improve physical function for children and young people with cerebral palsy: International clinical practice guideline. Developmental Medicine & Child Neurology, 64(5), 536–549. https://doi.org/10.1111/dmcn.15055

Jaramillo, J. A. (1996). Vygotsky's sociocultural theory and contributions to the development of constructivist curricula. Education, 117(1), 133–141. https://go.gale.com/ps/i.do?p=AONE&sw=w&issn=00131172&v=2.1&it=r&id=GALE%7CA18960235&sid=googleScholar&linkaccess=abs

Kohlberg, L. (1968). Early Education: A Cognitive-Developmental View. Child Development, 39(4), 1013–1062. https://doi.org/10.2307/1127272

Medina, M. S., Castleberry, A. N., & Persky, A. M. (2017). Strategies for Improving Learner Metacognition in Health Professional Education. American Journal of Pharmaceutical Education, 81(4). https://doi.org/10.5688/ajpe81478

Ogletree, B. T., Wofford, M. C., & Barton-Hulsey, A. (2022). Practical Approaches and Socially Valid Assessment Considerations for Learners with Emergent Communication and Severe Intellectual Disability. Advances in Neurodevelopmental Disorders, 6(4), 426–441. https://doi.org/10.1007/s41252-022-00303-4

Reeve, J., & Lee, W. (2019). A neuroscientific perspective on basic psychological needs. Journal of Personality, 87(1), 102–114. https://doi.org/10.1111/jopy.12390

Shea, S. E. (2012). Intellectual Disability (Mental Retardation). Pediatrics In Review, 33(3), 110–121. https://doi.org/10.1542/pir.33-3-110

Stolterman, E., & Wiberg, M. (2010). Concept-Driven Interaction Design Research. Human–Computer

Interaction, 25(2), 95–118. https://doi.org/10.1080/07370020903586696

Swanson, H. L. (1987). Information Processing Theory and Learning Disabilities: An Overview. Journal of Learning Disabilities, 20(1), 3–7. https://doi.org/10.1177/002221948702000102

Terras, M. M., Boyle, E. A., Ramsay, J., & Jarrett, D. (2018). The opportunities and challenges of serious games for people with an intellectual disability. British Journal of Educational Technology, 49(4), 690–700. https://doi.org/10.1111/bjet.12638

Thompson, R. A. (1993). Socioemotional Development: Enduring Issues and New Challenges. Developmental Review, 13(4), 372–402. https://doi.org/10.1006/drev.1993.1018

Thompson, R. A. (2001). Development in the First Years of Life. The Future of Children, 11(1), 21–

Design of an Arduino Microcontroller Unit to Monitor Temperature and Humidity of a Greenhouse and Modification Simulation using COMSOL Multiphysics

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ABSTRACT

The global agricultural sector supports human civilization by ensuring food production and security for an expanding global population. The water crisis and climate change are among the main challenges for the development of agriculture. Greenhouses provide controlled environments for sustainable crop cultivation, addressing these challenges and enhancing food production. Ensuring optimal conditions within a greenhouse necessitates the monitoring and controlling of multiple variables such as illuminance, temperature, relative humidity, and CO2 concentration. Hydroponic systems are essential for some crops in agriculture due to their efficiency and advantages, such as control over nutrients and environmental factors, space-saving, and cultivation without soil etc. Also, hydroponics decreases the likelihood of diseases and pests, supporting sustainable and localized food production. The greenhouse hydroponic section in Sri Lanka Nanotechnology Institute (SLINTEC) was designed with a force draft cooling mechanism and located in a dry area compared to high-altitude cities with cooler environments in the country. Therefore, maintaining the correct temperature and humidity was critical for crop growth. In this research, an Arduino microcontroller-based unit is designed to measure temperature, relative humidity, and illuminance. Results collected from the unit were plotted against the geometry of the greenhouse using Originlab software. Then, COMSOL Multiphysics is used to simulate the Greenhouse temperature profile while changing different factors such as airflow, water curtain temperature, and exhaust fan geometries. Then suggestions were given for the greenhouse conditions improvement.

Keywords **- Greenhouse, Hydroponics, Arduino microcontroller, COMSOL Multiphysics, Temperature, Simulation**

1. INTRODUCTION

The global agricultural industry is essential to maintaining human civilization, supplying food, and ensuring food security for a burgeoning population (Kaini, 2020). However, due to regional population growth and anticipated climatic changes, the issues posed by the water crisis are much more severe. In recent years, there has been a substantial trend toward new and sustainable farming techniques to address these problems and increase agricultural productivity (Panwar et al., 2011).

Growing crops in greenhouses improves agricultural quality and crop yield, resolving concerns about global food security (A. Badji et al., 2022). Greenhouse structures are made from steel wood or aluminum most commonly and covered with plastic films (polyvinyl chloride, polyethylene, and polyester), plastic panels (polyvinyl chloride rigid panels, fiberglass-reinforced plastic, acrylic, and polycarbonate rigid panels), or glass. These structures have different shapes and climate control mechanisms (Dalai, 2020).

Environmental parameters such as temperature, relative humidity, light intensity, carbon dioxide concentration, moisture percent in soil, and soil temperature can affect crop growth in greenhouses. Plastic or transparent covers that can transmit the light wavelengths used for plant photosynthesis will act as a barrier to separate the greenhouse microclimate from the outside. These covers will also control the light intensity and air movement that help the plant growth and reduce the disease spread (Cooper & Fuller, 1983).

Greenhouse environmental conditions can be monitored using Arduino microcontrollers, electronic devices, and electronic sensors. Some researchers have developed smart greenhouse monitoring and control systems by connecting these sensors and devices (Rushabh Shah et al., 2020), (Liu, 2022), (Yahaya et al., 2019), (Arshad, 2020).

In this research, an Arduino microcontroller unit was designed to measure the temperature and relative humidity of the SLINTEC greenhouse. Then modification simulation was carried out using COMSOL Multiphysics.

1.1 Slintec Greenhouse

SLINTEC greenhouse contains two different areas, which are the hydroponic area and the soil area. Those are shown in Figure 1 and Figure 2.

Figure 1. Hydroponic side

Figure 2. Soil floor side

Only the hydroponic side is considered in this research. The hydroponic system has 17 racks, and each rack contains 10 pipes. One pipe contains 48 hydroponic cups. Overall, there are 8160 Hydroponic cups (Figure 3).

Figure 3. Hydroponic racks

There are 9 nutrient tanks (Figure 4) supplying nutrients to the hydroponic racks. Each pump supplies 2 hydroponic racks. All pumps have 1 hp capacities. For nutrient circulation, the nutrient solution is pumped to the top of the hydroponic columns and flows down towards the tanks by gravity. The walls of the greenhouse are made of transparent glass.

Figure 4. Nutrient tanks

1.2 Climate Control System

Semi-automated shading panels, water sprinklers, exhaust fans, internal fans, and water curtains are used for climate control. The hydroponic side has 4 exhaust fans, and each has airflow rates of 44000 m^3/hr and power 1.1 kW (Figure 5).

Figure 5. Exhaust Fan

There are two water curtains to cool down the hydroponic side (13.2 m × 1.5 m × 2) (Figure 6).

Figure 6. Water curtain

The plan of the greenhouse hydroponic side is given in Figure 7.

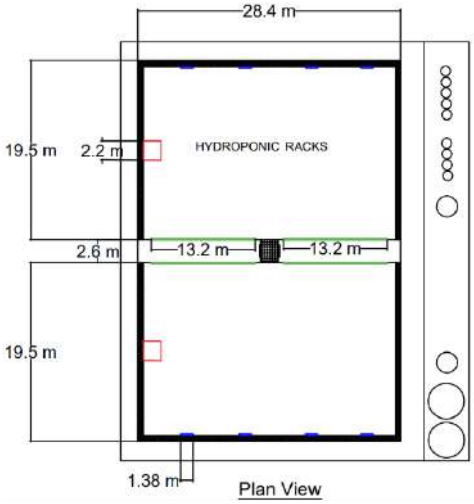
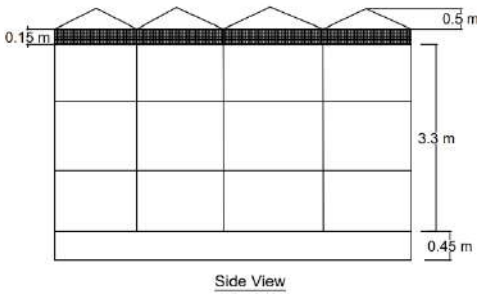


Figure 7: Greenhouse plan



Greenhouse Hydroponic side Volume is 2400 m³.

1.3 Operation Principle

Greenhouse inside pressure was dropped when exhaust fans started to run. Therefore, air draws through the water curtains into the greenhouse. Small water flow is given to the water curtains made with cellulose baffles to evaporate and cool down the baffle surfaces. The air flowing through the baffles cools down and increases the relative moisture. This cool humid air is used to cool down the greenhouse.

2. METHODOLOGY

2.1 Identifying the Time Period with the Highest Temperature of a Day

Extech SDL200 Data logging Thermometer (Figure 9) was used to measure the average temperature inside the greenhouse by locating three thermocouples widely apart to cover the greenhouse and collecting data from them within the daytime (highest temperatures).

Figure 9: Four-channel data logging thermometer (Extech SDL200)

Three thermocouples were located inside the greenhouse to take the average temperature inside. One thermocouple was located outside to get the atmospheric temperature. The time period with the highest temperature range was selected to

measure the coordinate vs. temperature using the Arduino sensor unit.

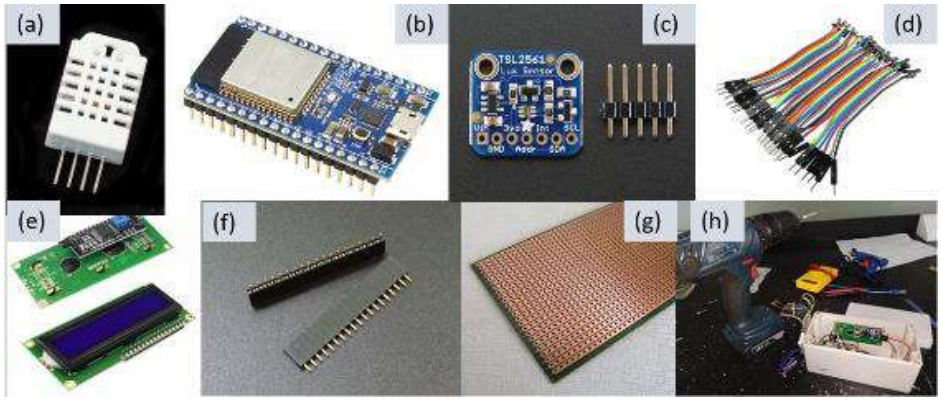
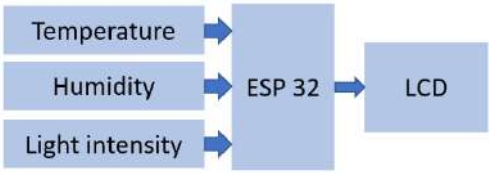


Figure 10. (a) DHT 11 temperature and humidity sensor, (b) ESP 32 board, (c) Adafruit TSL2561 Light sensor, (d) wires, (e) I2C LCD, (f) Headers, (g) Vero board, (h)Container, USB cable and power supply.

2.2 Preparation of Temperature and Humidity Measurement Unit

The sensor unit was built using an ESP 32 board and DHT 11 temperature and humidity sensor, Adafruit TSL2561 Light sensor, wires, I2C LCD, Headers, Vero board, Container, USB cable, and power supply (Figure 10).



The sensor unit was portable and powered by a power bank. The block diagram of the sensor unit is shown in Figure 11.

Figure 11. General block diagram

The sensor unit built is shown in Figure 12.

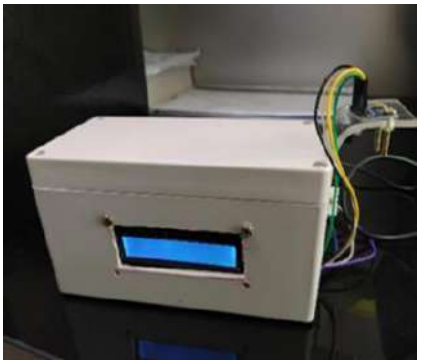


Figure 12. Completed temperature and humidity sensor unit.

The greenhouse plan was divided into a grid to measure the temperature and humidity, as shown in Figure 13. Then each point's temperature and humidity conditions were measured. Displayed values from the Arduino sensor unit were noted down in Microsoft Excel manually. OriginPro 8 was used to plot temperature and humidity 3D plots.

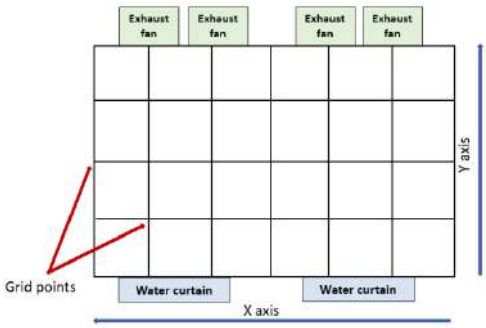


Figure 13. Grid of greenhouse plan

2.3 COMSOL Multiphysics Simulation for Improvements

Greenhouse real dimensions are $19.5\,m \times 28.4\,m \times 4\,m$ (L×W×H). Greenhouse has four exhaust fans. In the simulation, greenhouse air volume was divided into four and one exhaust fan and its' air volume was considered (W = 7.1 m). The 2D cut plain was taken through the exhaust fan for simplicity.

Due to the difficulty of showing the air volume without an exhaust fan from the 2D study, an assumption was made that an exhaust fan-size air outlet was present throughout the width of the selected air volume.

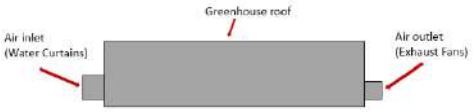


Figure 14. Greenhouse Geometry

Greenhouse Air inlet occurs from water curtains (height = 1.4 m). Greenhouse Air outlet occurs from exhaust fans (height = 1 m).

COMSOL Multiphysics 5.6a is used to simulate the fluid and temperature profiles of the greenhouse geometry.

The material was given as Air from the software library. The turbulent flow $k-\varepsilon$ model was used as physics for fluid flow. Heat transfer in fluids was selected for the heat transfer physics. Non-isothermal flow was selected as Multiphysics. Normal mesh size was selected. A stationary study was used for the simulation.

2.4 Boundary Conditions

2.4.1 Fluid Flow Boundary Conditions

Assumptions were made as follows for the simplification of the study.

1. Air flows from the air inlet and goes out from the air outlet where the pressure is zero instead of exhaust fans drawing air through water curtains.
2. Air mass flow was 44000 m^3/hr (14.7 kg/s), similar to exhaust fans, and fan efficiency was 50%, making air inflow 7.3 kg/s.

3. The air outlet (exhaust fan) has zero pressure supporting the greenhouse airflow.
4. The wall has no-slip boundary condition.

Table 1. Fluid flow boundary conditions

Inlet	7.3 kg/s
Outlet	0 Pa
Walls	No Slip

2.4.2 Heat Transfer Boundary Conditions

Assumptions were made as follows for the simplicity of the study.

1. The air inlet (water curtain) has a heat inflow of 29 ℃.
2. Heat flux was given from the greenhouse roof to replicate the solar radiation heat.
3. The air outlet has a heat outflow.
4. Walls are thermally insulated.
5. The thickness of the geometry is 7.1 m.

Table 2. Heat transfer boundary conditions

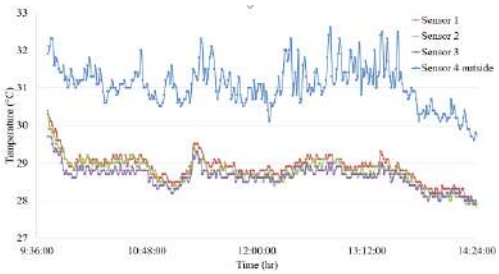
Inlet	Heat inflow (29 ℃)
Outlet	Heat outflow
Walls	Thermal insulation
Roof	Heat flux (990 w/m^2)
Roof temperature	40 ℃

Solar radiation to Sri Lanka (near the equator) = 1100 w/m^2 (*Solar Energy - Solar Radiation*, n.d.)

Light transmittance through greenhouse glass panels = 90% (*Unit 03: Glazing*, n.d.)

Resultant Solar radiation into the greenhouse = 990 w/m^2

3. RESULTS AND DISCUSSION



3.1 Temperature Data from Data Logger

Temperature data recorded from the data logging thermometer is given in Figure 16.

Figure 16. Greenhouse temperature data set from data logger

Sensor 1, sensor 2, and sensor 3 were located inside the greenhouse and showed similar temperature fluctuation. Sensor 4 was located outside to get the atmospheric temperature. When greenhouse exhaust fans were turned on, the temperature went down suddenly in the first 30 minutes. The greenhouse was at maximum temperature from 10.30 a.m. to 1.30 p.m. Therefore, this time period is used to measure the temperature and humidity of the greenhouse.

3.2 Temperature Data from Arduino Unit

The temperature profile measured from the sensor unit is given in Figure 17. These temperatures were measured from approximately 1 m height from the ground.

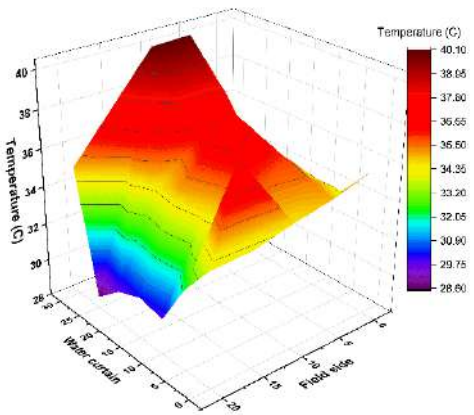
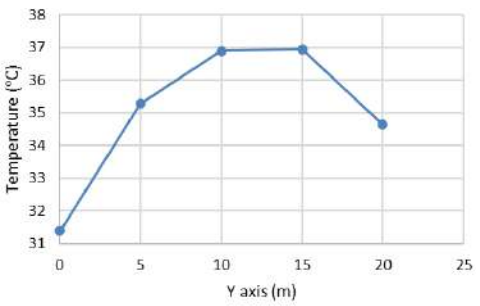


Figure 17. Temperature profile 3D plot (Source: OriginPro 8)

According to the results, the temperature is nearly 28 -29 °C near water curtains due to water evaporation cooling. In the middle of the greenhouse, there is a temperature peak which goes up to 40 °C. Near Exhaust fans, it drops again to 32-34 °C.



MS Excel was used to plot the average temperature along the greenhouse y-axis. (Figure 18)

Figure 18. Greenhouse average temperature along the Y axis.

Figure 18 shows an increase in temperature in the middle of the greenhouse.

The humidity profile measured from the sensor unit is given in Figure 19.

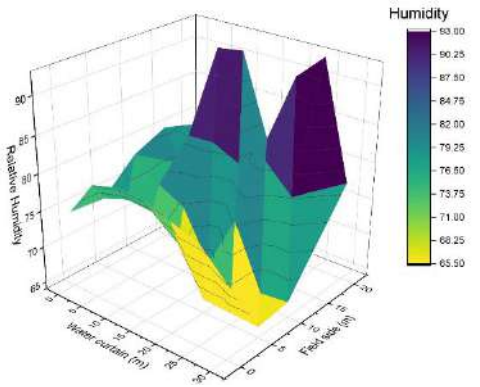


Figure 19. Temperature profile 3D plot (Source: OriginPro 8)

Relative humidity goes up to 93% near the water curtains. Relative humidity drops to 65% in the middle and rises to nearly 73% near exhaust fans.

MS Excel was used to plot the average humidity along the greenhouse y-axis. (Figure 20)

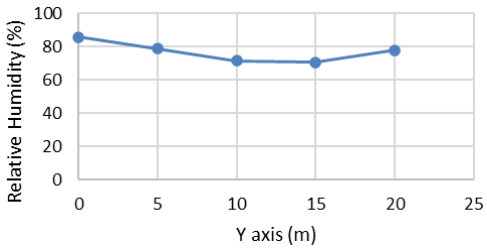


Figure 20. Greenhouse average relative humidity along the Y axis.

Figure 20 shows a slight decrease in humidity in the middle of the greenhouse. For the COMSOL Multiphysics Simulation, only temperatures were considered.

3.3 COMSOL Simulation

3.3.1 Existing Conditions Modelling

The air velocity profile with streamlines is given in Figure 21.

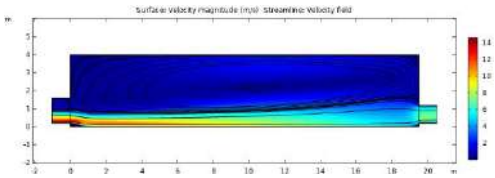


Figure 21. Air velocity profile and streamlines

Fig. 21 shows there is a high-velocity airflow at the bottom of the greenhouse. But the geometry top has stagnated air currents.

Figure 22 shows the pressure profile generated from airflow.

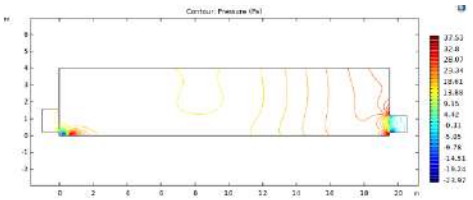


Figure 22. Pressure profile of greenhouse

Figure 23 shows the temperature profile and contour lines of the greenhouse.

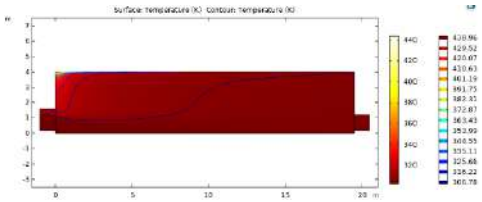


Figure 23. Temperature profile of greenhouse

The temperature profile exhibits a lower value at the bottom and a higher value at the top due to the airflow pattern in the greenhouse. The highest values at the top left generated from the simulation can be neglected.

A line graph was generated through a cutline (fig. 24) for a better analysis of the greenhouse temperature profile.

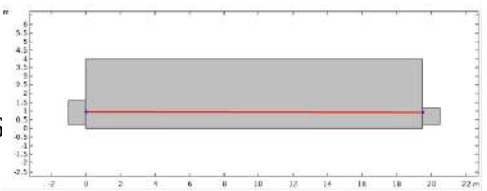


Figure 24. Cutline for the temperature

Figure 25 shows the temperature line graph through the cutline.

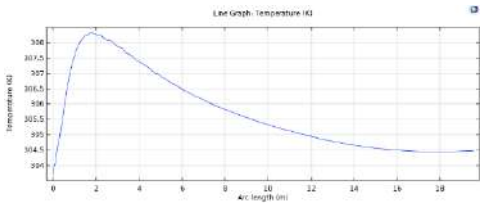


Figure 25. Temperature line graph

Temperature increases in the middle of the greenhouse and decreases at the outlet similar to measured temperature values previously.

3.3.2 Modifications

3.3.2.1 Exhaust Up Lifted

High temperatures were present at the top part of the greenhouse. Therefore, the exhaust fan vent was lifted to remove this heat more efficiently. The air velocity profile of the modified geometry is given in Figure 26.

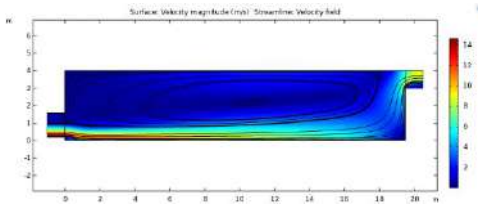
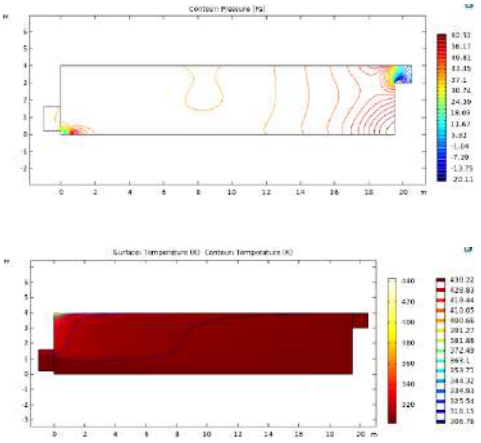


Figure 26. Air velocity profile and streamlines (with lifted exhaust fan vent)

The pressure profile of the lifted exhaust is shown in Figure 27.

Figure 27. Pressure profile (lifted exhaust



fan vent)

The temperature profile of the lifted exhaust is shown in Figure 28.

Figure 28. Temperature profile of greenhouse (lifted exhaust)

Figure 28 shows that lifted exhaust has caused the contour lines to change slightly.

Figure 29 shows the temperature line graph through the cutline.

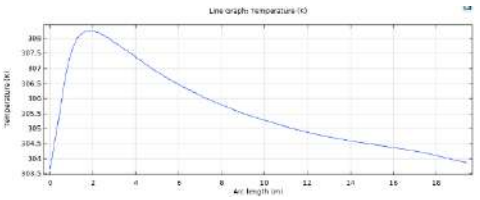


Figure 29. Temperature line graph (lifted exhaust)

According to the results, the temperature profile doesn't have a significant effect from lifted exhaust.

3.3.2.2 Exhaust from the Roof

Air exhaust was shifted to the top of the greenhouse to remove heat from the top section efficiently.

The air velocity profile of the modified geometry is given in Figure 30.

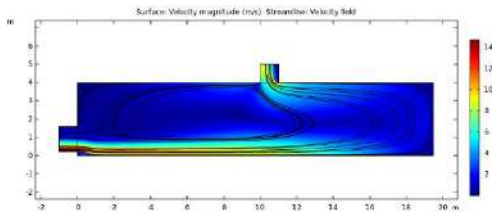


Figure 30. Air velocity profile and streamlines (top exhaust)

The pressure profile of the top exhaust is shown in Figure 31.

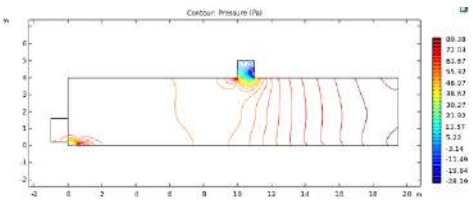


Figure 31. Pressure profile (top exhaust)

The temperature profile of the top exhaust is shown in Figure 32.

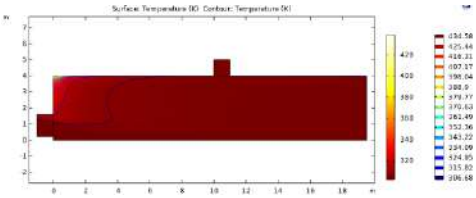


Figure 32. Temperature profile of greenhouse (top exhaust)

Temperature contour lines have shifted left, showing better heat removal from the greenhouse.

Figure 33 shows the temperature line graph through the cutline.

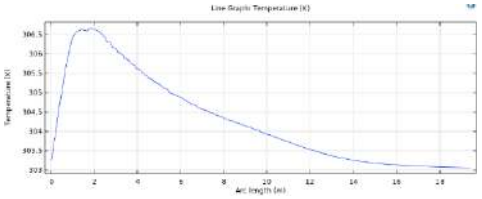


Figure 33. Temperature line graph (top exhaust)

The line graph shows a decrease in both the minimum temperature to 303 K and the maximum temperature to 307 K. Therefore, the simulation results indicate that the outlet located at the top showed slightly better heat removal when compared to the three different geometries of outlets. However, there is no significant improvement to the heat removal, only by modification to the air outlet geometry.

4. CONCLUSION

Greenhouse climate control is important to achieve maximum crop yield. Therefore, a wide range of technologies were used to control critical parameters in a greenhouse, such as temperature, light, humidity, etc. In this study, the temperature and humidity of the SLINTEC greenhouse were measured using an Arduino Microcontroller-based unit built locally. Recorded data showed the

greenhouse temperature was unsuitable for many plants. Therefore, COMOSL Multiphysics was used to simulate the temperature profile of the existing greenhouse conditions. Many assumptions were made to simplify this simulation, such as this study uses air inflow and zero pressure outlets instead of air exhaust from outlets. Then two more different air outlets were simulated to compare the temperature profiles. The results showed that relocating the air outlet to the top resulted in better heat removal compared to the other two air outlets. However, it is important to note that changing the air outlet location didn't contribute to a significant improvement in overall heat removal. Therefore, further studies can measure the greenhouse's temperature reduction by increasing air flow rates and decreasing the water curtains temperature.

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REFERENCES

Badji, A., Benseddik, A., Bensaha, H., Boukhelifa, A., & I. H. (2022). Design, technology, and management of greenhouse: A review. *Journal of Cleaner Production, 373*. https://doi.org/10.1016/j.jclepro.2022.133753.

Arshad, J. (2020). Intelligent greenhouse monitoring and control scheme: An arrangement of sensors, Raspberry Pi based embedded system and IoT platform. *Indian Journal of Science and Technology, 13*(27), 2811–2822. https://doi.org/10.17485/ijst/v13i27.311

Cooper, P. I., & Fuller, R. J. (1983). A transient model of the interaction between crop, environment and greenhouse structure for predicting crop yield and energy consumption. *Journal of Agricultural Engineering Research, 28*(5), 401–417. https://doi.org/10.1016/0021-8634(83)90133-6

Dalai, S. (2020). Greenhouses: Types and structural components. *Protected Cultivation and Smart Agriculture, December*.https://doi.org/10.30954/ndp-pcsa.2020.2

Kaini, M. (2020). Role of agriculture in ensuring food security. *International Journal of Humanities and Applied Social Science, 5*(1), 1–5. https://doi.org/10.33642/ijhass.v5n1p1

Liu, Y. (2022). Smart greenhouse monitoring and controlling based on NodeMCU. *International Journal of Advanced Computer Science and Applications, 13*(9), 597–600. https://doi.org/10.14569/IJACSA.2022.0130970

Panwar, N. L., Kaushik, S. C., & Kothari, S. (2011). Solar greenhouse an option for renewable and sustainable farming. *Renewable and Sustainable Energy Reviews, 15*(8), 3934–3945. https://doi.org/10.1016/j.rser.2011.07.030

Rushabh Shah, Manish Inamdar, Shreshthi Nalawade, Sahil Mujawar, & R. S. (2020). Automated monitoring and controlling of greenhouse. *International Research Journal of Engineering and Technology (IRJET), 29–37*.

Solar Energy - Solar Radiation. (n.d.). *Solarenergy.Org.Uk*. Retrieved August 24, 2023, from http://solarenergy.org.uk/solar-radiation

Unit 03: Glazing. (n.d.). *Greenhouse.Hosted.Uark.Edu*. Retrieved August 24, 2023, from https://greenhouse.hosted.uark.edu/Unit03/Printer_Friendly.html#:~:text=Typically%2C standard single layer glass

Yahaya, A., Abass, Y. A., & Adeshina, S. A. (2019). Greenhouse monitoring and control system with an Arduino system. *2019 15th International Conference on Electronics, Computer and Computation, ICECCO 2019, January 2021*. https://doi.org/10.1109/ICECCO48375.2019.9043188

A Survey on Fuel Consumption Measurement Methods of Road Vehicles

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ABSTRACT

The increasing price of fuel is influencing all the aspects of the global economy. As such, institutions and organizations of all kinds are kept on toes to reduce the expenses for fuel while ensuring the smooth run of their daily business activities. This is not different to the business organizations that run large fleets of vehicles to transport raw materials and deliver the products to the distributors. One major aspect of the reduction of expenses is to prevent the chances of fuel theft. The need for effective fuel consumption measurement methods is thus inevitable. A systematic method to determine the rate of fuel consumption would be key to identify abnormal changes of the fuel levels of vehicles. Combined with the time and the location, the data of a vehicle operating team will lay a solid foundation to track fuel theft from vehicles. Over the years, research works aiming the effective fuel consumption measurement methods have been published on scientific journals and conferences. Very recently, IOT has been used to build up internet enabled measurement devices for vehicles as much as other things. However, there seems to be a need to bring them together and categorize them for the benefit of future research work as well as the fuel theft prevention system development. This study attempts to figure out the work done by various researchers over the recent past on fuel consumption measurement methods and categorize them based on the technology used, convenience of implementing and advantages as well as disadvantages of those methods. The study identifies the limitations and challenges in fuel consumption measurement methods and the possible avenues that the future research work should take.

Keywords **- fuel consumption measurement, sensors, IOT.**

1. INTRODUCTION

Fuel prices are paramount to the economies. The consumer driven economy of the modern era relies heavily on the effective supply chain of goods and services at all levels of the manufacturing process starting from the raw materials to the finished products. Dependency of the supply chain

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to fuel consumption cost is ever more prominent in the contemporary socio-economic environment (Georgy Idrisov, 2015) (Setyawan, 2014). The world has experienced the impact of this dependency during the most recent Covid19 pandemic and the global economic uncertainty that followed (Izabela Dembińska, 2022) (Xinxin Zhang, 2021).

The business organizations of all scales are very conscious about fuel consumption as it generally accounts for a huge share of the annual expenses. Business organizations consume fossil fuel directly for driving machinery and running the vehicles. There are large fleets of vehicles for most of the business organizations that manufacture products and distribute them to markets. As such a significant annual share of expenses comes from fuel prices. Since fossil fuel is a valuable commodity, attempts to steal fuel from vehicle fuel tanks are so common (Urciuoli, 2020). Various methods attempted to cheat the fuel consumption of a vehicle and steal fuel from vehicle fuel tanks are being reported in news frequently.

As a remedy researchers investigate various methods to accurately measure fuel consumption. With the advent of advanced technology that enables effective embedded processing and instant long-distance communication areas like this have also been benefited. In the recent decades, high processing power on a small-scale single board computer became common and with the introduction to IOT data networks evolved such that anything can be given an IP address and connected to a TCP/IP network. Researchers did not hesitate to use these in to solve the problem of fuel consumption measurement. Their work has been published and reviewed in respective periodicals.

Since the diversity of such work can be broad and the focus of the research can be specific to certain application domains such as road vehicles, sea crafts and aircrafts. Some research works may be specific for certain machinery that consume fossil fuel and can be different to road vehicles in terms of the environment they apply to, noise levels they are subject to, supply voltages used and so on.

Therefore, a study on the diversity of the research work targeting fuel consumption measurement that classifies them and identifies the limitations, challenges and future research avenues seems to be legit. This survey addresses this requirement. The methodology used with an emphasis on the research questions asked, selection of articles, exclusion criteria, findings and analysis is presented below in the subsequent sections.

2. METHODOLOGY

This survey was carried out by following the steps described next. First, research questions were established. Then, finding relevant articles was done. The articles found were shortlisted by applying an exclusion criterion described later in this text. The selected articles were used to extract the relevant data and finally the literature was analyzed.

2.1 Establishing research questions

The following four research questions are asked in this study to make sure the essential aspects of the fuel consumption measurement methods are considered.

1. What are the recently published fuel consumption measurement methods?
2. How to classify fuel consumption measurement methods?
3. What are the limitations, challenges and future research avenues for fuel consumption measurement?

Surveying the literature to answer question 01 reveals the most recent developments in the subject area of this study. Answering question 02 reveals the possible methods of classification such as cost of implementation, accuracy of the methods and algorithms used to enable researchers to understand the diversity of the available methods. The third research question analyzes the limitations and challenges in implementing the published methods. This will enable researchers to figure out the future research avenues in fuel consumption measurement.

2.2 Finding relevant articles

The relevant articles were searched in the IEEE Xplore using advanced search option on 01st August 2023 and to ensure the study focuses on the most recent developments only those articles that were published after 2018 were selected. Those publications whose written language is not English were not considered for this survey. publications other than peer reviewed research articles such as newspaper and news magazine articles, government publications and the like were also not considered for this survey.

Keyword based search was done in two steps as the topic covers two aspects: fuel consumption measurement. The reason is that some of the articles may have focused on one aspect of the two. Articles on Fuel consumption measurement were searched using the keywords “fuel consumption measurement”, “fuel consumption monitoring”, “fuel level measurement” and “fuel level monitoring”, considering the possibility of the same aspect expressed in different words. The connective used was “OR” and the search was done with the option of “All Metadata”. The year range was adjusted to 2018 to 2023. Initial keyword-based search in IEEE Xplore resulted in 17 articles. The articles that focused on sea crafts were eliminated because the focus was on road vehicles with four wheels or more. Similarly, the articles that focused on driving behavior and one article that focused mainly on simulator design were also eliminated, leaving 9 articles to study.

2.3 Applying exclusion criteria

It is imperative to maintain a solid scope in a survey of research articles as the aims and objectives of the published work can be diverse, given the amount of scholarly work done around the globe. A broad research topic like fuel consumption measurement may include many application domains. Hence, the scope of this survey was limited to road vehicles. The fuel consumed is limited to gasoline and diesel both even though the two fuel types are quite different, because both fuel types are widely used in industries. The abstracts of

the research articles were read to identify the scope of them and those articles that do not fit this scope were excluded. The diagram in Figure 1 shows the method followed to select the relevant articles for the survey.

2.4 Extracting the relevant data

Once the relevant articles have been chosen, the next step of the study is to extract the data relevant to the survey to find out answers to the research questions. Carefully reading the methodology, results and discussions sections in the articles paved the way to extract the data. The extracted data was stored in a structured Microsoft Excel spreadsheet for further comparisons and analysis. This was helpful to understand the methods used and to develop a classification criterion for the existing methods of fuel consumption measurement.

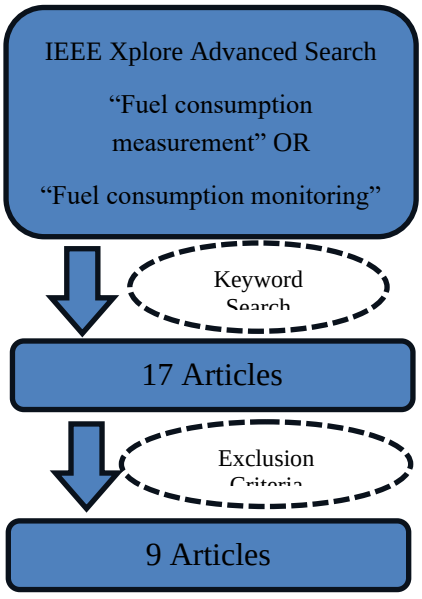

Figure 1 - Methodology in Brief

3. FINDINGS

The findings of the articles surveyed in this study are shown in this section. It presents the classification of fuel consumption measurement methods to be able to traverse through the varying features of these existing or proposed systems. This section thus answers research question 01 and 02 which was initially raised.

3.1 Classification of fuel consumption measurement methods

The survey revealed that the classification of fuel consumption methods can be done based on the way the sensors are used. This section presents the classification proposed.

3.1.1 Classification based on the sensing method used

Flow sensors and capacitive sensors along with ultra sonic sensors seems to be the most common sensors whereas load cells are also used in some methods. Some designs use multiple sensor types together. Figure 2 summarizes the classification proposed.

A single Flow sensor based methods

Flow sensors can be seen used by several research articles. A diesel flow sensor is used by Andres et al. (Andrés Baquero-Larriva, 2018) for the vehicles do not have a built in OBD or similar interface. The article shows that the design was low cost and easy to build. The design also has GPS data and it can log the time stamp (hh:mm:ss), position (latitude, longitude), altitude above sea level (m), instant speed (Km/h), instant flow (l/h), and accumulated flow (l). The method is implemented on an Arduino Mega.

A design based on a water flow sensor is presented by Wawan et al. (Wawan Purwanto, 2022) which is also implemented on an Arduino Uno. However, they have shown that this design does well only at constant RPMs of the engine. At variable RPMs the errors are significant.

A single capacitive sensor based methods

A method based on a single capacitive sensor is presented by Maksimov et al. (V. A. Maksimov, 2021). The claim that the device was calibrated only once and it requires recalibration only when the device service is required again. The article shows that the device showed a measurement accuracy of not worse than 1%. The article compares an analog measurement with a digital measurement and it claims that the difference between analog and digital data is not more than 0.77% for the minimum idle speed mode and not more than 0.75% for the high idle speed mode.

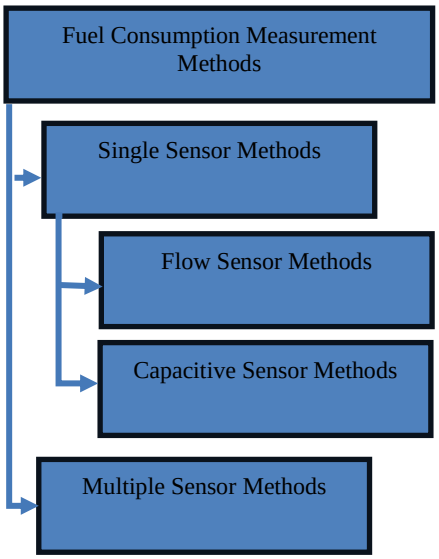

Figure 2 - Classification Method

A method based on a capacitive sensor is also presented by Aldan et al. (Aldan Sequeira, 2019). The method is using an NE555 timer based astable multivibrator for the measurements which depends on the capacitance. Their design uses two capacitors, one submerged in the fuel and the other above the fuel level. The article extends to analyse the possible errors in the design due to issues such as grounding. They also present the experimental data for diesel, gasoline, kerosene and transformer oil.

Multiple sensors based methods

A method based on a dry reed oil sensor and a floating ball oil sensor is presented by Liu et al. (Zhenhua Liu, 2018). They suggest a method such that refuelling the fuel tank is done step by step while the system is taking fuel level readings in the tank. These readings are used to calibrate the system. However, an additional tablet computer with a Bluetooth interface and a manual user input needed every time a calibration point is made. Another drawback of this method is that the fuel level of the tanks is measured only at the beginning of the day and only at the end of the day. Thus, it lacks the dynamic or real-time update of the fuel level. The design uses GPRS as the data network to connect to a remote device and the measurement system is implemented around a microcontroller.

A method based on an ultra-sonic sensor and a flow sensor is presented by Sakthimohan et al. (Sakthimohan. M, 2021). This design suggest that the two sensors can be used obtain a more reliable measurement. The design is implemented

on an Arduino Uno. The article does not present the type of filtering used for any of the sensors though.

A different approach is taken by Phalannadwa et al. (Phalanndwa L. Makhwathana, 2020) in which a reed sensor and a load cell is being used. The objective is to be able to measure the mass of the fuel quantity available in the tank and the density of the fuel in the tank. The system then calculates the volume of the fuel in the tank using the basic principles. This design is also implemented on an Arduino Uno.

A method that measures the fuel consumption and then upload data to a cloud-based repository is presented by Sanketh et al. (Sanketh B Prabhu, 2022). The design however relies on a mobile phone to provide the access to cloud and visualize the data. A highlight of this design is that they have used a vibration sensor also along with an ultra-sonic sensor and a flow sensor. To install the designed system in the vehicle a prior analysis after a capacity measurement is needed.

4. DISCUSSION

This section answers the research questions 03 that was initially raised.

4.1 Limitations

The survey observed that the published work has some limitations. One such limitation is that authors have given very little focus on the filtering aspect of the sensor data in the published articles. Particularly those methods proposed for live fuel consumption measurement while the vehicle is running must focus on inevitable vibrations. Methods that use flow sensors and ultra sonic sensors should be more thorough on this aspect.

Several methods published were observed to use Arduino library functions in the firmware. Given that Arduino is primarily meant for hobbyists, there arise concerns on the reliability of the calculations done in those methods.

Some articles had mentioned that the experiments were done at constant RPMs of the vehicle and that the readings were not reliable when the RPM varies. This raises the concern that the proposed method might be far from practical use.

Most of the published work subject to this survey seems to be covering a broad range of vehicles and thus attempting to make the design too generic. Designs of fuel consumption measurement methods for specific vehicle categories were rare within the scope of this survey.

IOT is one technology that could be used in this domain. However, the use of IOT is very limited in the articles surveyed. Some designs use GPRS or GSM phones which might be considered old fashioned.

A significant issue in the literature is that the articles have not thoroughly analysed the algorithms used or at least the algorithm is touched very lightly. This appears to be huge setback for the other researchers who study this area for further improvements.

Another major drawback in the literature that were analysed is that none of them particularly mention the cost of the design. Several designs claim to be low-cost. However, there are very little evidence in the set of articles to rank these designs based on the cost of implementation.

4.2 Challenges

Lack of funding could be a reason to the shortage of rigorous experimental setups for the experiments. This could be a major challenge for the researchers to overcome. Plans for in-depth analysis of the fuel consumption of a certain category of vehicles may need a huge budget.

Thinking beyond a basic embedded system design layout to introduce fault tolerance, redundancy and reliability seems to be a challenge. A paradigm shift in the thinking pattern in designing novel methods could be needed to overcome this.

That is also related to the thinking pattern for low-cost designs. Even though low-cost designs are admirable, a proper analysis is essential to quantify the quality against the cost. It is quite understandable that the main objective of measuring the fuel consumption to reduce the recurrent cost of fuel should not be compromised by a poor design that claims to be low in cost.

4.3 Future Research Work

It was observed that there are several future research avenues in fuel consumption measurement. One such area is the use of proper hardware and software filtering techniques for the sensor outputs. There seems to be very little attention paid to using processing elements such as FPGAs other than mid-range microcontrollers for fuel consumption measurement devices. An obvious advantage will be the ability to incorporate better filter stages in the design with the available processing power.

Only a few articles were observed using some redundancy in the design to make the readings more reliable. Hence, using redundant measurement techniques to determine a more reliable reading of the fuel consumed is another research area that can be focused on by the future researchers.

It is evident that the future research work should get the best of IOT for solutions which are accessible to all stakeholders conveniently. An opening of a major research avenue is observed in this area for the future work.

Further, it is evident that the attention on the information security applicable to fuel consumption measurement methods is very little. Therefore, that also appears to be a potential area of research to the future.

5. CONCLUSION

The survey conducted, answers the research questions raised initially by providing data and analysis up to the level of the articles gathered. Recent developments in the area are identified and a classification method is proposed for the fuel consumption measurement methods based on the sensors used. The study discusses the limitations, challenges and future research avenues possible. Authors expect the outcome of this article will be beneficial for the researchers to improve the research work in the fuel consumption measurement in the future.

REFERENCES

Aldan Sequeira, N. K. (2019). Fuel Level Detector. *International Conference on System, Computation, Automation and Networking (ICSCAN)* (pp. 1-5). Pondicherry, India: IEEE .

Andrés Baquero-Larriva, G. A.-C. (2018). Low cost data adquisition system to register fuel consumption in diesel engine vehicles. *2018 Congreso Internacional de Innovación y Tendencias en Ingeniería (CONIITI)* (pp. 1-4). Bogotá, Colombia: IEEE.

Georgy Idrisov, M. K. (2015). A theoretical interpretation of the oil prices impact on economic growth in contemporary Russia. *Russian Journal of Economics, 1*(3), 257-272.

Izabela Dembińska, A. B.-D. (2022). The Impact of the COVID-19 Pandemic on the Volume of Fuel Supplies to EU Countries. *Energies , 15*(22).

Phalanndwa L. Makhwathana, Z. W. (2020). Integrated Fuel Quantity Measurement. *XXX International Scientific Symposium 'Metrology and Metrology Assurance (MMA)* (pp. 1-4). Sozopol, Bulgaria: IEEE.

Sakthimohan. M, E. R. (2021). Digital Fuel Monitoring System For Automobiles. *Second International Conference on Electronics and Sustainable Communication Systems* (pp. 6-10). Coimbatore, TamilNadu, India: IEEE.

Sanketh B Prabhu, D. K. (2022). IoT Enabled Fuel Level Monitoring and Automatic Fuel Theft Detection System. *13th International Conference on Computing Communication and Networking Technologies (* (pp. 1-7). Kharagpur, India: IEEE.

Setyawan, D. (2014). The Impacts of the Domestic Fuel Increases on Prices of the Indonesian Economic Sectors. *Energy Procedia, 47*, 47-55.

Urciuoli, L. (2020). Fuel theft in road freight transport: understanding magnitude and impacts of anti-theft devices. *Journal of Transportation Security, 13*, 1-18.

V. A. Maksimov, N. V. (2021). The Use of Capacitive Sensors when Measuring Fuel Consumption for Warming Up Road Transport. *Intelligent Technologies and Electronic Devices in Vehicle and Road Transport Complex* (pp. 1-5). Moscow, Russia: IEEE.

Wawan Purwanto, H. M. (2022). Microcontroller Based Automatic Fuel Consumption Gauge. *International Conference of Science and Information Technology in Smart Administration (ICSINTESA)* (pp. 139-142). Bali, Indonesia: IEEE.

Xinxin Zhang, Z. L. (2021). Impact of COVID-19 pandemic on energy consumption and carbon dioxide emissions in China's transportation sector. *Case Studies in Thermal Engineering, 26*.

Zhenhua Liu, Y. L. (2018). A Method for Dynamic Measurement of Trucks' Fuel Consumption. *3rd International Conference on Intelligent Transportation Engineering* (pp. 154 - 158). Singapore: IEEE.

7. ACKNOWLEDGMENT

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A Semi-Analytical Approach for Boundary Layer Convection Heat Transfer in Case of High-speed Flow Over a Flat Plate

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ABSTRACT

Many real-world problems can be expressed as systems of nonlinear differential equations. Previously, perturbation techniques have been used to find solutions for these types of problems. Unfortunately, they are dependent on small or large physical parameters. In this paper, the Optimal Homotopy Analysis Method (OHAM) to obtain series-based solutions for the convection heat transfer problem within the boundary layer in the case of high-speed flow over a flat plate. The OHAM is an analytic approximation method suitable for highly nonlinear problems. Unlike perturbation techniques, the HAM is independent of any small or large physical parameters. The governing partial differential equations are transformed to nonlinear ordinary differential equations through a suitable similarity transformation. The obtained results, with errors, are presented graphically and tabulated. The effects of physical parameters on the flow are analyzed graphically. The obtained solutions are admitting a remarkable accuracy. This analytic approach is more general and can be used to analyze complicated models arising in science and engineering. Finally, an implementation is proposed.

Keywords: Optimal Homotopy Analysis Method (OHAM), boundary layer, convection heat transfer, high-speed flow, flat plate

1. INTRODUCTION

Most of the time we know nonlinear ordinary differential equations for boundary-value problems are much more

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difficult to solve compared to linear ones. People have been working on linear problems for a long time, so we know a lot about them. However, when it comes to nonlinear problems finding exact answers is really hard. To understand these nonlinear problems we use numerical methods. When exact or analytical solutions are discovered, generalizing these results to other nonlinear systems of differential equations remains a challenging task. Due to such difficulties, we have wanted a more general technique. The aim of this research is to apply OHAM to solve our problem and analyze the effect of heat transfer parameters on the flow.

2. BASIC IDEA OF HOMOTOPY ANALYSIS METHOD

We consider the following nonlinear ordinary differential equation,

$$\mathcal{N}[u(x)] = 0 \qquad (1)$$

Where $\mathcal{N}$ is a nonlinear operator, x denotes the independent variable, $u(x)$ is an unknown function, respectively. By means of the general traditional homotopy method, Lio (2003) constructs the so-called zero-order deformation equation

$$(1-q)\mathcal{L}[\emptyset(x;q) - u_0(x)] = q\hbar\mathcal{N}[\emptyset(x;q] \qquad (2)$$

Where $q \in [0,1]$ is an embedding parameter, $\hbar$ is a nonzero auxiliary parameter, $\mathcal{L}$ is an auxiliary linear operator, $u_0(x)$ is an initial approximation of $u(x)$ and $\emptyset(x;q)$ is an unknown function. It is important to note that, one has great freedom to choose the auxiliary parameter $\hbar$ and linear operator $\mathcal{L}$ in OHAM. Obviously, when $q = 0$ and $q = 1$, both $\emptyset(x,0) = u_0(x)$ and $\emptyset(x,1) = u(x)$ hold. Thus as q increases from 0 to 1, the solution $\emptyset(x;q)$ varies from the initial guess $u_0(x)$ to the solution $u(x)$. Expanding $\emptyset(x;q)$in Taylor series with respect to q, one has

$$\emptyset(x;q) = u_0(x) + \sum_{m=1}^{+\infty} u_m(x;q)q^m, \qquad (3)$$

where

$$u_m(x) = \frac{1}{m!}\frac{\partial^m \emptyset(x;q)}{\partial q^m}|_{q=0}. \qquad (4)$$

If the auxiliary linear operator, the initial guess, and the auxiliary parameter $\hbar$ are so properly chosen, then the series (3) converges at $q = 1$ and

$$\emptyset(x;1) = u_0(x) + \sum_{m=1}^{+\infty} u_m(x;q), \qquad (5)$$

Differentiating (2) m times with respect to the embedding parameter q and then setting $q = 0$ and finally dividing them by $m!$ we have the so-called m^{th}-order deformation equation

$$\mathcal{L}[u_m(x) - \chi u_{m-1}(x)] = \hbar\mathcal{R}_m, \qquad (6)$$

where

$$\mathcal{R}_m(u_{m-1}) = \frac{1}{(m-1)!}\frac{\partial^{m-1}\mathcal{N}[\emptyset(x;q)]}{\partial q^{m-1}}|_{q=0}, \qquad (7)$$

and

$$\chi_m = \begin{cases} 0, & m \le 1, \\ 1, & m > 1 \end{cases}.$$

3. GOVERNING EQUATIONS

Boundary layer flow over a flat plate is governed by the continuity and the Navier–Stokes equations. Under the boundary layer assumptions and a constant property assumption, the continuity and Navier–Stokes equations become:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \quad (8)$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + v\frac{\partial^2 y}{\partial y^2} + g\beta(T - T_\infty). \quad (9)$$

Under a boundary layer assumption, the energy transport equation is also simplified

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial^2 y} + \frac{\mu}{\rho C_p}\left(\frac{\partial u}{\partial y}\right)^2. \quad (10)$$

The term newly added $\frac{\mu}{\rho C_p}\left(\frac{\partial u}{\partial y}\right)^2$ represents a viscous effect on the flow. It cannot be neglected when the flow is high-speed. From Eqs. (9) and (10), the solution to the momentum equation and energy equation is coupled with each other. However, when a pressure gradient acts perpendicular to the gravitational force, the buoyancy force becomes negligible. The following dimensionless variables are introduced in the transformation:

$$\eta = y\sqrt{\frac{U_\infty}{vx}}, \qquad \theta(\eta) = \frac{T - T_w}{T_\infty - T_w} \quad (11)$$

where θ is the non-dimensional form of the temperature. using equations (8) to (11), it is possible to simplify the governing equations into a pair of equations, wherein the function f is dependent on the similarity variable (η):

$$f''' + \frac{1}{2}ff'' = 0, \quad (12)$$

$$\theta'' + \frac{1}{2}Prf\theta' = PrEc(f'')^2. \quad (13)$$

Where f is connected to the velocity (u) through $f' = \frac{u}{U_\infty}$. where U_∞ represents the free stream velocity in forced convection. The boundary conditions are derived from the similarity variables, for the forced convection scenario:

$$f(0) = 0, f'(0) = 0, f'(\infty) = 1, \quad \theta(0) = 0, \theta(\infty) = 1. \quad (14)$$

where the prime denotes differentiation with respect to η. The Prandtl number and Eckert number are defined as follows:

$$Pr = \frac{v}{\alpha} \quad \text{and} \quad Ec = \frac{U_\infty^2}{c_p(T_w - T_\infty)}.$$

4. OHAM SOLUTION

In order to solve Eqs. (12), (13), and (14) by HAM, we choose the linear operators

$$\mathcal{L}_f = \frac{\partial^3}{\partial^3\eta} - 4\frac{\partial}{\partial\eta}, \quad (15)$$

$$\mathcal{L}_\theta = \frac{\partial}{\partial\eta} + 1. \quad (16)$$

initial approximations

$$f_0(\eta) = \eta - 1 + e^\eta, \quad (17)$$

$$\theta_0(\eta) = 1 - e^\eta - \eta e^\eta. \quad (18)$$

Furthermore, Eqs. (12) and (13) suggest that we define the nonlinear operators as

$$\mathcal{N}_{f^\wedge}[f^\wedge] = \frac{\partial^3 f^\wedge}{\partial\eta^3} + \frac{1}{2}f^\wedge\frac{\partial^2 f^\wedge}{\partial\eta^2}, \quad (19)$$

$$\mathcal{N}_{\theta^\wedge}[f^\wedge, \theta^\wedge] = \frac{\partial^2\theta^\wedge}{\partial\eta^2} + \frac{1}{2}Prf^\wedge\frac{\partial\theta^\wedge}{\partial\eta} - PrEc\frac{\partial^2 f^{\wedge 2}}{\partial\eta^2}, \quad (20)$$

It can be seen that when $q = 0$, we have $f^\wedge(\eta; 0) = f_0(\eta)$ and $\theta^\wedge(\eta; 0) = \theta_0(\eta)$, while when $q = 1$ we have $f^\wedge(\eta; 1) = f(\eta)$ and $\theta^\wedge(\eta; 1) = \theta(\eta)$. To obtain $f_m(\eta)$ and $\theta_m(\eta)$, we recursively solve the m^{th} order deformation equations,

$$\mathcal{L}_f[f_m(\eta) - \chi f_{m-1}(\eta)] = \hbar_f\mathcal{R}_m^f \quad (21)$$

$$\mathcal{L}_\theta[\theta_m(\eta) - \chi\theta_{m-1}(\eta)] = \hbar_\theta\mathcal{R}_m^\theta. \quad (22)$$

with the initial conditions

$$f_m(0) = 0, f'_m(0) = 0, f'_m(\infty) = 0, \quad \theta_m(0) = 0, \theta_m(\infty) = 0. \quad (23)$$

5. RESULTS AND DISCUSSION

To compute the optimal value of the convergence-control $\hbar_f$ and $\hbar_\theta$, we

evaluate the error and minimize over $\hbar_f$ and $\hbar_\theta$. For the m^{th} order approximation, the exact squared residual error is given by

$$\mathcal{E}^{\wedge f}_{m}(\hbar_f) = \int_0^\infty (\mathcal{N}_f[f_m(\eta)])^2\, d\eta, \quad (24)$$

$$\mathcal{E}^{\wedge \theta}_{m}(\hbar_f, \hbar_\theta) = \int_0^\infty (\mathcal{N}_\theta[f_m(\eta), \theta_m(\eta)])^2\, d\eta. \quad (25)$$

In practice, it is often too CPU intensive to evaluate $\mathcal{E}^{\wedge f}_{m}$ and $\mathcal{E}^{\wedge \theta}_{m}$, even for relatively low orders of approximation. To overcome this difficulty, we use discrete squared residual error,

$$\mathcal{E}^{f}_{m}(\hbar_f) = \frac{1}{N+1}\sum_{i=0}^{N}\left(\mathcal{N}_f\left[\sum_{j=0}^{m} f_j(\eta_i)\right]\right)^2, \quad (26)$$

$$\mathcal{E}^{\theta}_{m}(\hbar_f, \hbar_\theta) = \frac{1}{N+1}\sum_{i=0}^{N}\left(\mathcal{N}_\theta\left[\sum_{j=0}^{m} f_j(\eta_i), \sum_{j=0}^{m} \theta_j(\eta_i)\right]\right)^2. \quad (27)$$

where $\eta_i = i\delta\eta$ and N is an integer. For the m^{th} order approximation, the optimal values of $\hbar_f$ and $\hbar_\theta$ are determined by minimizing the total error, defined by $\mathcal{E}^{t}_{m}(\hbar_f, \hbar_\theta) = \mathcal{E}^{f}_{m}(\hbar_f, \hbar_\theta) + \mathcal{E}^{\theta}_{m}(\hbar_f, \hbar_\theta)$.

Here, we illustrate the accuracy of the method used in the present study. Consider the case where $Pr = 1$ and $Ec = 1$. Using the aforementioned method, we obtained the 10th-order approximate solution. The corresponding optimal converge control parameters are found to be $\hbar_f = -1.2867$ and $\hbar_\theta = 0.1937$ with a total error $\mathcal{E}^{t}_{10} = 4.2 \times 10^{-4}$. It is found that the total discrete residual error decreases as a function of the order of approximation, as shown in Fig.4. Moreover, the total discrete squared residual at the 3rd-order homotopy approximation is used to find the optimal convergence-control parameters.

Table 1: The results of OHAM for $f(\eta)$, $f'(\eta)$ and $\theta(\eta)$

$\boldsymbol{\eta}$	$f(\boldsymbol{\eta})$	$f'(\boldsymbol{\eta})$	$\theta(\boldsymbol{\eta})$
0	0	0	0
0.5	0.046941	0.187454	0.103207
1.0	0.186675	0.370112	0.232130
1.5	0.414936	0.539999	0.380946
2.0	0.722918	0.687407	0.536872
2.5	1.097240	0.804380	0.683555
3.0	1.521720	0.888104	0.806619
3.5	1.980310	0.941763	0.898189
4.0	2.459660	0.972483	0.957739
4.5	2.950300	0988205	0.990194
5.0	3.446460	0.995416	1.003160

Table 2: Minimum of the total discrete squared residual $\mathcal{E}_m$ and the corresponding optimal value of $\hbar_f$ and $\hbar_\theta$ of the m^{th} order approximations given by OHAM.

m	Optimal value of $\hbar_f$	Optimal value of $\hbar_\theta$	Minimum of $\mathcal{E}_m(10^{-3})$
2	−1.4041	0.1629	4.35
3	−1.2867	0.1937	3.10
4	−1.4849	0.1441	1.82
5	−1.3227	0.2119	1.25
6	−1.3227	0.1941	1.01
7	−1.3618	0.2147	0.623
8	−1.3389	0.1990	0.569
9	−1.4697	0.1921	0.396
10	−1.4251	0.1777	0.392

Table 3: The used CPU time according to the m^{th} order approximations given by HAM.

m	CPU time
2	9.0
3	15.6
4	26.0

5	37.8
6	56.8
7	83.9
8	123.7
9	181.9
10	273.8

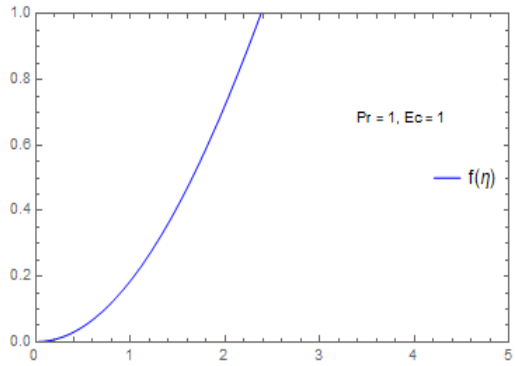

Figure 1: Graph of $f(\eta)$ Vs η

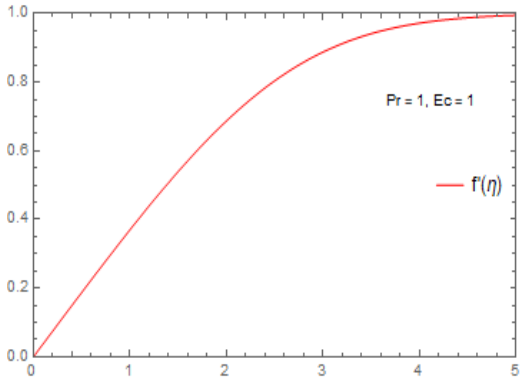

Figure 2: Graph of $f'(\eta)$ Vs η

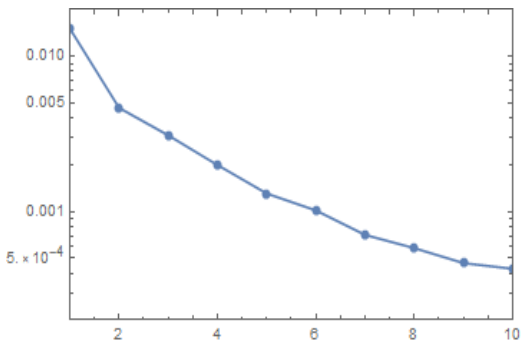

Figure 4: Total discrete squared residual error $\mathcal{E}^t$ Vs order of approximations m.

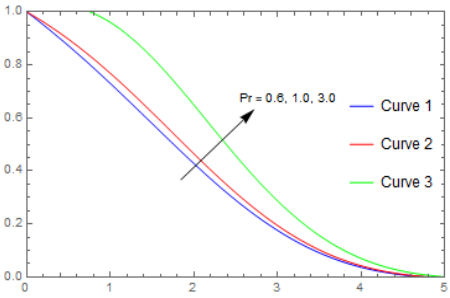

Figure 3: Graph of $1-\theta(\eta)$ Vs η. Curve 1: $Ec = 1, Pr = 0.6$; . Curve 2: $Ec = 1, Pr = 1.0$; . Curve 3: $Ec = 1, Pr = 3$.

5. CONCLUSION AND FUTURE WORK

The method of homotopy analysis was extended and successfully used to solve systems of coupled nonlinear differential equations. The solutions to these nonlinear systems have a remarkable level of accuracy. Finally, we conclude it can be used to solve boundary layer convection heat transfers in case of high-speed flow over a flat plate problem.

However, it is valid for only constant free stream velocity (U_∞). Therefore, it is still an open problem to apply this method to solve the above problem with variable free stream velocity. Here $U_\infty = Cx^n$ and $n = \frac{x}{U_\infty}\frac{dU_\infty}{dx}$. Where n is the pressure gradient on both velocity and temperature distributions in the boundary layer.

REFERENCES

Akyildiz, F. T., & Vajravelu, K. (2008). Magnetohydrodynamic flow of a viscoelastic fluid. Physics Letters A, 372(19), 3380-3384.

Baxter, M., Dewasurendra, M., & Vajravelu, K. (2018). A method of directly defining the inverse mapping for solutions of coupled systems of nonlinear differential equations. Numerical Algorithms, 77, 1199-1211.

Dewasurendra, M., Baxter, M., & Vajravelu, K. (2018). A method of directly defining the inverse mapping for solutions of non-linear coupled systems arising in convection heat transfer in a second grade fluid. Applied Mathematics and Computation, 339, 758-767.

Esmaeilpour, M., & Ganji, D. D. (2007). Application of He's homotopy perturbation method to boundary layer flow and convection heat transfer over a flat plate. Physics Letters A, 372(1), 33-38.

Fan, T., & You, X. (2013). Optimal homotopy analysis method for nonlinear differential equations in the boundary layer. Numerical Algorithms, 62, 337-354.

Fathizadeh, M., & Rashidi, F. (2009). Boundary layer convective heat transfer with pressure gradient using Homotopy Perturbation Method (HPM) over a flat plate. Chaos, Solitons & Fractals, 42(4), 2413-2419.

Jiji, L. M., & Jiji, L. M. (2006). Heat convection (p. 434). Berlin: Springer.

Liao, S. (2003). Beyond perturbation: introduction to the homotopy analysis method. CRC press.

Liao, S. (2010). An optimal homotopy-analysis approach for strongly nonlinear differential equations. Communications in Nonlinear Science and Numerical Simulation, 15(8), 2003-2016.

Liao, S. (2012). Homotopy analysis method in nonlinear differential equations. Beijing: Higher education press.

Liao, S. J. (1997). A kind of approximate solution technique which does not depend upon small parameters - II. An application in fluid mechanics. International Journal of Non-Linear Mechanics, 32(5), 815-822.

Liao, S. J. (1999). An explicit, totally analytic approximate solution for Blasius' viscous flow problems. International Journal of Non-Linear Mechanics, 34(4), 759-778.

Liao, S., & Zhao, Y. (2016). On the method of directly defining inverse mapping for nonlinear differential equations. Numerical Algorithms, 72(4), 989-1020.

Marinca, V., & Herişanu, N. (2008). Application of optimal homotopy asymptotic method for solving nonlinear equations arising in heat transfer. International communications in heat and mass transfer, 35(6), 710-715.

Niu, Z., & Wang, C. (2010). A one-step optimal homotopy analysis method for nonlinear differential equations. Communications in Nonlinear Science and Numerical Simulation, 15(8), 2026-2036.

Tani, I. (1977). History of boundary layer theory. Annual review of fluid mechanics, 9(1), 87-111.

Vajravelu, K., Gregory, G., Li, R., Dewasurendra, M., & Prasad, K. V. (2016). Hydromagnetic flow and heat transfer of an upper-convected Maxwell fluid in a parallel plate channel with stretching walls.

Yabushita, K., Yamashita, M., & Tsuboi, K. (2007). An analytic solution of projectile motion with the quadratic resistance law using the homotopy analysis method. Journal of Physics A: Mathematical and theoretical, 40(29), 8403.

Environmental and Health Impacts of Improper Disposal of Solar Panels

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ABSTRACT

This study provides an in-depth examination of the global usage and disposal practices of solar panels, with a particular focus on their environmental and health impacts. Drawing on authoritative publications from the International Renewable Energy Agency (IRENA), the US Environmental Protection Agency (EPA), and the European Union (EU), the research uncovers significant issues related to the end-of-life management of solar panels.

The findings reveal that solar panels, which have become increasingly prevalent due to the global shift towards renewable energy sources, contain hazardous materials such as lead and cadmium. If not disposed of properly, these materials can leach into the soil, contaminating groundwater and posing a threat to both ecosystems and human health.

The study underscores the urgent need for effective and globally implemented strategies for solar panel disposal. It advocates for practices that not only prevent environmental contamination and health hazards but also promote the recycling and reuse of valuable materials contained in the panels. By doing so, it contributes to the vision of a circular economy, where resources are kept in use for as long as possible, and waste generation is minimized.

The study concludes with a call to action for policymakers, industry stakeholders, and the public, emphasizing the importance of awareness and proactive measures in achieving more sustainable solar panel disposal practices. It also suggests areas for future research, including the monitoring of the implementation and effectiveness of solar panel disposal strategies globally. This research serves as a valuable resource for those involved in renewable energy and sustainability, providing insights that can guide future actions and decisions.

Keywords **- Solar Panel Disposal, Environmental Impacts, Health Risks.**

1. INTRODUCTION

The transition to renewable energy sources is a global imperative in the face of climate change. Among these, solar energy has emerged as a key player, with its usage seeing a significant increase globally (International Renewable Energy Agency [IRENA], 2019). Solar panels, the primary technology for harnessing solar energy, have become a common sight in many parts of the world. However, as the number of solar panels increases, so does the challenge of their disposal at the end of their life cycle.

Solar panels, like any other product, have a finite lifespan. At the end of their useful life, they become waste that needs to be managed. The US Environmental Protection Agency (EPA) has highlighted the importance of proper solar panel recycling (EPA, 2021). Despite this, the practices for solar panel disposal vary greatly across different regions.

In the European Union, for instance, the Directive 2012/19/EU on waste electrical and electronic equipment (WEEE) provides guidelines for the disposal of electronic waste, including solar panels (European Union [EU], 2012). However, many countries outside the EU lack comprehensive regulations and practices for solar panel disposal. This gap in regulation and practice can lead to improper disposal of solar panels, which can have severe environmental and health impacts.

This study aims to delve into this under-researched area. It will examine the global usage and disposal practices of solar panels, assess their environmental and health impacts, and provide recommendations for their proper disposal. The objectives of this study are to provide a detailed examination of global solar panel usage, discuss current practices for solar panel disposal, explore the environmental consequences and potential health risks associated with improper solar panel disposal, and compare these findings with previous studies.

By shedding light on this issue, this study hopes to contribute to the ongoing discourse on renewable energy and sustainability. It seeks to provide policymakers, industry stakeholders, and the public with valuable insights that can guide future actions towards more sustainable solar panel disposal practices.

2. METHODOLOGY

In this study, the focus was on publications from the International Renewable Energy Agency (IRENA), the US Environmental Protection Agency (EPA), and the European Union (EU).

The selection of the International Renewable Energy Agency (IRENA), the US Environmental Protection Agency (EPA), and the European Union (EU) as the primary sources for this study was based on several factors.

Firstly, these organizations have a long-standing history and extensive experience in the field of renewable energy and environmental regulation. IRENA was officially founded in Bonn, Germany, on 26 January 2009 (International Renewable Energy Agency [IRENA], 2009). The EPA was created on December 2, 1970, by

President Richard Nixon to protect human health and the environment (US Environmental Protection Agency [EPA], 2023). They have been involved in this area of study for a longer period compared to most other parties, which adds to the reliability and depth of their publications.

Secondly, these organizations have a broad geographical coverage. IRENA provides a global perspective (IRENA, 2023), the EU offers a European viewpoint (IRENA, 2023), and the EPA gives an American outlook (US Environmental Protection Agency [EPA], 2023). This wide coverage ensures that the study encompasses diverse practices and regulations across different regions.

Thirdly, these organizations are known for their rigorous research methodologies and their commitment to scientific integrity. The data and insights provided in their publications are based on comprehensive research and thorough analysis, which adds to the credibility of this study (International Renewable Energy Agency [IRENA], 2019; US Environmental Protection Agency [EPA], 2023; European Union [EU], 2023).

Lastly, these organizations not only provide data but also set guidelines and regulations in their respective regions. Their publications, therefore, offer valuable insights into both the current state of affairs and the direction of future developments in solar panel usage and disposal.

While there are indeed many emerging parties in this field, the depth, reliability, and geographical coverage of the publications from IRENA, the EPA, and the EU make them particularly suited for the objectives of this study. However, it's important to note that the inclusion of other parties in future research could provide additional perspectives and further enrich the understanding of this topic.

For IRENA publications, a search was conducted using the keywords "Solar panels", "recycling", "English", and "publication". This yielded 196 articles. To further refine the search, additional keywords such as "developing countries", "end-of-life management", and "future predictions" were used. This narrowed down the selection to the 5 references used in this study.

For EU publications, the search was conducted on the website of the Publication Office of the EU. The keywords used were "EU law", "EU publications", "English", "Legislations", "Research report", and "Solar Panel". This resulted in 533 results from 2021 to 2023. The content was further separated using "developing countries", "potential and challenges", and "assessment of technology" to narrow down to the 6 references used here.

For the US EPA, a direct search was conducted for legislation on Solar panels. This search yielded the three references used in this study.

This methodology ensured that the research was based on authoritative sources and that the selected articles were most relevant to the study's objectives. It also allowed for a comprehensive examination of the topic from different perspectives - global (IRENA), European (EU), and American (US EPA).

3. GLOBAL SOLAR PANEL USAGE AND DISPOSAL

Solar energy has seen a significant increase in usage globally. According to the International Renewable Energy Agency (IRENA), the adoption of solar energy is part of a broader global energy transformation towards renewable sources (IRENA, 2019). This transformation is driven by the need to reduce greenhouse gas emissions and mitigate the impacts of climate change.

Solar panels, which are the primary technology for harnessing solar energy, have become a common sight in many parts of the world. However, as the number of solar panels increases, so does the challenge of their disposal at the end of their life cycle (US Environmental Protection Agency [EPA], 2021).

The end-of-life management of solar photovoltaic panels is a critical aspect of their lifecycle (IRENA, 2016). When solar panels reach the end of their useful life; which is typically around 25-30 years, they become waste that needs to be managed properly. However, the practices for solar panel disposal vary greatly across different regions US Environmental Protection Agency [EPA], 2021).

Improper disposal of solar panels can have severe environmental and health impacts. Therefore, it is crucial to develop and implement effective strategies for solar panel disposal globally. These should not only focus on mitigating the environmental impacts of solar panel waste but also on promoting the recycling and reuse of valuable materials contained in the panels. This would contribute to a more circular economy, where resources are kept in use for as long as possible, and waste is minimized (Clean Energy Technology Observatory, 2023).

4. ENVIRONMENTAL IMPACTS

Improper disposal of solar panels can have severe environmental consequences. Solar panels contain several hazardous materials, including heavy metals like lead and chemicals like cadmium. If not disposed of properly, these materials can leach into the soil, contaminating groundwater and posing a threat to ecosystems (US Environmental Protection Agency [EPA], 2021).

Traces of hazardous heavy metals in solar panels could put a serious strain on the environment if the world's estimated 3,700 square kilometers of panels are not disposed of carefully (International Renewable Energy Agency, 2016).

Moreover, the sheer volume of solar panel waste is a concern. With the increasing adoption of solar energy, the number of end-of-life solar panels is expected to rise significantly in the coming years. This could lead to a substantial increase in electronic waste, which already poses a significant environmental challenge globally (International Renewable Energy Agency [IRENA], 2016).

In the European Union, regulations such as the Directive 2012/19/EU on waste electrical and electronic equipment (WEEE) aim to mitigate these environmental impacts by setting guidelines for the disposal of electronic waste, including solar panels (European Union [EU], 2012). However, many regions around the world lack such comprehensive regulations, leading to inconsistent and often inadequate disposal practices.

5. HEALTH IMPACTS

The potential health risks associated with improper solar panel disposal are a significant concern. Solar panels contain several hazardous materials, including heavy metals like lead and chemicals like cadmium (US Environmental Protection Agency [EPA], 2021).

Exposure to these contaminants can have serious health effects. For instance, lead is a potent neurotoxin that can cause cognitive impairment, particularly in children. Cadmium is a carcinogen and can cause lung and prostate cancer. Moreover, these heavy metals can bioaccumulate in the food chain, posing a risk to wildlife and humans alike (US Environmental Protection Agency [EPA], 2021).

In the European Union, regulations on waste electrical and electronic equipment aim to mitigate these health risks by setting guidelines for the disposal of electronic waste, including solar panels (European Union [EU], 2012). However, many regions around the world lack such comprehensive regulations, leading to inconsistent and often inadequate disposal practices.

Therefore, it is crucial to develop and implement effective strategies for solar panel disposal globally. These should not only focus on mitigating the health impacts of solar panel waste but also on promoting the recycling and reuse of valuable materials contained in the panels. This would contribute to a more circular economy, where resources are kept in use for as long as possible, and waste is minimized (Clean Energy Technology Observatory, 2023).

6. DISCUSSION

The findings of this study highlight the significant environmental and health impacts associated with the improper disposal of solar panels. These impacts are largely due to the presence of hazardous materials in solar panels, such as heavy metals like lead and chemicals like cadmium, which can leach into the soil and contaminate groundwater (US Environmental Protection Agency [EPA], 2023).

These findings align with previous studies that have also highlighted the environmental and health risks associated with improper solar panel disposal (International Renewable Energy Agency [IRENA], 2016). However, this study further emphasizes the need for effective strategies for solar panel disposal globally, particularly in regions that currently lack comprehensive regulations and practices.

The study also underscores the importance of a circular economy, where resources are kept in use for as long as possible, and waste is minimized (Clean Energy Technology Observatory, 2023). This approach not only mitigates the environmental and health impacts of solar panel waste but also promotes the recycling and reuse of valuable materials contained in the panels.

Moreover, the study highlights the role of policymakers, industry stakeholders, and the public in achieving more sustainable solar panel disposal practices. It calls for increased awareness and proactive measures to ensure that solar panels are disposed of properly at the end of their life cycle. The European Union, for instance,

has made significant contributions to the energy transition in 2020 and 2021, including the development of standards for photovoltaic energy systems (European Union [EU], 2023).

7. CONCLUSION

In conclusion, this study underscores the urgent need for proper solar panel disposal practices globally. The improper disposal of solar panels poses significant environmental and health risks due to the leaching of hazardous materials into the soil and groundwater.

To mitigate these risks, it is crucial to develop and implement effective strategies for solar panel disposal. These strategies should focus not only on preventing environmental contamination and health hazards but also on promoting the recycling and reuse of valuable materials contained in the panels. This would contribute to a more circular economy, where resources are kept in use for as long as possible, and waste is minimized (Clean Energy Technology Observatory, 2023).

Future research should continue to explore this topic and monitor the implementation and effectiveness of solar panel disposal strategies globally. Policymakers, industry stakeholders, and the public should be made aware of the findings of this study to guide future actions towards more sustainable solar panel disposal practices. It also suggests areas for future research, including the monitoring of the implementation and effectiveness of solar panel disposal strategies globally. This research serves as a valuable resource for those involved in renewable energy and sustainability, providing insights that can guide future actions and decisions.

REFERENCES

(2023). EPA Research.
Clean Energy Technology Observatory. (2023). Overall strategic analysis of clean energy technology in the European Union.
European Union (EU). (2012). Directive2012/19/EU on waste electrical and electronic equipment (WEEE).
European Union (EU). (2021). Standards for photovoltaic energy systems - Summary of the Joint Research Centre's contribution to international and European standards in 2020 and 2021.
European Union (EU). (2021). Summary of the European Solar Test Installation's contribution to the energy transition in 2020 and 2021.
European Union (EU). (2022). Sustainable power sector development in Uzbekistan and Tajikistan.
European Union (EU). (2023). Overview of the potential and challenges for agri-photovoltaics in the European Union.
European Union (EU). (2023). State-of-the-art for assessment of solar energy technologies.
European Union. (2023). History of the EU.
International Renewable Energy Agency (IRENA). (2016). End-of-life management: Solar Photovoltaic Panels.
International Renewable Energy Agency (IRENA). (2019). Advancing Renewables in Developing Countries.
International Renewable Energy Agency (IRENA). (2019). Global energy transformation: A roadmap to 2050.
International Renewable Energy Agency (IRENA). (2021). Off-grid renewable energy statistics.
International Renewable Energy Agency. (2009). Founding Conference of the International Renewable Energy Agency.
International Renewable Energy Agency. (2023). Country Profiles.
US Environmental Protection Agency (EPA). (2023). End-of-Life Solar Panels: Regulations and Management.
US Environmental Protection Agency(EPA). (2021). Solar Panel Recycling: What You Need to Know.
US Environmental Protection Agency.
US Environmental Protection Agency. (2023). EPA Guidance Documents.
US Environmental Protection Agency. (2023). EPA History.

Characterization and Analysis of the Antibacterial and Antioxidant Efficacy of Chitosan-based Edible Biodegradable Food Packaging Films Loaded with Lemongrass (Cymbopogon Citratus) Essential Oil

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Abstract

There is a growing demand for developing eco-friendly packaging solutions instead of conventional plastic packaging to minimize non-biodegradable waste and improve food quality and safety. In this study, active edible packaging films were developed using chitosan (Chn), and the film fabrication was done using different concentrations (0.5%, 1%, and 1.5%) of lemongrass essential oil (LEO), which was

used as the active ingredient. The films were synthesized using the casting method and were characterized based on physical, optical, mechanical, antioxidant, and antimicrobial properties and biodegradability. The results showed that increasing the concentration of LEO resulted in thicker films and a reduction in the moisture content, which ranged between 10.5% and 26.8%. The chitosan-based films containing LEO (Chn+LEO) exhibited superior water resistance in comparison to the films without LEO (Chn) due to the hydrophobic properties of LEO. The soil biodegradability of the films decreased within 28 days with increasing LEO concentration. The tensile strength of the films decreased with increasing LEO concentration, while the elongation at break increased with increasing LEO content. An increase in the concentration of LEO led to a significant ($p<0.05$) rise in total color difference (ΔE) and a significant ($p<0.05$) decrease in the whiteness index. The antimicrobial properties against Staphylococcus aureus, Bacillus cereus, Klebsiella pneumoniae, and Escherichia coli of the films were enhanced by the LEO incorporation and mainly depended on their concentration. Increasing the concentration of LEO has been shown to significantly ($p<0.05$) improve its antioxidant properties. In particular, the IC_{50} values of 0.5%, 1%, and 1.5% Chn+LEO films were 0.44, 0.21, and 0.19 mg/mL, respectively. These results proved that chitosan-based films incorporated with LEO have promising antioxidant and antimicrobial properties, making them effective for use as sustainable packaging materials.

Keywords **- Antimicrobial, antioxidant, biodegradable, chitosan films, lemongrass essential oil**

1. INTRODUCTION

Food packaging protects food products from physical, chemical, and biological influences. However, these non-renewable, non-biodegradable, synthetic packaging materials have serious environmental drawbacks, mainly due to their accumulation, leading to huge environmental pollution. Currently, edible and biodegradable films are a fast-emerging technology with increased attention among researchers and consumers, which acts as an alternative to synthetic food packaging. Edible packaging is synthesized utilizing various biopolymers such as alginate, agar, chitosan, carrageenan, lipids, etc. (Kaushani et al., 2022)

Chitosan is a prominent biopolymer sourced from the exoskeletons of crustaceans such as shrimp, crabs, and lobsters. It is derived by deacetylating chitin, a fundamental structural element in these shells. This transformation yields a distinctive polymer characterized by its exceptional attributes and extensive applicability due to its biodegradability, biocompatibility, non-toxicity, and antimicrobial properties (Hafsa et al., 2016). Furthermore, chitosan presents significant benefits as a material for edible packaging due to its good film-forming properties.

Active packaging involves the integration of active substances directly into packaging materials, instead of adding them to the food itself (Kaushani, 2022). This approach

aims to enhance the shelf life of food products while safeguarding and enhancing their sensory qualities. Consequently, novel active packaging strategies incorporating natural active compounds present advantageous alternatives to traditional packaging methods.

In order to synthesize active packaging, essential oils (EOs) can be used as natural active ingredients. Essential oils derived from plant extracts possess inherent antimicrobial properties. When these oils are integrated into edible packaging films, they have the potential to not only increase the films' antimicrobial efficacy but also mitigate water solubility, enhance vapor resistance, and decelerate lipid oxidation in the packaged product (Ojagh et al., 2010).

Among EOs, lemongrass (Cymbopogon citratus) essential oil (LEO) mainly contains monoterpenes such as citral, which is a mixture of neral and geranial (Contini et al., 2022). LEO can be added to chitosan-based films as natural active materials to produce active packaging films with antioxidant and antimicrobial properties.

Therefore, the present study aimed to assess the effect of the addition of various concentrations of LEO on the physical, optical, mechanical, antimicrobial, and antioxidant properties and biodegradability of chitosan composite films.

2. METHODOLOGY

Chitosan-based films were prepared using the method described by Hafsa et al. (2016) with slight modifications. The chitosan film-forming solutions were prepared by dispersing chitosan (2%) and glycerol (0.75g/g chitosan) in 1% (v/v) of glacial acetic acid solution. Various concentrations (0.5%, 1.0%, and 1.5% of total volume) of lemongrass essential oil and Tween 80 (0.20% of essential oil) were incorporated in the film-forming solution. All formulations were mixed in a homogenizer to form a homogenous solution and then degassed under a vacuum. The formulations were transferred to glass molds and dried at ambient conditions. The dried films were then removed from the Petri dishes and conditioned at 50 ± 5% relative humidity and 25 ± 2 °C until analysis.

The physical properties such as thickness (Chen et al., 2021), moisture content (Ojagh et al., 2010), water solubility (Ojagh et al., 2010), optical properties such as surface color difference (ΔE) and whiteness index (Keshari et al., 2022), and mechanical properties such as tensile strength and elongation at break (ASTM D882-10) of the films were analyzed. Each film sample underwent testing in three replicates to ensure data accuracy.

The film biodegradability was tested using the soil degradation method (Kaya et al., 2018).

The antioxidant activity of film samples was evaluated using a 1,1-diphenyl-2-picrylhydrazyl (DPPH) free radical scavenging assay (Chen et al., 2021).

A quantitative assay of the antimicrobial activity of the films was done using the liquid culture medium assay (Leceta et al., 2013). The antimicrobial activities of chitosan-based films were tested against four food-borne pathogenic bacteria (gram-positive: Staphylococcus aureus, Bacillus cereus, gram-negative: Klebsiella

pneumoniae, Escherichia coli) isolated in the lab from spoiled fruits and vegetables.

Analysis of variance (ANOVA) was conducted to evaluate the variations among the physical, optical, mechanical, antioxidant, and antimicrobial properties of the edible biodegradable packaging films. MINITAB 17 software was employed for the statistical analysis, and differences were regarded as statistically significant when the $p < 0.05$.

3. RESULTS AND DISCUSSION

3.1 Physical properties of films

3.1.1 Film thickness

According to Figure 1, The addition of lemongrass essential oil (LEO) to chitosan-based film-forming emulsions led to an increase in the thickness of the films compared to the control samples and film thickness increased with the rise in the concentration of LEO which ranged between 0.10 mm and 0.18 mm. This could be due to the dispersed micro-droplets of EO in the polymeric matrix and due to the interaction between the oil molecules and the chitosan matrix which influence the kinetics of film formation and the arrangement of molecules. There is a significant effect of the addition of LEO on the film thickness ($p < 0.05$).

3.1.2 Moisture content

It was observed that the incorporation of LEO, caused a significant decrease ($p < 0.05$) in the moisture content of the films, from 26.81% to 10.53%. When increasing the EO concentration, the moisture content decreased significantly ($p < 0.05$). As chitosan is highly hydrophilic, the control films (with no EO) exhibited the highest moisture content, as expected. The combination of molecular entanglement and viscosity, which naturally occurs in pure chitosan films, is enhanced by the incorporation of LEO in chitosan-based films. The presence of LEO adds an additional layer of complexity to the film's structure, making it even more resistant to moisture absorption and retention compared to control films. The covalent bonding between LEO and the functional groups of polymeric matrices decreased the polysaccharide-water interactions by hydrogen bonding, ultimately leading to a decrease in the moisture content of films loaded with EO (Han Lyn & Nur Hanani, 2020).

3.1.3 Water solubility

It was found that the solubility declined significantly ($p < 0.05$) with increasing LEO concentration. This suggests that the water resistance of the films was improved due to the increase in hydrophobicity of the films caused by the possible addition of EOs. Additionally, the components of LEO such as terpenes and phenols decreased the interaction of hydroxyl groups with water molecules, resulting in low solubility of the films (Benavides et al., 2012). This reduction in water solubility is advantageous for packaging films, as it can enhance the film's resistance to moisture and help preserve the quality of the packaged product.

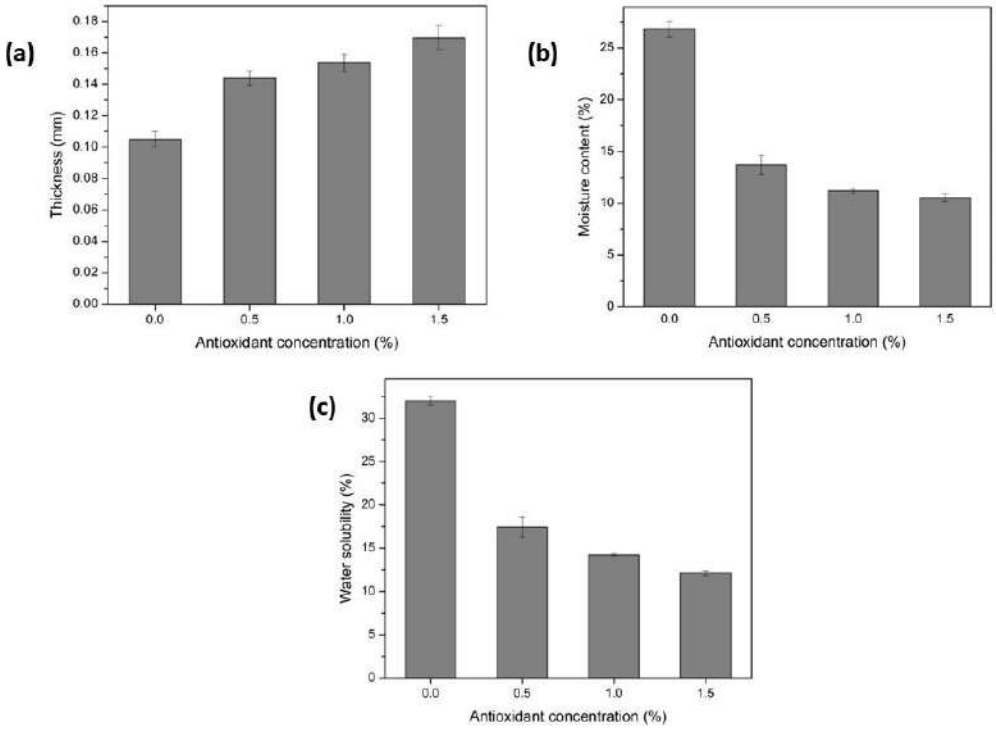


Figure 1. (a) Thickness, (b) moisture content (%), and (c) water solubility (%) variations of Chn+LEO films. Vertical bars represent ± standard deviation of means

3.2 Optical properties

3.2.1 Surface color difference (ΔE) and whiteness index

Chitosan-based films incorporated with LEO showed a total color difference (ΔE) significantly greater ($p < 0.05$) than the control film which increases with increasing concentration (Figure 2). This behavior is attributed to the decrease in brightness (L*) and a shift in color toward yellow (+b*). This variation in the luminosity induced by the incorporation of LEO could be due to the molecular alteration of chitosan. The increase in the yellow coloration of the Chn+LEO films could be due to the interaction between the chitosan and color compounds present in LEO such as citral and beta-caryophyllene

(Azarakhsh et al., 2014). However, the values of L* significantly decreased with increasing concentration.

The significant increase in ΔE values and the decrease in whiteness index values in all films indicate that more colored films are obtained.

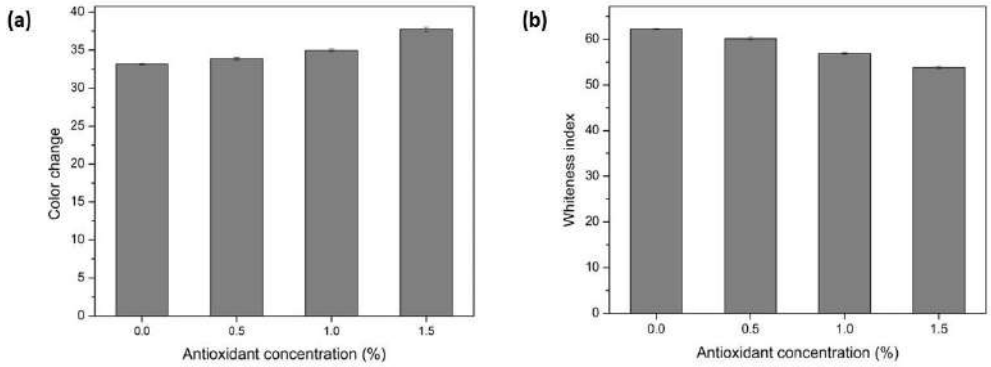


Figure 2. Variations in (a) surface color change (ΔE) and whiteness index (b) of chitosan-based films incorporated with lemongrass essential oil (Chn+LEO). Vertical bars represent ± standard deviation of means

3.3 Mechanical properties

3.3.1 Tensile strength and elongation at break

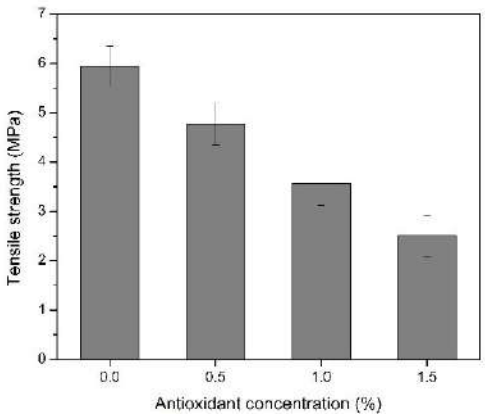
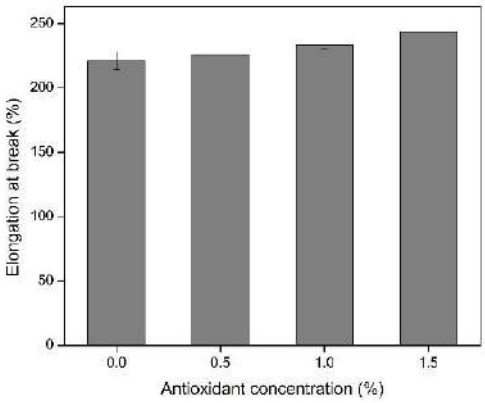


Figure 3. Variations in tensile strength of chitosan-based films incorporated with lemongrass essential oil (Chn+LEO). Vertical bars represent ± standard deviation of means

The evaluation of the elongation at break (EB) for the films containing LEO demonstrated an increase, whereas the tensile strength (TS) declined as the concentration of EO increased (Figure 3-4). The addition of 1.5% of LEO into chitosan films significantly ($p < 0.05$) reduced their TS as compared with the control film. Lemongrass essential oil, being a natural essential oil, can act as a plasticizer for the chitosan matrix. The plasticization effect of LEO weakens the

inter and intra-molecular forces between chitosan molecules, leading to the increase



of weaker polymer–oil interactions over stronger intermolecular interactions in the film matrix and prevention of the formation

Figure 4. Variations in elongation at break of chitosan-based films incorporated with lemongrass essential oil (Chn+LEO). Vertical bars represent ± standard deviation of means

of rigid structure. This results in a decrease in TS and an increase in the EB values which enhances the flexibility and ductility of the chitosan-based films, (Bekhit et al., 2022).

3.4 Film biodegradability

The biodegradation of the films depends mainly on moisture and chemical structure, which is evident from the weight change. To determine the rate of biodegradation for different films, the weight changes were recorded at different time intervals (Figure 5). The chitosan films without LEO (control films) showed the highest percentage of weight loss compared to Chn+LEO films after 28 days, which are naturally biodegradable macromolecular polymers of hydrophilic nature. So that the soil moisture can easily penetrate the polymer network, weakening the polymer chains and being hydrolyzed by soil microorganisms. The addition of

Figure 5. The soil biodegradability chitosan-based films (Chn) incorporated with 0.5% (v/v), 1% (v/v), and 1.5% (v/v) of lemongrass essential oil (Chn+LEO) at different day intervals

LEO with increasing concentration, the films' biodegradability decreased compared to the control due to the film's hydrophobicity, intermolecular interactions, and microbial compatibility.

3.5 Antioxidant activity (DPPH-free radical scavenging assay)

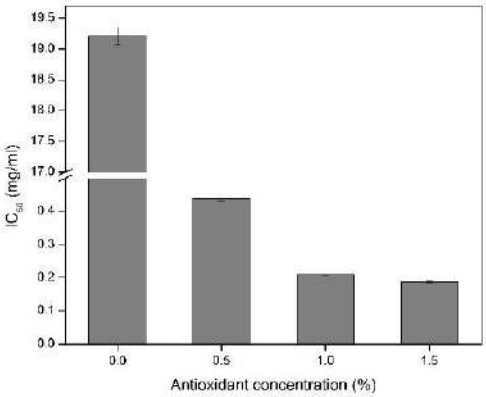
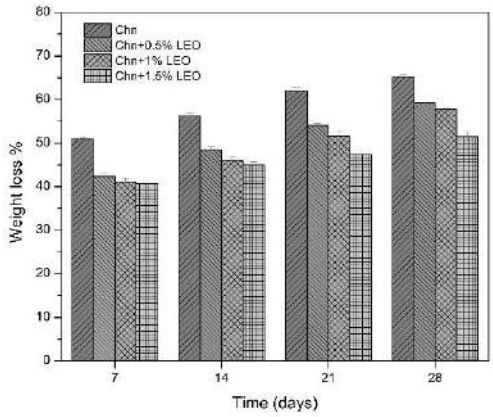


Figure 6. IC50 values of chitosan-based films incorporated with lemongrass essential oil (Chn+LEO). Vertical bars represent ± standard deviation of means

The incorporation of the EO had a significant effect ($p < 0.05$) on the DPPH free radical scavenging activities of the films (Figure 6). The antioxidant activity increased significantly ($p < 0.05$) (IC50 decreased) when EO concentration increased. Among the fabricated films, the



highest DPPH free radical scavenging activity was obtained for the films incorporated with 1.5% LEO. The higher radical scavenging activity of the LEO could be due to the presence of active compounds such as citral, geraniol, neral, myrcene, limonene, and beta-caryophyllene in LEO. The chitosan films without LEO showed some scavenging activity on DPPH. This is due to the presence of amino groups and hydroxyl groups in the chitosan structure. These functional groups can donate electrons and neutralize free radicals, including the DPPH radicals (Hafsa et al., 2016). These results revealed that LEO-containing chitosan films hold great antioxidant activities making them ideally suitable for food packaging films.

3.6 Antimicrobial activity

The antimicrobial activity of edible films incorporated with LEO was studied against Gram-positive bacteria (S. aureus and Bacillus cereus) and Gram-negative bacteria (Klebsiella pneumoniae and E. coli). As expected, films incorporated with LEO had stronger antimicrobial activities than pure chitosan film. At the stationary growth phase, the optical density values at 650 nm (OD650nm) of the pure chitosan films and bacterial suspension without edible films were higher than those of films with 1.5% LEO. Furthermore, the edible films incorporated with LEO had a stronger inhibition on S. aureus (OD650nm at 0.512) than on E. coli (OD650nm at 0.537). Chitosan films containing 1.5% LEO demonstrated the highest antimicrobial activity against the four strains, with greater effectiveness observed against the Gram-positive bacteria compared to the Gram-negative bacteria. This is because Gram-negative bacteria possess an outer membrane that acts as a barrier, making it more challenging for hydrophobic substances to penetrate and exert their antimicrobial effects. This difference in cell wall structure contributes to the observed variation in effectiveness against different bacterial strains. (Benavides et al., 2012).

CONCLUSIONS

Chitosan holds significant application as a biopolymer for active food packaging. The findings highlight that chitosan-based films incorporating lemongrass essential oil have the potential for active film applications due to their low affinity towards water and exceptional antimicrobial and antioxidant effectiveness as demonstrated in vitro. The lemongrass essential oil incorporation has led to reduced moisture content and water solubility in the fabricated films. The tensile strength of the chitosan composite films was lowered by the incorporation of

EOs, whereas the percentage of EAB of the films was improved by the addition of EOs. The antioxidant and antimicrobial properties were enhanced by the EO incorporation, which is critical for food packaging applications. Thus, developing edible films from chitosan and lemongrass essential oil offers innovative approaches to improve microbial safety and extend the shelf life of food products.

REFERENCES

Kaushani, K. G., Priyadarshana, G.7, Katuwavila, N. P., Jayasinghe, R. A., & Nilmini, A. H. L. R. (2022). Recent Advances of Edible Packaging as an Alternative in Food Packaging Applications. 34(10), 2523–2537. http://dx.doi.org/10.14233/ajchem.2022.23822

Azarakhsh, N., Osman, A., Ghazali, H. M., Tan, C. P., & Mohd Adzahan, N. (2014). Lemongrass essential oil is incorporated into alginate-based edible coating for shelf-life extension and quality retention of fresh-cut pineapple. Postharvest Biology and Technology, 88, 1–7. https://doi.org/10.1016/j.postharvbio.2013.09.004

Bekhit, A. E. A., Pratap-singh, A., Chatli, M. K., & Anwer, K. (2022). Preparation and Physiochemical Characterization of Bitter Orange Oil Loaded Sodium Alginate and Casein Based. 1–15.

Benavides, S., Villalobos-carvajal, R., & Reyes, J. E. (2012). Physical , mechanical and antibacterial properties of alginate film : Effect of the crosslinking degree and oregano essential oil concentration. Journal of Food Engineering, 110(2), 232–239. https://doi.org/10.1016/j.jfoodeng.2011.05.023

Chen, J., Wu, A., Yang, M., Ge, Y., Pristijono, P., Li, J., Xu, B., & Mi, H. (2021). Characterization of sodium alginate-based films incorporated with thymol for fresh-cut apple packaging. Food Control, 126(February), 108063. https://doi.org/10.1016/j.foodcont.2021.108063

Contini, L. R. F., Zerlotini, T. de S., Brazolin, I. F., dos Santos, J. W. S., Silva, M. F., Lopes, P. S., Sampaio, K. A., de Carvalho, R. A., Venturini, A. C., & Yoshida, C. M. P. (2022). Antioxidant chitosan film containing lemongrass essential oil as active packaging for chicken patties. In Journal of Food Processing and Preservation (Vol. 46, Issue 1). https://doi.org/10.1111/jfpp.16136

Hafsa, J., Smach, M. ali, Ben Khedher, M. R., Charfeddine, B., Limem, K., Majdoub, H., & Rouatbi, S. (2016). Physical, antioxidant and antimicrobial properties of chitosan films containing Eucalyptus globulus essential oil. Lwt, 68(December), 356–364. https://doi.org/10.1016/j.lwt.2015.12.050

Han Lyn, F., & Nur Hanani, Z. A. (2020). Effect of Lemongrass (Cymbopogon citratus) Essential Oil on the Properties of Chitosan Films for Active Packaging. Journal of Packaging Technology and Research, 4(1), 33–44. https://doi.org/10.1007/s41783-019-00081-w

Kaushani, K. G., Rathnasinghe, N. L., Katuwawila, N., Jayasinghe, R. A., Nilmini, A. H. L. R., & Priyadarshana, G. Trends in Smart Packaging Technologies for Sustainable Monitoring of Food Quality and Safety. International Journal of Research and Innovation in Applied Science, July, 7-30. http://dx.doi.org/10.51584/IJRIAS.2022.7702

Kaya, M., Khadem, S., Cakmak, Y. S., Mujtaba, M., Ilk, S., Akyuz, L., Salaberria, A. M., Labidi, J., Abdulqadir, A. H., & Deligöz, E. (2018). Antioxidative and antimicrobial edible chitosan films blended with stem, leaf and seed extracts of Pistacia terebinthus for active food packaging. RSC Advances, 8(8), 3941–3950. https://doi.org/10.1039/c7ra12070b

Keshari, D., Tripathi, A. D., Agarwal, A., Rai, S., Srivastava, S. K., & Kumar, P. (2022). Effect of α-dl tocopherol acetate (antioxidant) enriched edible coating on the physicochemical, functional properties and shelf life of minimally processed carrots (Daucus carota subsp. sativus). Future Foods, 5(March), 100116. https://doi.org/10.1016/j.fufo.2022.100116

Leceta, I., Guerrero, P., Ibarburu, I., Dueñas, M. T., & Caba, K. De. (2013). Characterization and antimicrobial analysis of chitosan-based films. Journal of Food Engineering, 116(4), 889–899. https://doi.org/10.1016/j.jfoodeng.2013.01.022

Ojagh, S. M., Rezaei, M., Razavi, S. H., & Hosseini, S. M. H. (2010). Development and evaluation of a novel biodegradable film made from chitosan and cinnamon essential oil with low affinity toward water. Food Chemistry, 122(1), 161–166. https://doi.org/10.1016/j.foodchem.2010.02.033

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Towards the Advancement of Cervical Cytological Screening and Diagnosis

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ABSTRACT

Squamous abnormalities are divided into low-grade and high-grade by the cytology classification systems. Cytology-based screening of cervical cancer has led to a decline in the incidence of, and mortality from, cervical carcinoma. The introduction of liquid-based cytology (LBC) as an adjunct to the conventional papanicolaou (pap) smear technique has shown improvements in specimen adequacy and laboratory productivity which also aids in human papillomavirus (HPV) detection for triage of low-grade abnormality. LBC is considered ideal for automation-assisted interpretation of cervical cytology but has been reported less sensitive. Co-testing of pap with HPV DNA testing is potentially useful in detecting cervical cancer precursors and in follow-up women on responses to therapy with high-grade cervical intraepithelial neoplasia (CIN). HPV testing and visualization methods and colposcopy is identified as accurate and cost-effective for cervical cancer screening, especially in resource-poor settings.

Keywords **- Cervical cancer; Screening; Pap test; Pap smear; Cytology; Human papillomavirus; Liquid-based cytology**

1. INTRODUCTION

Cervical carcinoma has been identified as the third most common cancer among women worldwide and it leads the way in causing the highest number of cancerdeaths in women of the developing world (Bedell et al., 2019). An annual mortality of 266,000 and new cases of 528,000 had been reported in 2012. Its prevalence is significantly higher in high-income countries compared to low- and middle-income countries.

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Developed countries have incorporated vaccination and screening programmes to reduce this burden of disease by lowering the incidence of cervical cancer (Vu et al., 2018). Previous studies state that women in Bangladesh, India, Nepal, and Sri Lanka experience one-third of the world's cervical cancer. This indicates a knowledge gap in the application of proper screening methods and diagnosis followed by treatment along with inadequate awareness of disease distribution and determinants (Sankaranarayanan et al., 2008).

The main approach for the primary prevention of cervical smears is considered human papillomavirus (HPV) vaccination. Early detection of precancerous lesions and inclusion of efficient screening techniques lead to secondary prevention whereas tertiary prevention involves applying reasonable treatment of detected precancerous lesions followed by the reduction in invasive cervical cancer incidence. Screening for cervical cancers is performed using several techniques including; cytology, visual identification using magnivisualizer, acetic acid, and lugol's iodine, and HPV testing and with the aid of the combination of these (Aggarwal, 2014).

2. CERVICAL CARCINOMA AND HPV INFECTION

The transformation zone of the uterine cervix is subjected to physiological metaplasia when adolescence begins. The glandular epithelium in this region transforms into squamous epithelium. Cervical cancer emerges in this transformation zone (Kitchener et al.,2006).

Cervical cancers can be either squamous cell carcinoma or adenocarcinoma(Rodríguez et al., 2008). The infection with HPV and its persistence, progression of infection to precancerous lesions, and invasion are significantly important steps in cervical carcinogenesis (Bedell et al., 2019).

HPV infection is commonly diagnosed in sexually active young women. The persisting infection results in cervical intraepithelial neoplasia (CIN) in which the CIN-1 is regarded as causing only manifestations of the infection and the most severe condition CIN-3 causes an increased risk of cervical cancer progression (Kitchener et al., 2006). The HPV strains of high risk are responsible for over 99% of cervical dysplasia (precancerous lesions) and cervical carcinomas, whereas the low-risk strains are associated with anogenital warts or may be asymptomatic. The high-risk strains of HPV have the greatest oncogenic potential (Bedell et al., 2019; Walboomers et al., 1999). Type 16 and type 18 high-risk HPV genotypes are known to contribute to approximately 70% of cervical cancers. A combination of some oncogenic strains causes about 25% of cervical carcinomas including types 31, 33, 35, 39, 45, 51, 52, 56, 58,

59, and 68 (Workowski, 2015). As CIN

-1 (low grade) and CIN-2 (moderate grade) are not the stages of cervical cancer,

invasive cervical cancer develops from CIN-3 (high grade) and it would take more than a decade (Santesso et al., 2016).

The lengthy transmission of cancer provides an opportunity for early detection by exfoliative cytology. Only around 1% of women diagnosed with HPV infection progress into cervical cancer without secondary prevention (Kitchener et al., 2006).

Recommendations for CIN-1 consist of monitoring the progress, and the diagnosis of CIN-2 and CIN-3 is recommended to be followed by treatments including thermoablation, cryotherapy, loop electrosurgical excision procedure (LEEP), and cold knife conization (CKC) (Santesso et al.,2016; Stanley, 2010).

3. CERVICAL CANCERSCREENING TECHNIQUES

3.1 Cervical Cytology Procedure

Dr. George Papnicolaou introduced cervical cytology into clinical practice in 1940 (Papanicolaou, 1940; Sherwani et al., 2007). Cervical cytology is regarded as virtually the most promising examination procedure to discover the malignant changes in cervical epithelium in inapparent carcinoma of the uterine cervix and for the early detection of the cancer (Dunn Jr & Schweitzer, 1981).

A. Specimen collection

Specimen collection follows an easy procedure but requires trained personnel and causes minimum discomfort to the patient. The sample is evaluated based on the cellular morphology by the expertise of a cytopathologist (Dunn Jr & Schweitzer, 1981).

A vaginal speculum is used to visualize the uterine cervix to obtain a cell sample. The cervical sample is collected from the transformation zone, so-called the squamocolumnar junction, from the squamous epithelium from the vaginal part of the cervix, and the endocervical epithelium. A commercially available instrument having a tip is used for collection by rotating it around the uterine cervix (Koss et al., 1984).

Commonly used sampling devices include cervical/Ayre's spatula, endocervical brush, and cervical broom. During the collection, the endocervical brush is never used alone. Three methods are recommended for adequate sampling: spatula alone, cervical broom, and combined use of spatula and endocervical brush to obtain the ectocervical sample and endocervical sample respectively (Smith, 2011).

The smear is prepared on a clean glass slide by rapid and careful pressing of thesampling instrument on the slide followed by fixation of the smear in 70% alcohol fixative for 15 minutes or by spray fixatives. The fixation is done to avoid air-drying artifacts (Koss, 1989).

B. Specimen processing

The fixed smears are recorded into the system in the laboratory followed by giving an identification or reference number. The freshly prepared solutions of Papanicolaou stain should be used for the staining procedure of the smears. Finally, the stained smears are protected with a glass coverslip. Screening of the smears is done following the drying (Koss, 1989).

"Diagnosis of Uterine Cancer by the Vaginal Smear" in 1943. The procedure of microscopic examination of both normal and abnormal smears of the vagina and cervix followed by their classification is now conventionally known as the "Papanicolaou Smear" and was introduced by them (Bedell et al., 2019).

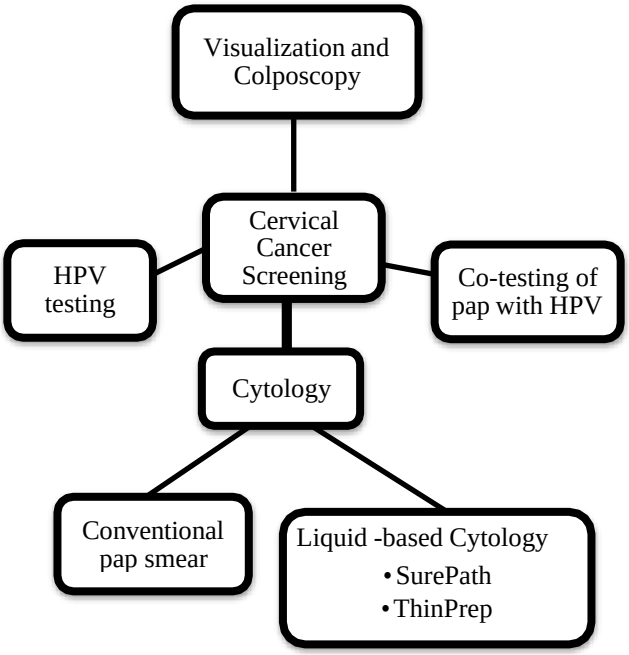

Figure 1. Different methods of cervical cancer screening in current clinical practice

3.2 Cytology-based Cervical Cancer Screening Techniques

3.2.1 The Papanicolaou (pap) Smear Technique

Dr. Papanicolaou in collaboration with Herbert Traut, a gynecologist pathologist published a landmark book,

The initiation for this technique was by Dr. George Papanicolaou who researched the reproductive cycles of guinea pigs. His conclusions stated that the prediction of the reproductive cycles of guinea pigs can be done by timed examination of the smears of the vaginal secretions. In 1920, his focus was on the cytopathology of the human reproductive cycle. Dr. Papanicolaou applied his findings and was able to examine normal and cancerous cervical cells in smears prepared on microscopic glass slides with the cervical specimens. The research of Dr. Papanicolaou was continued with Dr. Herbert Traut thereafter (Bedell et al., 2019).

The pap smear expeditiously became the gold standard for screening cervical carcinoma due to ease of performance, cost-effectiveness, and reproducibility. The incidence of cervical cancer significantly declined with the use of pap smears worldwide (Tan & Tatsumura, 2015).

3.2.2 Liquid-based Cytology (LBC)

An improvement in the performance of the cervical cytology test was required due to certain limitations associated with the conventional pap smear technique.

With advances in cytotechnology, the LBC was introduced in the mid-1990s. Certain procedural differences can be discerned in the LBC technique compared to conventional pap smears. Similar to the conventional cytology method, cervical specimens are collected from the uterine cervix using plastic devices, either a cervical broom or a combination of plastic spatula and endocervical brush. The collected cells are placed in a preservative liquid instead of spreading the exfoliated cells onto a microscopic slide. The preserved cells are transported to the cytologylaboratory followed by the processing and preparation of smears (Smith, 2011).

The Food and Drug Administration (FDA) agency has approved two LBC systems as about 80-90% of the pap tests performed in the USA are LBC (Yim & Park, 2005). The two systems are SurePath and Thin Prep which are recognized for their widespread use worldwide (Smith, 2011).

A. SurePath System

In this processing technique of LBC, the cervical sample is subjected to aspiration through a syringe which disaggregates the cellular clumps and the mucus. The resultant cell suspension needs to be layered on the top of a density gradient medium. Density gradient centrifugation is utilized to separate the red blood cells from epithelial cells. The cell pellet obtained from the centrifugation process is inserted into a robotic workstation. This cell pellet predominantly consists of cervical epithelial cells. The inserted pellet is resuspended in the robotic workstation followed by transfer onto a glass slide. A single procedure allows a maximum number of 48 samples to be processed (Smith, 2011).

B. Thin Prep System

In the Thin Prep technique, mechanical agitation is incorporated to break up the cell clumps and mucus. A membrane filter is used for filtering the liquid preservative solution accompanied by transferring the filtration onto a glass slide and staining. Different types of

Thin Prep processors do have different capacities for the number of specimens processed at a time. Only one specimen can be processed per cycle using the Thin Prep 2000 processor whereas the Thin Prep 3000 and 5000 are capable of processing up to 80 and 160 samples respectively a single time as those are automated processors (Smith, 2011).

3.2.4 Advantages of LBC

Multiple theoretical and practical advantages of LBC have been suggested which include; a higher number of representative cell collection and preparation from the sampling device to glass slide, reduced number of unsatisfactory specimens by filtration of debris and blood, higher productivity, much easier examination and interpretation of smears due to preservation of cells which improves sensitivity and specificity (Smith, 2011).

The significantly important benefit of LBC is the availability of the remainingspecimen for subsequent molecular testing such as HPV testing and testing for infection with chlamydia and gonorrhea in addition to cytology (Bedell et al., 2019). Moreover, being capable of being subjected to computer-assisted evaluation of specimens is also advantageous in LBC (Smith, 2011).

It is deduced that the introduction of LBC has brought improvements in the cervical cytology screening by implementing increased adequacy and lesser time for screening compared with conventional cytology (Baker, 2002;Bolick & Hellman, 1998; Carpenter & Davey, 1999; Cheung et al., 2003; Díaz- Rosario & Kabawat, 1999; Dupree et al., 1998; Guidos & Selvaggi, 1999; SM; Smith, 2011; Tench, 2000; Vassilakos et al., 1999; Weintraub & Morabia, 2000).

3.3 Automation and Cervical Cytology

Partial automation is obtained in the cervical cytology screening process withthe incorporation of the LBC technique and its association with computer-assisted evaluation of cervical smears (Husain, 1994). In conventional pap smears, the presence of obscuring blood, mucus and inflammatory cells, and some other causes hamper the introduction of automation into conventional cervical smear screening (Smith, 2011).

Semi-automated smear screening is a consequential advancement in clinical use for cervical cytology with the coupled mechanisms of LBC and improved computerized image analysis. This was aided by the appreciable refinements of LBC through the presentation of cervical cells avoiding obscuring blood, mucus, and inflammatory cells near-monolayer of cells with clear boundaries of cells and nuclei for better recognition (Smith, 2011).

The screening of cervical cancer has made it easier for laboratory cytotechnologists with the integration of automation. Two advanced systems are recommended for primary cervical screening which consist of a highly automated microscope and an image analyser. These commercially available systems were approved by the US FDA. The approval was granted for both systems based on the ability to recognize neoplastic abnormalities of cervical cells to an equivalent or a greater proportion compared with manual screening (Biscotti et al., 2005; Wilbur et al., 2009). However, previous studies do not provide sufficient evidence to determinethe cost-effectiveness and advantages ofclinical use of automated and semi- automated cervical screening over conventional pap screening (Broadstock, 2001; Willis et al., 2005). Despite the suggested advantages and

convenience of automation in cervical cytology, some studies have reported no significant difference between automation-assisted screening and conventional cervical screening for the risk estimation of cervical carcinoma (Anttila et al., 2011).

The approved commercially available two systems are the BD FocalPoint™ Slide Profiler and the ThinPrep™ Imaging System.

The BD FocalPoint™ Slide Profiler machine shares similarities with an annual workload of 144,000 slides for a 7-day working week or 103,000 slides for a 5-day working week, and is capable of scanning 400 SurePath slides per 24 hours. A score of 0.0 to 0.1 is assigned to each slide using multiple algorithms depending on the abnormality and probability. The background and the cellular features of the cervical smear decide the threshold score. The cytotechnologist does not need to attend to the smears that score below the primary threshold reducing the workload of screening. If this system is integrated with an automated microscope, it will automatically locate the slide at the first relevant view followed by positioning all suspicious locations with abnormal cells and features for the screening.

The cervical smears are rapidly scanned and 22 fields are located in batches of ThinPrep LBC slides. The fields of interest are known as "fields of view" (FOV). The marked positions of the FOVs are coordinated along with the identification information of slides. One imaging system screens 400 slides per 24 hours. Following the completion of imaging of a batch, the cytotechnologist observes the slides using a review microscope automatically in each programmed FOV. This process will allow the screening time to be significantly reduced (Smith, 2011).

As per the findings, the automation-assisted reading of cervical smears reports 8% or less sensitivity compared with manual reading and therefore is not recommended currently for primary cervical screening (Smith, 2011).

3.2 Co-testing of Pap with HPV testing

A strong causal relationship between persistent HPV infection of the genital tract with high-risk HPV genotypes has been recognized with the occurrence of cervical carcinoma. This association has led to the evolution of different HPV, DNA and RNA detection systems (Bosch et al., 2008; Gravitt et al., 2008).

LBC offers a perfect background to implement HPV DNA testing and similar molecular technologies. Clinical application of detection of high-risk HPV DNA is considered potentially useful. Those include;

A. Detection of cervical cancer precursors either alone or combined with cytology

B. Follow-up women who had undergone treatments for high-grade CIN followed by accurate identification of whether they have been cured or not

C. Routine screening of cervical cytological abnormalities of low grade which requires immediate referral for colposcopy

D. Follow-up women having abnormal screening results; negative for colposcopy and biopsy (Cuzick et al., 2008).

The HPV testing was added to cervical

cytology by the current cervical cancer screening guidelines.

Signal amplification techniques or nucleic acid amplification with polymerase chain reaction (PCR) can be used for HPV DNA testing in cervical specimens. The first FDA-approved high-risk HPV detection test is the Hybrid Capture II HPV DNA Assay (Digene). Another four tests received FDA approval subsequently and those include: APTIMA HPV Assay (Gen-Probe), Cobas HPV test (Roche Molecular Systems), Cervista HPV HR (Hologic), and Cervista HPV 16/18 (Hologic).

The sensitivity of pap tests for detecting high-grade neoplasia has been increased from 50-85% to nearly 100% with the use of combined high-risk HPV testing with cytology (Martin-Hirsch & Wood, 2011; Yim & Park, 2005).

Co-testing of HPV DNA with cytology is performed at 5-year intervals due to high cost, slow progression of HPV infection to carcinoma, and high negative predictive value for high-grade neoplasia. The co-testing was approved for cervical cancer screening by FDA in2003 especially in 30-years or older women (Obstetricians & Gynecologists,2016).

According to current guidelines, 21-29-year-old women are recommended to be tested with cervical cytology alone and screened every 3 years. The co-testing with high-risk HPV testing is preferred for 30-65-year-old women every 5 years alongside the screening with cytology alone every 3 years (Martin-Hirsch & Wood, 2011; Obstetricians & Gynecologists, 2016).

3.2 HPV Testing for Primary Cervical Cancer Screening

HPV testing has been recommended to be utilized as the primary screening modality by the emerging economic and clinical evidence of recent studies. Primary screening with HPV DNAtesting is capable of detecting over 90% of all high-grade CIN and cervical carcinoma. It is noted about 6% lessspecific and about 25% more sensitive than cytology at atypical squamous cells of undetermined significance (ASCUS) or borderline nuclear change. Typing for the high-risk HPV genotypes (type 16 and 18) will enhance the specificity as well as testing for detection of the presence of biomarkers (p16), and viral E6 and E7 detection by mRNA coding (Cuzick et al., 2008; Gravitt et al., 2008). The USA has recommended performing HPV testing in the management of low-grade cytological abnormalities (Wright Jr et al., 2002).

An increased life expectancy and decreased cancer risk at a reasonable cost are suggested to be accomplished by the incorporation of primary screening with HPV DNA followed by LBC (Sherlaw-Johnson & Philips, 2004). A decrease in medically significant lesions is expected along with a reduction in the performance of cytology as a result of the progression of HPV vaccination (Cuzick et al., 2008; Kohli et al., 2007). Primary HPV testing is considered the preferred screening procedure in this kind of situation with triage to cytological screening (Goldhaber-Fiebert et al., 2008).

3.2.1 Visualization and Colposcopy for Primary Cervical Cancer Screening

Certain limitations of cytology have led to the development of alternative screening methods. The Visualizationwith Acetic acid (VIA) method and visualization with Lugol's Iodine (VILI) method is identified as an accurate and cost-effective screening method in resource-poor areas (Bedell et al.,

2019).

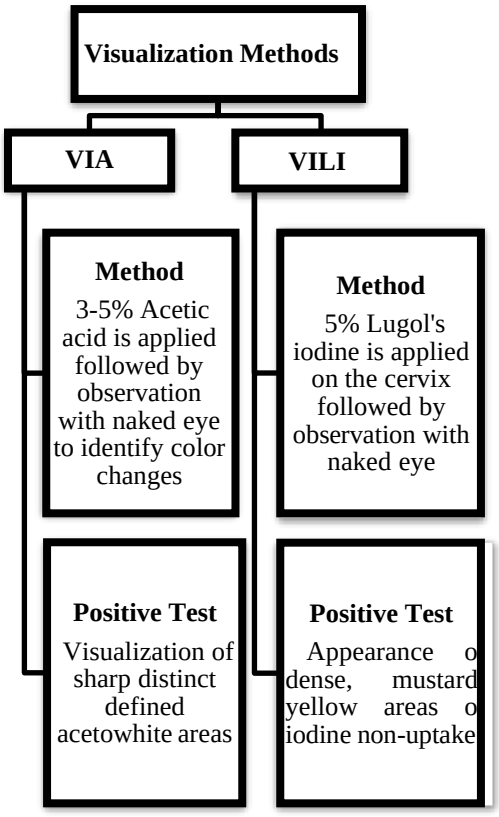

Figure 2. Procedure and the positive test results of Visualization methods forPrimary Cervical Cancer Screening

The implementation of VIA and VILI have been demonstrated to be feasible and safe while high sensitivity (range 66-96%) and specificity (range 64-98%) was reported in VIA for detecting high- grade dysplasia (Gaffikin et al., 2003; Muwonge et al., 2010; Nessa et al., 2010; Ngoma et al., 2010). The likelihood of the development of cervical cancer is reported as lower in women with VIA-negative screening results and considered a more accurate screening method (Sankaranarayanan et al., 2009; Sauvaget et al., 2011).

Advancements in digital optical technology have led to the development of portable digital colposcopes providing ultra-high-resolution digital images that can be magnified compared to conventional colposcopy. Certain systematic reviews have provided evidence of higher sensitivity and specificity of digital colposcopy over VIA (Hermens et al., 2016). The Enhanced Visual Assessment System (MobileODT, Israel) is an example that uses advanced optics similar to that in Android smartphones and is common in low-resource settings (Bedell et al., 2019).

The intriguing story is that the current practice focuses on developing software of artificial intelligence algorithms toaid digital colposcopic image interpretation which would predict the probability of CIN 2 positive lesions (Huet al., 2019).

3.2.2 A Glimpse into the Future of Cervical Cancer Screening

A 70% decline in deaths from cervical cancer can be expected if a woman is screened a single time in her life after 35 years of age, and an 85% decline following cervical screening every 5 years (Bedell et al., 2019). Cytology-based screening has resulted in the above decrease in the incidence of and mortality from cervical carcinoma but

repeated testing at frequent intervals is required to achieve acceptable efficiency. The introduction and advancement of LBC have shown the possibility of testing for high-risk HPV aiding the diagnosis of low-grade abnormality and follow-up of CIN after treatment. An improvement is evident in the laboratory productivity of cervical cytology due to the incorporation of

automation. Emerging screening technologies have been assessed compared to conventional cytology.

HPV testing in HPV-vaccinated populations is considered the primary screening procedure which replaces cytology (Smith, 2011). The diagnosis and treatment of cervical cytology which is known to be the traditional cervical cancer prevention strategy has been replaced where the prevention is focused on detecting and vaccination against the causative agent HPV.

Examination of cervical surface morphology by visualization method and colposcopic images would provide easy accessibility even in low-resource environments, especially with improved sensitivity and specificity of cervical cancer screening. The performance of digital colposcopy on women with the incorporation of artificial intelligence software could allow accurate diagnosis and immediate treatments by the health care provider aiding in focusing the time to treat CIN 2 positive lesions.

4. CONCLUSION

Early detection of cervical carcinoma has been done by exfoliative cytology. Several advancements have been reported in cervical cytological screening techniques since the introduction of the Papanicolaou smear technique by Dr. George Papanicolaou. Certain limitations associated with the conventional pap smear technique were overcome by the liquid-based cytology being more convenient. The incorporation of automation in cytology suggested no significant difference from conventional cervical screening in cervical cancer risk estimation. It is not recommended currently for primary cervical screening for being less sensitive compared with manual reading. Moreover, co-testing of HPV DNA with cytology is considered potentially useful in the detection of high-risk HPV resulting in increased sensitivity of detecting high-grade neoplasia by this combination. The capability of detecting high-grade CIN and cervical carcinoma over 90% suggests that HPV DNA testing to be used as the primary screening modality. HPV testing followed by LBC indicates decreased cancer risk and thereby increased life expectancy. The visualization methods for primary cervical cancer screening include using either acetic acid or lugol's iodine being cost-effective and accurate suggesting appropriate use in resource-poor settings. Alternative screening methods have been developed to prevail over some limitations of cytology techniques and have reached the required increased sensitivity, cost-effectiveness, and easy accessibility.

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REFERENCES

Aggarwal, P. (2014). Cervical cancer: can it be prevented? World Journal of Clinical Oncology, 5(4), 775.

Anttila, A., Pokhrel, A., Kotaniemi- Talonen, L., Hakama, M., Malila, N., & Nieminen, P. (2011). Cervical cancer patterns with automation- assisted and conventional cytological screening: A randomized study. International Journal of Cancer, 128(5), 1204-1212.

Baker, J. J. (2002). Conventional and liquid-based cervicovaginal cytology: A comparison study with clinical and histologic follow-up. Diagnostic Cytopathology, 27(3), 185-188.

Bedell, S. L., Goldstein, L. S., Goldstein, A. R., & Goldstein, A. T. (2019). Cervical Cancer

Screening: Past, Present, and Future. Sexual Medicine Reviews, 8(1), 28-37.

Biscotti, C. V., Dawson, A. E.,Dziura, B., Galup,L., Darragh, T., Rahemtulla, A., & Wills-Frank, L. (2005). Assisted primary screening using the automated ThinPrep Imaging System. AmericanJournal of Clinical Pathology, 123(2), 281-287.

Bolick, D. R., & Hellman, D. J. (1998). Laboratory implementation and efficacy assessment of the ThinPrep cervical cancer screening system. Acta Cytologica, 42(1), 209-213.

Bosch, F. X., Burchell, A. N., Schiffman, M., Giuliano, A. R., de Sanjose, S., Bruni, L., Tortolero-Luna, G., Kjaer, S. K., & Munoz, N. (2008). Epidemiology and natural history of human papillomavirus infections and type-specific implications in cervical neoplasia. Vaccine, 26, K1- K16.

Broadstock,M.(2001). Effectiveness and cost effectiveness of automated and semi-automated cervical screening devices: a systematic review of the literature. New Zealand Medical Journal, 114 (1135), 311.

Carpenter, A. B., & Davey, D. D. (1999). ThinPrep® Pap Test™: Performance and biopsy follow-up in a university hospital. Cancer Cytopathology: Interdisciplinary International Journal of the American Cancer Society, 87(3), 105-112.

Cheung, A. N., Szeto, E. F., Leung,B. S., Khoo, U. S., & Ng, A.

W. (2003). Liquid-based cytology and conventional cervical smears: a comparison study in an Asian screening population. Cancer Cytopathology: Interdisciplinary International Journal of the American Cancer Society, 99(6), 331-335.

Cuzick, J., Arbyn, M., Sankaranarayanan, R., Tsu, V., Ronco, G., Mayrand, M.-H., Dillner, J., & Meijer, C. J. (2008). Overview of human papillomavirus-based and other novel options for cervical cancer screening in developed and developing countries. Vaccine, 26, K29- K41.

Díaz-Rosario, L. A., & Kabawat, S.E. (1999). Performance of a fluid-based, thin-layer Papanicolaou smear method in the clinical setting of an independent laboratory and an outpatient screening population in New England. Archives of Pathology and Laboratory Medicine, 123(9), 817-821.

Dunn Jr, J. E., & Schweitzer, V. (1981). The relationship of cervical cytology to the incidence of invasive cervical cancer and mortality in Alameda County, California, 1960 to 1974. American Journal of Obstetrics and Gynecology, 139(8), 868-876.

Dupree, W. B., Suprun, H. Z.,Beckwith, D. G., Shane, J. J., & Lucente, V. (1998). The promise and risk of a new technology: The Lehigh Valley Hospital's experience with liquid-based cervical cytology. In (Vol. 84, pp. 202-207): Wiley Online Library.

Gaffikin, L., Lauterbach, M., & Blumenthal, P. D. (2003). Performance of visual inspection with acetic acid for cervical cancer screening: a qualitative summary of evidence to date. Obstetrical and Gynecological Survey, 58(8), 543-550.

Goldhaber-Fiebert, J. D., Stout, N. K., Salomon, J. A., Kuntz, K.M., & Goldie, S. J. (2008). Cost-effectiveness of cervical cancer screening with human papillomavirus DNA testing and HPV-16, 18 vaccination. Journal of the National Cancer Institute, 100(5), 308-320.

Gravitt, P. E., Coutlée, F., Iftner, T., Sellors, J. W., Quint, W. G., & Wheeler, C. M. (2008). New technologies in cervical cancer screening. Vaccine, 26, K42-K52.

Guidos, B. J., & Selvaggi, S. M. (1999). Use of the Thin Prep® Pap Test™ in clinical practice. Diagnostic Cytopathology, 20(2), 70-73.

Hermens, M., Ebisch, R. M., Galaal, K., & Bekkers, R. L. (2016). Alternative Colposcopy Techniques. Obstetrics and Gynecology, 128(4), 795-803.

Hu, L., Bell, D., Antani, S., Xue, Z., Yu, K., Horning, M. P., Gachuhi, N., Wilson, B., Jaiswal, M. S., & Befano, B. (2019). An observational study of deep learning and automated evaluation of cervical images for cancer screening. Journal of the National Cancer Institute, 111(9), 923-932.

Husain, O. N. (1994). The history of automated cell scanners. Automated Cervical Cancer Screening'HK Grohs and OA Nasseem Hussain (eds) Igaku-Shoin: New York.

Kitchener, H. C., Castle, P. E., & Cox, J. T. (2006). Achievements and limitations of cervical cytology screening. Vaccine, 24, S63-S70.

Kohli, M., Ferko, N., Martin, A., Franco, E., Jenkins, D., Gallivan, S., Sherlaw- Johnson, C., & Drummond, M. (2007). Estimating the long-term impact of a prophylactic human papillomavirus 16/18 vaccine on the burden of cervical cancer in the UK. British Journal of Cancer, 96(1), 143-150.

Koss, L. G. (1989). The Papanicolaou Test for Cervical Cancer Detection: A Triumph and a Tragedy. Journal of the American Medical Association, 261(5), 737-743.

Koss, L. G., Schreiber, K., Oberlander, S. G., Moussouris, H. F., & Lesser, M. (1984). Detection of endometrial carcinoma and hyperplasia in asymptomatic women. Obstetrics and Gynecology, 64(1), 1-11.

Martin-Hirsch, P. L., & Wood, N. J. (2011). Cervical cancer. British Medical Journal clinical evidence, 2011.

Muwonge, R., da Ganda Manuel, M., Filipe, A. P., Dumas, J. B., Frank, M. R., & Sankaranarayanan, R. (2010). Visual screening for early detection of cervical neoplasia in Angola. International Journal of Gynecology and Obstetrics, 111(1), 68-72.

Nessa, A., Hussain, M. A., Rahman,J. N., Rashid, M. H. U., Muwonge, R.,& Sankaranarayanan, R. (2010). Screening for cervical neoplasia in Bangladesh using visual inspection with acetic acid. International Journal of Gynecology and Obstetrics, 111(2), 115-118.

Ngoma, T., Muwonge, R., Mwaiselage, J., Kawegere, J., Bukori, P., & Sankaranarayanan, R. (2010). Evaluation of cervical visual inspection screening in Dar es Salaam, Tanzania. International Journal of Gynecology and Obstetrics, 109(2), 100-104.

Obstetricians, A. C. o., & Gynecologists. (2016). Cervical cancer screening and prevention. Practice bulletin (157), 1-20.

Papanicolaou, G. (1940). Introduction of Pap smear in early detection of cervical malignancies. American Journal of Clinical Pathology, 19, 301-308.

Rodríguez, A. C., Schiffman, M., Herrero, R., Wacholder, S., Hildesheim, A., Castle, P. E., Solomon, D., Burk, R., & Group, P. E. G. (2008). Rapid clearance of human papillomavirus and implications for clinical focus on persistent infections. Journal of the National Cancer Institute, 100(7), 513-517.

Sankaranarayanan, R., Bhatla, N., Gravitt, P. E., Basu, P., Esmy, P. O., Ashrafunnessa, K., Ariyaratne, Y., Shah, A.,& Nene, B. M. (2008).

Human papillomavirus infection and cervical cancer prevention in India, Bangladesh, Sri Lanka and Nepal. Vaccine, 26, M43- M52.

Sankaranarayanan, R., Nene, B. M., Shastri, S. S., Jayant, K., Muwonge, R., Budukh, A. M., Hingmire, S., Malvi, S. G., Thorat, R., & Kothari, A. (2009). HPV screening for cervical cancer in rural India. New England Journal of Medicine, 360(14), 1385-1394.

Santesso, N., Mustafa, R. A., Schünemann, H. J., Arbyn, M., Blumenthal, P. D., Cain, J., Chirenje, M., Denny, L., De Vuyst, H., & Eckert, L. O.

N. (2016). World Health Organization Guidelines for treatment of cervical intraepithelial neoplasia 2–3 and screen-and-treat strategies to prevent cervical cancer. International Journal of Gynecology and Obstetrics, 132(3), 252-258.

Sauvaget, C., Fayette, J.-M., Muwonge, R., Wesley, R., & Sankaranarayanan, R. (2011). Accuracy of visual inspection with acetic acid for cervical cancer screening. International Journal of Gynecology and Obstetrics, 113(1), 14-24.

Sherlaw-Johnson, C., & Philips, Z. (2004). An evaluation of liquid-based cytology and human papillomavirus testing within the UK cervical cancer screening programme. British Journal of Cancer, 91(1), 84-91.

Sherwani, R., Khan, T., Akhtar, K., Zeba, A., Siddiqui, F., Rahman, K., & Afsan, N. (2007). Conventional Pap Smear and Liquid Based Cytology for Cervical Cancer Screening - A Comparative Study. Journal of Cytology, 24(4), 167-172.

SM, M. Evaluation of HPV/LBC Cervical Screening Pilot Studies (First Report of the Department of Health on Evaluation of LBC). Sutton: Institute of Cancer Research.

Smith, J. H. (2011). Cytology, liquid- based cytology and automation. Best Practice and Research Clinical Obstetrics and Gynaecology, 25(5), 585-596.

Stanley, M. (2010). Pathology and epidemiology of HPV infection in females. Gynecologic Oncology, 117(2), S5-S10.

Tan, S. Y., & Tatsumura, Y. (2015). George Papanicolaou (1883– 1962): discoverer of the Pap smear. Singapore Medical Journal, 56(10), 586.

Tench, W. (2000). Preliminary assessment of the AutoCyte PREP. Direct-to-vial performance. The Journal of Reproductive Medicine, 45(11), 912-916.

Vassilakos, P., Saurel, J., & Rondez,R. (1999). Direct-to-vial use of the AutoCyte PREP liquid-based preparation for cervical-vaginal specimens in three European laboratories. Acta cytologica, 43(1), 65-68.

Vu, M., Yu, J., Awolude, O. A., & Chuang, L. (2018). Cervical cancer worldwide. Current Problems in Cancer, 42(5), 457-465.

Walboomers, J. M., Jacobs, M. V., Manos, M. M., Bosch, F. X., Kummer, J. A., Shah, K. V.,

Snijders, P. J., Peto, J., Meijer, C. J., & Muñoz, N. (1999). Human papillomavirus is a necessary cause of invasive cervical cancer worldwide. The Journal of Pathology, 189(1), 12-19.

Weintraub, J., & Morabia, A. (2000). Efficacy of a liquid-based thin layer method for cervical cancer screening in a population with a low incidence of cervical cancer. Diagnostic Cytopathology, 22(1), 52-59.

Wilbur, D. C., Black-Schaffer, W. S., Luff, R. D., Abraham, K. P., Kemper, C., Molina, J. T., & Tench, W. D. (2009). The Becton Dickinson FocalPoint GS Imaging System: clinical trials demonstrate significantly improved sensitivity for the detection of important cervical lesions. American Journal of Clinical Pathology, 132(5), 767-775.

Willis, B. H., Barton, P., Pearmain, P., Bryan, S., & Hyde, C. (2005). Cervical screening programmes: can automation help? Evidence from systematic reviews, an economic analysis and a simulation modelling exercise applied to the UK. NIHR Health Technology Assessment Programme: Executive Summaries.

Workowski, K. A. (2015). Centers for Disease Control and Prevention sexually Transmitted diseases treatment guidelines. Clinical Infectious Diseases, 61(suppl_8), S759-S762.

Wright Jr, T. C., Cox, J. T., Massad, L. S., Twiggs, L. B., & Wilkinson, E. J. (2002). 2001 consensus guidelines for the management of women with cervical cytological abnormalities. Journal of the American Medical Association, 287(16), 2120-2129.

Yim, E.-K., & Park, J.-S. (2005). The role of HPV E6 and E7 oncoproteins in HPV- associated cervical carcinogenesis. Cancer Research and Treatment: Official Journal of Korean Cancer Association, 37(6),319-324.

The Battle Against Leprosy in Sri Lanka

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ABSTRACT

Sri Lanka eliminated human leprosy in 1995. However, the cases are increasingly reported within the country and according to the recent updates of World Health Organization (WHO), Sri Lanka is one of the major countries who battle against leprosy. Human leprosy or Hansen's disease is a bacterial infection and there are two major clinical manifestations observed in humans, i.e., paucibacillary leprosy and multibacillary leprosy. Leprosy can be completely healed through multidrug therapy. However, timely detection and treatment is important to prevent disease complications, i.e., permanent damage to the skin, nerves, limbs, and eyes. In future studies, we will focus on genetic and immunological aspects of human leprosy in Sri Lanka.

Keywords - Leprosy, antibody, asymptomatic, diagnosis

1. INTRODUCTION

Human leprosy (also known as Hansen's disease) is a bacterial infection caused by Mycobacterium leprae, which affects the nerves, skin, eyes, and nasal mucosa (Weekly epidemiological report, 2021). Recent statistics point to a rising trend of the disease incidence, even though Sri Lanka eliminated leprosy in 1995. According to recent updates, Sri Lanka is one of 23 "global priority countries" for leprosy (WHO, 2023).

Leprosy can be completely healed through multidrug therapy. However, timely detection and treatment is important to prevent disease complications, i.e., permanent damage to the skin, nerves, limbs, and eyes (CDC, 2017).

Active disease transmission in the community indicated by the higher

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proportion of child cases, increasing late presentations and poor detection due to visible deformities of patients are recently highlighted within the country. The increasing number of relapses among treated patients highlight the possibility of drug resistance (WHO, 2023).

Therefore, immediate interventions and a change of focus to address the new challenges for disease control in Sri Lanka is recommended (WHO, 2023). In future studies, we will focus on genetic and immunological aspects of local causative organism and associated clinical manifestations of human leprosy. Genetic variations of the bacterial species causing the local disease has not yet been identified. Genetic characterization of the local causative organism and improving genetic diagnostic tools would be important for enhancing case detection including drug resistant cases (Mi et al., 2020). Due to greater than 10 years of incubation time, accurate antibody detection tools will be useful for asymptomatic case detection, proper follow ups and increasing timely treatment.

2. CURRENT DISTRIBUTION OF HUMAN LEPROSY IN SRI LANKA

Cases are still reporting from almost all the districts in Sri Lanka. Even though the disease has been eliminated from some Divisional Secretariat Divisions of some districts (e.g., five divisions of Badulla, Matale, and Trincomalee, three or more than three divisions of Anuradhapura, Galle, Mannar, Jaffna and Vavuniya), both child and adult leprosy transmission has not interrupted in most of the divisions in some districts (Anti-Leprosy Campaign, 2023). Among them, Colombo is one of the major hotspots of the disease where both child and adult leprosy transmission has not been interrupted yet in 12 Divisional Secretariat Divisions out of 13 total divisions. Child leprosy transmission has been interrupted in the other division (i.e., Padukka). However, the adult leprosy transmission is still yet to be interrupted from that region (Anti-Leprosy Campaign, 2023).

3. CURRENT DIAGNOSTIC METHODS USED FOR HUMAN LEPROSY IN SRI LANKA

In Sri Lanka, the major diagnostic method used for leprosy is clinical diagnosis. Besides to clinical diagnosis, slit skin smear test is available in most of the hospital laboratory settings in Sri Lanka. After clinically suspecting a patient of leprosy further confirmation of the disease is carried out using the slit skin smear test done under light microscope (Anti-Leprosy Campaign, 2023).

In addition, there are molecular methods available for leprosy diagnosis which are mainly based on polymerase chain reaction (PCR) based methods. Molecular methods are rarely used for patient diagnosis. However, it is important for confirming the patients who are negative with other conventional methods and for detecting the positivity in poor responders for the drugs.

Several serological methods are available in other countries. Even though serological methods are not commonly used for diagnosis of leprosy, it is important as a point-of-care test in the early identification of leprosy (Leturiondo et al., 2019). For example, PGL1 and NDO-LID rapid tests are commonly used serological methods for leprosy. However, the sensitivity and specificity of these tests are approximately in the range of 30.0% to 80.0% with

different clinical manifestations of leprosy (Leturiondo et al., 2019). Serological methods are still not widely used in clinical settings in Sri Lanka (Anti-Leprosy Campaign, 2023).

4. FUTURE PERSPECTIVES

There are two major clinical manifestations observed in humans, i.e., paucibacillary leprosy and multibacillary leprosy also known as tuberculoid leprosy and lepromatous leprosy (CDC, 2017; Parkash, 2009). Usually, paucibacillary leprosy represents 2 to 5 skin lesions while more than 5 skin lesions are detected in multibacillary leprosy (Parkash, 2009). When considering the immune responses associated with the disease, paucibacillary leprosy is mainly associated with the cell-mediated immune responses while multibacillary leprosy is mainly characterized by the humoral immune response or antibody response.

According to the statistics of Anti-Leprosy Campaign, Sri Lanka, cases are increasingly detected within the country. More than 1300 new cases were reported in 2022 (Anti-Leprosy Campaign, 2023). Both paucibacillary and multibacillary cases are detected within the country while multibacillary cases, drug resistant cases and other atypical clinical forms are gradually increased (Somatunga, 2000). The studies in related to leprosy causative organism, its genetic identification and associated immune responses are scarce in Sri Lanka (Somatunga, 2000; Kasturiaratchi et al, 2002).

Therefore, the future studies will be mainly focused on genetic identification of local causative organism, and development of accurate diagnostic tools. Due to greater than 10 years of incubation time, accurate antibody detection tools will be useful for asymptomatic case detection (Goulart et al, 2015), proper follow ups and increasing timely treatment.

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REFERENCES

Anti-Leprosy Campaign (ALC), Sri Lanka. (2023). https://leprosycampaign.health.gov.lk/

Centers for Disease Control and Prevention. (2023). Diagnosis and treatment of Hansen's disease (leprosy). https://www.cdc.gov/leprosy/treatment/index.html

Goldsby, R. A., Kindt, T. J., Kuby, J., & Osborne, B. A. (2003). Immunology (5th ed.). W.H. Freeman and Company.

Goulart, I. M. B., Araujo, S., Filho, A. B., de Paiva, P. H. R., & Goulart, L. R. (2015). Asymptomatic leprosy infection among blood donors may predict disease development and suggests a potential mode of transmission. Journal of Clinical Microbiology, 53(10), 3345-3348.

Kasturiaratchi, N. D., Settinayake, S., & Grewal, P. (2002). Processes and challenges: how the Sri Lankan health system managed the integration of leprosy services. Leprosy Review, 73, 177-185.

Leturiondo, A. L., Noronha, A. B., do Nascimento, M. O. O., Ferreira, C. O., Rodrigues, F. C. R., Moraes, M. O., & Talhari, C. (2019). Performance of serological tests PGL1 and NDO-LID in the diagnosis of leprosy in a reference Center in Brazil. BMC Infectious Diseases, 19, 22.

Mi, Z., Liu, H., & Zhang, F. (2020). Advances in the immunology and genetics of leprosy. Frontiers in Immunology, 11, 567.

Parkash, O. (2009). Classification of leprosy into multibacillary and paucibacillary groups: an analysis. Pathogens and Disease, 55(1), 1-5.

Somatunga, L. C. (2000). Status of leprosy-Sri Lankan experience. Japanese Journal of Leprosy, 69, 143-146.

Weekly Epidemiological Report. (2021). A publication of the Epidemiological Unit, Ministry of Health, Nutrition and Indigenous Medicine, Sri Lanka. https://www.epid.gov.lk/storage/post/pdfs/vol_48_no_02-english_1.pdf

World Health Organization. (2023). World Leprosy Day 2023: WHO calls for renewed efforts in the battle against leprosy. https://www.who.int/srilanka/news/detail/29-01-2023-world-leprosy-day-2023--who-calls-for-renewed-efforts-in-the-battle-against-leprosy

Exploration of the Relationship Between Mindfulness and Cerebral Asymmetry in Meditating and Non-Meditating Adults in Sri Lanka

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ABSTRACT

Cerebral asymmetry is the differential specialization of the two cerebral hemispheres, which improves brain efficiency. Abnormalities in cerebral asymmetry are evident in neuro-developmental abnormalities and in neuro-pathological and neuro-psychiatric conditions. Practice of meditation is thought to enhance cerebral asymmetry. The present study, which is a questionnaire-based survey under the quantitative paradigm, aims to explore the impact of meditation practices to enhance cerebral asymmetry. To achieve the aim of the study, the relationship between mindfulness quality & cerebral asymmetry was explored in two independent samples of adult Sri Lankan meditators (n=47) and adult Sri Lankan non-meditators (n=45). Purposive and voluntary sampling methods were used.

Past literature suggests that handedness asymmetry is an indication of cerebral asymmetry. As such, the study used Edinburgh's handedness inventory to assess handedness asymmetry as an indication of cerebral asymmetry. The quality of mindfulness was assessed using the five-facet mindfulness questionnaire. The findings of the study revealed that meditators were significantly greater in mindfulness ($p<0.05$) and in cerebral asymmetry ($p<0.05$), than the non-meditators. Further the study findings revealed a significant weak positive relationship between non-reactivity facet of mindfulness and cerebral asymmetry, in the meditating sample. So, the study concluded the capacity of meditation to enhance not only cerebral asymmetry but also bodily

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asymmetries, through a phenomenon called linked asymmetries.

Keywords **- cerebral asymmetry, linked asymmetry, handedness asymmetry, meditation, mindfulness.**

1. INTRODUCTION

Cerebral lateralization or hemispheric specialization is not unique to humans, but is common among many vertebrates (Schmidt, 2008). According to Geschwind and Galaburda (1985), differential specialization of the two halves of the brain, whether structural or functional, can be inferred as cerebral asymmetry. According to a review article by Jonathan and Earle (1981, p. 155), several researchers have hypothesized that meditation manipulates the state of attention and awareness in the mind. This inhibits the cognitive functions of the dominant left cerebral hemisphere causing a shift in mental experience to the non-dominant right cerebral hemisphere. Further, it reactivates the left brain at later stages of meditation, ultimately resulting in an alteration of cerebral asymmetry. Cerebral asymmetry and handedness asymmetry are linked, and some authors explain this relationship using a phenomenon called "linked asymmetries" (Geschwind & Galaburda, 1985; Sha *et al*., 2021). Hence the present study uses handedness asymmetry as an indicator of cerebral asymmetry.

There is a vast amount of literature that supports a link between cerebral asymmetry and handedness asymmetry. It is postulated that in humans there is an innate genetic bias towards left hemispheric dominance, while individual differences in magnitude and direction of hemispheric dominance is later established by environmental influences including prenatal influences. (Geschwind & Galaburda, 1985; Sha *et al*., 2021). According to Geschwind and Galaburda (1985), the influences that impose asymmetry on brain structures also impose asymmetry on other systems of the body as well. Accordingly, the "linked asymmetry" phenomena states that slowing of growth of one structure leads to enlargement of the opposite homologous structure as of the adjacent structures. Further, the discovery of left hemispheric specialization for language and the fact that the majority of the population are right-handed led to the assumption that handedness is rooted in cerebral asymmetry (Geschwind & Galaburda, 1985; Sha *et al*., 2021). The fundamental brain pattern in the majority of the population is where the left hemisphere contains specific brain areas responsible for language function and certain motor skills (Geschwind & Galaburda, 1985; Sha *et al*., 2021). This fact too supports the idea for a link between cerebral asymmetry and handedness asymmetry. Further support for the notion that handedness asymmetry is associated with cerebral asymmetry comes from studies by Foundas *et al*. (1998) and Foundas *et al*. (1995). The study by Foundas *et al*. (1998) measured the study participants' PTr (pars-triangularis) and POP (pars-opercularis) in the Broca's area

which are crucial neuro-anatomic areas required in language-speech production. The study revealed a significant leftward asymmetry in PTr in both right handers and left handers, though the asymmetry was higher in right handers. In the meantime, the asymmetry in POP was leftward in right handers and the same was rightward in left handers. Further, the handedness scores measured via a handedness inventory was positively associated with POP asymmetry. Foundas *et al*. (1995) study which explored anatomical asymmetries of PT (planum temporale) and PTr (pars-triangularis), revealed that right-handed subjects show significant leftward asymmetry in PT & PTr while left handers showed no significant asymmetry in PT & PTr.

Many researchers use the quality of mindfulness as a measure of meditative experience (Baer *et al*., 2006; De Bruin *et al*., 2012; Jermann *et al*., 2009). According to Segal *et al*. (as cited in Baer *et al*., 2006) mindfulness is being attentive to incoming experience and investigation of it without being judgmental or reactive to the experience. As such mindfulness consists of multiple facets such as observing moment to moment experience, being non-judgmental & being non-reactive. In contrast, Brown, and Ryan (as cited in Baer *et al*., 2006) argued mindfulness construct to be a single factor and described mindfulness in terms of being attentive & awareness in the present moment while acceptance is a part of being fully attentive in moment-to-moment experience. Further Baer *et al*. (2006), stated that mindfulness is a skill that can be cultivated without necessarily being engaged in meditation.

According to Geschwind and Galaburda (1985), the standard cerebral dominance (i.e. left hemispheric dominance for both language and handedness) could be altered in specific instances such as due to certain prenatal influences including specifically the male related factor testosterone, and also in certain neuro-developmental (e.g.: dyslexia, autism), neuro-pathological (e.g.: Alzheimer's disease) and psychiatric conditions (e.g.: schizophrenia, bipolar disorder), resulting in random or anomalous dominance (i.e., the association between speech lateralization & hand lateralization is random). Further, greater the cerebral asymmetry less will be the individual's susceptibility to neuro-developmental disorders such as downs syndrome (Grouios *et al*., 2013), dyslexia (Geschwind & Galaburda, 1985) & autism (Geschwind & Galaburda, 1985); neuro-pathological conditions such as Alzheimer's disease (Liu *et al*., 2018); and psychiatric disorders such as bipolar disorder (Pettigrew & Miller, 1998) and schizophrenia (Ribolsi *et al*., 2014). According to Shannahoff-Khalsa (1993), asymmetry of the brain's electrical activity (EEG) naturally alters during shifting from different states of consciousness such as from wakefulness to sleep, from REM sleep to NREM sleep and vice versa and during cognitive task performances. Most interestingly, this innate cerebral asymmetry could be enhanced intentionally by meditative experience (Jonathan & Earle, 1981). Accordingly, meditation manipulates attention by inhibiting the left hemisphere cognitive processes resulting in a shift to dominate the right hemisphere and ultimately the left brain is reactivated

during later stages of meditation. But the other literature on the direction of cerebral specialization due to meditative experience has revealed mixed findings. In a study by Tang *et al*. (2015), which compared integrative body mind training and relaxation training, revealed that both practices were able to enhance left biased cerebral blood flow. Further in support of this leftward asymmetry due to meditative experience, a study by Zhou and Liu (2017), which explored the effect of an 8-week mindfulness training in altering frontal EEG asymmetry revealed that the session enhances frontal EEG asymmetry during emotional challenge. In contrast to evidence for functional specialization of frontal/anterior part of the left cerebral hemisphere due to meditation practice, evidence is there for structural specialization of the right cerebral hemisphere. A randomized control study by Santarnecchi *et al*. (2015), revealed that MBSR recipients showed a significant increase in thickness in the cortex of right insula and somato-sensory cortex. Though Jonathan and Earle (1981) propose a "right hemisphere theory of meditation" with the inhibition of left-brain cognitive functions, they suggest that excitatory and inhibitory forces are functional within both cortical hemispheres, and ultimately both hemispheres are affected equally with the progression of meditative practice.

Each specific task is fractionized between the two cerebral hemispheres (Serrien *et al*. as cited in Schmidt, 2008). Accordingly coordinated activity of both cerebral hemispheres is needed to carry out a specific coherent function/task. This coordination between the two cerebral hemispheres is mainly achieved by a phenomenon called inter-hemispheric switching. That is the control of function switches from one cerebral hemisphere to the other (Schmidt, 2008). Earlier it was assumed that corpus callosum modulates inter-hemispheric switching, but now it has been shown the possibility of brain stem neuro-modulatory system as well, in achieving inter-hemispheric switching (Schmidt, 2008). According to Nowak *et al*. (2017), there is a two-way relationship between structural connectivity & functional connectivity between the two cerebral hemispheres. That means not only the structural connectivity leads to functional connectivity, but functional connectivity too may lead to structural connectivity. Werntz *et al*. (as cited in Shannahoff-Khalsa, 1993), has carried out a study to show that the rhythm of the alternating EEG (electro-encephalogram) asymmetry of the two cerebral hemispheres is coupled with the alternating & lateralized autonomic activity in the nasal mucosa of the two nostrils. Accordingly, the alternating & lateralized autonomic activity in the nasal mucosa results in alternating vasoconstriction and vasodilation in the nasal mucosa. That means when blood vessels of one side are constricted, the blood vessels of the other side are dilated and then the reversal of it takes place and so on. In the meantime, a study by Coote and Spyer (2018) revealed a relationship between respiratory activity, vascular tone, and autonomic control. It was revealed that the respiratory activity is coupled with the control of vascular tone at the level of sympathetic pre-ganglionic neurons. Further, literature has supported respiratory

regulation as an integral part of meditative practice. According to Brown *et al*. (2013), all most all meditative practices include or combine breath practices with other phenomena. So ultimately all these findings support for the possibility of breath practices in meditative practices in causing cerebral asymmetry via autonomic nervous system in the brain stem using the mechanism of interhemispheric switching.

The present quantitative study which is a questionnaire-based survey, aims at exploring the capacity of meditation practice in enhancing cerebral asymmetry, which is beneficial to an individual in the domains of cognitive functioning (Tzourio-Mazoyer, 2016) and psychological functioning (Santarnecchi *et al*., 2015). The understanding gained from the present study would help further understand the significance of meditation in enhancing brain asymmetry for better cognitive and emotional functioning. Further, there is lack of research which assesses the impact of meditation practice on bodily asymmetries in addition to cerebral asymmetries. The present study aims at addressing this research gap as well.

1. METHOD

2.1 Participants & Sampling

Data were collected from 2 samples of participants: A sample of meditators above 18 years of age and from a sample of non-meditators above 18 years of age. Meditators (n=47) included nuns and other meditators from an educational convent in Colombo, Sri Lanka. The mediator's sample was achieved using the purposive sampling method. Non-meditators were recruited using the voluntary/ self-selected sampling method (google form invitations distributed via social media, among Sri Lankans who were above 18 years of age).

2.2 Design

The study is a questionnaire-based study under the quantitative paradigm which utilizes an independent sample design.

2.3 Variables

In the study the independent variable (IV) is mindfulness, and the dependent variable (DV) is cerebral asymmetry.

2.4 Materials

The study employed 3 questionnaires; a demographic questionnaire, the Edinburgh's handedness inventory (Oldfield, 1971), and the five facet mindfulness questionnaires (Baer *et al*., 2006). The demographic questionnaire included questions regarding age, gender, & characteristics of meditation practice (only in meditators).

The Edinburgh's handedness inventory which is an empirically tested standardized questionnaire measures handedness asymmetry on a quantitative basis and was used as an indicator of cerebral asymmetry. The laterality quotient (L.Q.) scores were calculated as in equation (1), for the handedness scores.

Equation (1)

$$L.Q. = \frac{\sum \mathbb{X}(\mathbb{R}) - \sum \mathbb{X}(\mathbb{L})}{\sum \mathbb{X}(\mathbb{R}) + \sum \mathbb{X}(\mathbb{L})} \times 100$$

$L.Q.$ = Laterality quotient

$\sum \mathbb{X}(\mathbb{R})$ = total number of pluses for right hand use

$\sum \mathbb{X}(\mathbb{L})$ = total number of pluses for left hand use

L.Q. scores range from -100 to +100. Minus

values indicate leftward asymmetry for handedness, while plus scores indicate rightward asymmetry for handedness. Then, decile values for the L.Q. scores were calculated according to values given in Oldfield (1971). This is a measure obtained by relating L.Q. ranges to its frequency distribution in the general population. Decile values gives equal weightings to right-handed scores and left-handed scores and range from 1 to 10. In all the analyses decile values of L.Q. scores were taken as a measure of cerebral asymmetry.

The five-facet mindfulness questionnaire (FFMQ) developed by Baer *et al*. (2006), is an empirically tested standardized psychometric questionnaire which assesses the mindfulness of an individual by assessing its 5 facets, namely, observing, describing, awareness, non-judging of inner experience and non-reactivity to inner experience. The scores for total mindfulness and its 5 facets range from 1 to 5.

2.5 Procedure

Data collection from the meditating participants of the Catholic educational convent and its meditating contacts were done physically, in small groups, at the Catholic educational convent in Colombo; adhering to the ethical guidelines imposed by the ethics committee of Cardiff school of sport & health sciences, U.K. Each participant was assigned a participant reference number to ensure anonymity. Upon written consent for participation in the study, the meditating participants filled out the 3 paper questionnaires.

Non-meditating participants were invited to the study via an online message circulated through social media and data were collected via google forms. The participants were informed of their implied consent. Then they were directed to the 3 questionnaires in the google forms to fill out.

2.6 Method of analysis

Demographic data were analyzed using descriptive statistical analyses.

As data were not normally distributed, non-parametric inferential statistical tests were applied.

A Mann-Whitney U test was carried out to test the hypothesis that mindfulness scores of meditating adults will be significantly greater than that of non-meditating adults. Another Mann-Whitney U test was carried out to test the hypothesis that the cerebral asymmetry of meditating adults will be significantly greater than that of non-meditating adults. The meditating sample included only females, but the non-meditating sample included both females and males. Hence to see whether the gender difference had an effect on decile values (cerebral asymmetry), another Mann-Whitney U test was carried out between non-meditating males and non-meditating females on their decile values (cerebral asymmetry).

A Spearman correlational analysis was conducted to test the hypothesis, higher the mindfulness of meditators, higher they will

be in their cerebral asymmetry. Similar as above, Spearman correlational analyses was conducted for non-meditators as well, to test the hypothesis, higher the cerebral asymmetry, higher they will be in their mindfulness. All statistical analyses were carried out using SPSS 20 software.

2. RESULTS

3.1 Demographic data & other qualitative data

Meditators had a mean age of 39.5 (Standard Deviation=20) while for non-meditators it was 34.4 (Standard Deviation=11). Meditators sample consisted of 100% females, while non-meditators sample contained 42% (n=19) males and 55% (n=26) females. Meditating participants were very variable in their type and duration of meditation practice.

Both meditators and non-meditators' mindfulness seemed to increase with age and showed a positive gross linear relationship, in scatter plots. While both meditators and non-meditators' age vs. decile values (cerebral asymmetry) did not seem to show a significant pattern in scatter plots.

3.2 Effect of meditation on mindfulness scores

The Mann-Whitney U test revealed that the mean mindfulness score is significantly greater in meditators than in non-meditators ($p<0.05$). The meditators had a mean mindfulness score of 3.35 (Standard Deviation = 0.38; variance = 0.14), while for non-meditators the score was 3.2 (Standard Deviation =0.33; variance = 0.11). So, the findings suggest that the meditators were under the effect of mindfulness.

3.3 Effect of meditation on cerebral asymmetry

The Mann-Whitney U test revealed that the mean decile value (mean cerebral asymmetry score) is significantly greater in meditators than in non-meditators ($p<0.05$). Meditators had a mean decile value (mean cerebral asymmetry score) of 7.62 (Standard Deviation = 2.82; variance = 7.98), while for the non-meditators the mean decile value (mean cerebral asymmetry score) was 5.89 (Standard Deviation = 3.37; variance = 11.37). To see whether there is an effect of gender differences on cerebral asymmetry (decile values), another Mann-Whitney U test was carried out between non-meditating females (n=26) and non-meditating males (n=19) on their mean decile values (mean cerebral asymmetry scores). It revealed a mean decile value (mean cerebral asymmetry score) of 4.95 (Standard Deviation = 3.34; variance = 11.16) for non-meditating males, while a mean decile value (mean cerebral asymmetry score) of 6.58 (Standard Deviation = 3.29; variance = 10.81) was revealed for non-meditating females. But interestingly gender differences in mean decile values (mean cerebral asymmetry scores) for non-meditators was not significant ($p>0.05$).

3.4 Relationship between mindfulness & cerebral asymmetry, in meditators

Spearman correlational analyses (one-tailed) were conducted in the meditating sample to test the hypothesis whether that

for meditators higher their mindfulness higher they will be in their cerebral asymmetry. The Spearman rho revealed a significant positive weak correlation ($r = 0.28$; $p<0.05$) between the non-reactivity facet of mindfulness & decile values (cerebral asymmetry), in the meditators. The non-reactivity facet in meditators in turn showed significant positive correlations with total mindfulness score, awareness facet & some of the other facets of mindfulness.

3.5 Relationship between cerebral asymmetry & mindfulness, in non-meditators

A Spearman correlational analysis (one-tailed) was conducted to test the hypothesis that for non-meditators the higher the cerebral asymmetry higher they will be in mindfulness scores, as a developmental phenomenon. The Spearman rho revealed no significant findings other than a significant weak negative relationship ($r = -0.34$; $p<0.05$) between decile values (cerebral asymmetry) & observing facet of mindfulness, in non-meditators.

3. DISCUSSION

The present quantitative study which is a questionnaire-based survey, explored the effectiveness of meditation in enhancing cerebral asymmetry in two independent samples of adult meditators ($n = 47$) and adult non-meditators ($n = 45$), in Sri Lanka. The study assessed handedness asymmetry as an indicator of cerebral asymmetry & mindfulness and its five facets as an indicator of meditation experience. The author hypothesized meditators to have significantly greater scores on mindfulness than the non-meditators. And as expected the Mann-Whitney U test revealed a significantly high mean mindfulness score in meditators than in non-meditators. It is a finding which is consistent with the study findings in De Bruin *et al*. (2012), which compared the psychometric properties of the Dutch version of the FFMQ (FFMQ-NL) with its English version. De Bruin *et al*. (2012) study revealed that the total FFMQ-NL score as well as the scores for rest of the five facets of mindfulness was significantly greater in meditators than in non-meditators. So, it shows that the meditators in the present study were under the influence of mindfulness, which could be attributed to their meditative experience.

Further, the author also hypothesized that meditators would be significantly greater on cerebral asymmetry, than the non-meditators. As expected, the Mann-Whitney U test revealed that in meditators the handedness asymmetry, which was used as an indicator of cerebral asymmetry, to be significantly greater than in non-meditators. Hence in the present study, the increase in cerebral asymmetry in meditators could be attributed to their better mindfulness scores. This finding is consistent with most of the existing empirical findings which have explored the effect of meditation in enhancing cerebral asymmetry (Santarnecchi *et al*., 2015; Tang *et al*., 2015; Zhou & Liu, 2017). Some studies have revealed mainly a greater anterior and leftward functional asymmetry due to meditation practices (Tang *et al*., 2015; Zhou & Liu, 2017), while other studies have revealed greater rightward structural asymmetry due to meditation practices (Santarnecchi *et al*., 2015). But these

studies have employed different types & durations of meditation practices. Further, some of these studies have assessed structural cerebral asymmetries while other studies have assessed functional cerebral asymmetries. And hence difficult to come to a general conclusion regarding direction of asymmetry due to meditation experience. Further, Jonathan and Earle (1981), in their review article has emphasized meditation causing initial inhibition of left brain leading to rightward brain asymmetry and reactivation of the left brain when meditation practice progresses. The present study used handedness asymmetry as an indicator of cerebral asymmetry and this assumption is supported by Geschwind and Galaburda (1985) and as well as by Sha *et al*. (2021), by proposing the phenomena of "linked asymmetries". According to Geschwind and Galaburda (1985), the "linked asymmetry" phenomena refer to the idea of alteration of asymmetry in one structure due to emergence or alteration of asymmetry in another structure. Geschwind and Galaburda (1985) & Sha *et al*. (2021), also emphasize the idea that handedness is rooted in cerebral asymmetry due to the observation of left hemispheric specialization for language and for the fact that the majority of the population are right-handed. So, all these supports the idea that in the present study, the increase in handedness asymmetry in meditators could be attributed to their enhanced cerebral asymmetry.

In the present study the meditating sample consisted only of female participants and hence is gender biased. But the non-meditating sample was not gender biased since it constituted of both males and females. Geschwind and Galaburda (1985), has presented data that majority of the highly asymmetric right handers are females while majority of the highly asymmetric left handers are males. Further they have shown that right handers constitute about 85% of the population, left handers constitute 7.5-10% of the population, while ambidextrous individuals (laterality score between -30 to +30) constitute 5% of the population. They further revealed that the majority of the ambidextrous individuals are males. But in the present study the decile values of laterality quotient scores were employed in the study, which is a measure obtained by relating laterality quotient ranges to its frequency distribution in the general population according to Oldfield (1971), which gives equal weightings to the right-handed scores and left-handed scores. Hence it can be speculated that in the present study, as a consequence of using decile values of laterality quotient scores, the females and males in the non-meditating sample did not show significant differences on handedness asymmetry (cerebral asymmetry). So, it can be inferred that in the present study gender of the participants did not act as an extraneous variable for handedness asymmetry scores (cerebral asymmetry scores). Further, the impact of gender differences on mindfulness scores was not clarified in the analysis because there is not much empirical support for gender differences in mindfulness.

The present study also hypothesized a significant positive relationship between mindfulness and cerebral asymmetry, in the meditating sample, as a result of effect of

meditation experience. The present study findings in the meditators revealed a significant weak positive correlation between the non-reactivity facet of mindfulness and decile values (cerebral asymmetry scores). The non-reactivity facet in turn showed significant positive correlations with total mindfulness score, awareness facet of mindfulness and some of the other facets of mindfulness. This study finding seems to be consistent with findings in Jerman *et al*. (2009). Jerman *et al*. (2009) study explored the psychometric properties of the French translation of "mindful attention awareness scale" (MAAS) and its data was shown to best fit with a single factor model. Brown and Ryans' 2004 study (as cited in Baer *et al*., 2006), who are the developers of MAAS, argues mindfulness construct to be a single factor, and describes mindfulness in terms of being attentive to & awareness in the present moment & acceptance as a part of being fully attentive in moment-to-moment experience. Further, they argue acceptance to be constituted of being non-judgmental and non-reactive. And hence the present study findings on the correlational analysis between mindfulness and decile values (cerebral asymmetry scores), in meditators seem to be more consistent with mindfulness measured according to a one factor structure. Hence the present study would have shown more strong and significant findings if mindfulness was assessed according to a single factor structure. So, it can be inferred that in the present study, the effect of meditation might be stronger in actual, than revealed by study findings.

The author also hypothesized that in the present study non-meditators too will show significant associations between cerebral asymmetry and mindfulness, as a developmental phenomenon. And the present study findings revealed that in non-meditators, a significant weak negative correlation exists between decile values (cerebral asymmetry scores) and the observing facet of mindfulness. In Baer *et al*. (2006) study, which assessed the capacity of mindfulness facets in predicting psychological symptoms revealed that in non-meditators, only the observing facet of mindfulness to be positively correlated with psychological symptoms. As a possible explanation to this finding Baer *et al*. (2006) states that may be the items in the observing facet of mindfulness does not capture noticing experience that is specific to mindfulness and the observing facet may be a representative of transition from non-meditative status to meditative experience. From finding in Baer *et al*. (2006) it can be speculated observing facet of mindfulness to be an indicator of psychological symptoms. The present study correlation findings in non-meditators revealed higher the cerebral asymmetry (decile values) less is the observing facet score, i.e., higher the cerebral asymmetry (decile values) less is the psychological symptoms. So, it shows that an asymmetric brain is highly advantageous to an individual. According to Vallortigara and Rogers (2005), cerebral lateralization enhances neural capacity since focusing on one function by one cerebral hemisphere leaves the other to focus on another function. Further, cerebral lateralization avoids duplication of neural functions by the two cerebral hemispheres

thus saving neural space and facilitates parallel processing by the two cerebral hemispheres resulting in the capacity for multi-tasking.

Empirical evidence on how cerebral asymmetry changes with age has shown mixed results. According to a review study by Geschwind and Galaburda (1985), with increasing age the individuals become more leftward asymmetric. In the meantime, a study by Zhong *et al*. (2017), revealed that rightward topological asymmetries in white matter network declined from adolescents to young adulthood. But in the present study both meditators & non-meditators did not show a significant pattern for age vs. cerebral asymmetry (decile values) in the scatter plots and it may be explained by the fact that in the present study the direction of asymmetry was not taken into consideration. A study by Alispahic and Hasanbegovic-Anic (2017), in a questionnaire-based survey explored how mindfulness changes with age and gender in the Bosnian general population. Its study findings revealed that older participant groups scored significantly higher on all aspects of mindfulness than younger age groups. In consistent with those study findings, the present study showed that both meditators and non-meditators mindfulness to increase with age. Alispahic and Hasanbegovic-Anic (2017) explains his study findings by saying that as the individuals mature in age, they find better ways to adapting to emotional challenge and hence become less judging of themselves and the others, and the same explanation seem to explain the present study finding. But in the present study since there are no significant age differences between the meditating participants and non-meditating participants, the age of the participants does not seem to bias the mindfulness scores or the cerebral asymmetry study findings.

When considering limitations of the study, a main concern seems to be not using probability sampling method. Although in the present study, both the samples were obtained using non-probability sampling method, the original pool of participants from which the non-meditators were selected seem to be significantly greater than that of the meditators. But when comparing the characteristics of the two samples the major differences seem to be better educational level of the meditators and the gender biasedness of the meditators. Gender biasedness has been clarified in the statistical analysis. Differences in educational level may have biased the mindfulness scores, which in turn may have impacted cerebral asymmetry scores. Though this seems a drawback of the study, this fact indirectly supports meditation practices while directly supports mindfulness, as a way to enhance cerebral asymmetry, because one of the best ways to achieve mindfulness is via practicing meditation.

Further, cerebral asymmetry is altered in neuro-developmental (Geschwind & Galaburda, 1985; Grouios *et al*., 2013), neuro-pathological (Liu *et al*., 2018) and psychiatric conditions (Pettigrew & Miller, 1998; Ribolsi *et al*., 2014). Since the present study participants were not screened for such conditions, it is another limitation of the study. So future studies could explore the possibility of replication of the present

study by using probability sampling method at the same time, controlling for extraneous variables.

4. CONCLUSION

In conclusion, the present study was able to replicate past empirical evidence on the capacity of meditation experience to enhance cerebral asymmetry, by using a simple, fast and a non-invasive method. It is a more practical and safe method for analysis of cerebral asymmetry that can be used in high-risk groups such as in children, to explore the effect of meditation experience. Further the study provides new insights that meditation can not only enhance brain asymmetry but also can enhance bodily asymmetries. Finally, the study findings highlight the importance of meditation as a way that can enhance both brain and bodily asymmetries for a better functioning individual, an effect that cannot be induced in an individual by any drug treatment or surgical treatment.

ETHICS STATEMENT

We confirm that we have obtained the approval of the ethics committee of Cardiff school of sport & health sciences, UK for our research proposal and affirm that this work is consistent with their guidelines.

6. REFERENCES

Alispahic, S., & Hasanbegovic-Anic, E. (2017). Mindfulness: Age and gender differences in a Bosnian sample. *Psychological thought, 10*(1), 155-166. https://www.researchgate.net/publication/316560770_Mindfulness_Age_and_Gender_Differences_on_a_Bosnian_Sample

Baer, R. A., Smith, G. T., Hopkins, J., Kreitemeyer, J., & Toney, L. (2006). Using self-report assessment methods to explore facets of mindfulness. *Assessment, 13*(1), 27-45. https://www.researchgate.net/publication/7329545_Using_Self-Report_Assessment_Methods_to_Explore_Facets_of_Mindfulness

Bishop, D. V. M. (2013). Cerebral asymmetry and language development: Cause, correlate or consequence? *Science, 340*(6138). https://www.researchgate.net/publication/237843642_Cerebral_Asymmetry_and_Language_Development_Cause_Correlate_or_Consequence

Brown, R. P., & Gerbarg, P. L. (2013). Therapeutic mind-body practices: Yoga,___breathing techniques, and meditation for treatment of stress, depression, anxiety, PTSD, ADHD, and schizophrenia. In R. P. Brown, P. L. Gerbarg & F. Muench (Eds.), *Breathing practices for treatment of psychiatric and stress-related medical conditions* (pp.122-140). Elsevier. https://www.researchgate.net/publication/266814424_Therapeutic_mind-body_practices_Yoga_breathing_techniques_and_meditation_for_treatment_of_stress_depression_anxiety_PTSD_ADHD_and_schizophrenia

Coote, J. H., & Spyer, K. M. (2018). Central control of autonomic function. *Brain, and neuroscience advances. 2*,1-5. https://journals.sagepub.com/doi/pdf/10.1177/2398212818812012

De Bruin, E. T., Topper, M., Muskens, J. G. A. M., Bogels, S. M. & Kamphius, J. H. (2012). Psychometric properties of the five-facet mindfulness questionnaire (FFMQ) in a meditating and non-meditating sample. *Assessment, 19*(2), 187-197. https://www.researchgate.net/publication/224966634_Psychometric_Properties_of_the_Five_Face

ts_Mindfulness_Questionnaire_FFMQ_in_a_Meditating_and_a_Non-meditating_Sample

Foundas, A. L., Eure, K. F., Luevano, L. F. and Weinberger, D. R. (1998). MRI asymmetries of Broca's area: The Pars Triangularis and Pars Opercularis. *Brain and_language, 64,* 282-296. https://pubmed.ncbi.nlm.nih.gov/9743543/

Foundas, A. L., Leonard, C. M. & Heilman, K. M. (1995). Morphologic cerebral asymmetries and handedness. The Pars Triangularis and Planum Temporale. *JAMA Neurology, 52*(5), 501-508. https://jamanetwork.com/journals/jamaneurology/article-abstract/593458

Geschwind, N., & Galaburda, A. M. (1985). Cerebral lateralization, biological mechanisms, associations, and pathology: A hypothesis and a program for research. *Archives of neurology, 42.* https://www.researchgate.net/publication/19166504_Cerebral_lateralization_Biological_mechanisms_associations_and_pathology_I_A_hypothesis_and_a_program_for_research

Jerman, F., Billieux, J., Lari, F., Van der Linden, M., D'Argembeau, A., Bondolfi, G., & Zermatten, A. (2009). Mindfulness attention awareness scale (MAAS): Psychometric properties of the French translation and exploration of its relation with emotion regulation strategies. *Psychological assessment, 21*(4), 506-514. https://www.researchgate.net/publication/40040921_Mindful_Attention_Awareness_Scale_MAAS_Psychometric_Properties_of_the_French_Translation_and_Exploration_of_Its_Relations_With_Emotion_Regulation_Strategies

Jonathan, B., & Earle, B. (1981). Cerebral laterality and meditation: A review of the literature. *The journal of transpersonal psychology, 3*(2), 155-173. http://www.atpweb.org/jtparchive/trps-13-81-02-155.pdf

Liu, H., Zhang, L., Xi, Q., Zhao, X., Wang, F., Men, W., & Lin, Q. (2018). Changes in brain lateralization in patients with mild cognitive impairment and Alzheimer's disease: A resting state functional magnetic resonance study from Alzheimer's disease neuroimaging initiative. *Frontiers in neurology, 9*(3). https://www.frontiersin.org/articles/10.3389/fneur.2018.00003/full

Nowak, A., Vallacher, R., Zochowski, M., & Rychwalska, A. (2017). Functional synchronization: The emergence of coordinated activity in human systems. *Frontiers in psychology, 8* (945). https://www.frontiersin.org/articles/10.3389/fpsyg.2017.00945/full

O'Regan, L., & Serrien, D. J. (2018). Individual differences and hemispheric asymmetries for language and spatial attention. *Frontiers in human neuroscience, 12.* https://www.researchgate.net/publication/328072327_Individual_Differences_and_Hemispheric_Asymmetries_for_Language_and_Spatial_Attention

Oldfield, R. C. (1971). The assessment of analysis of handedness: The Edinburgh inventory. *Neuropsychologia. 9,* 7-113. http://andersgade.dk/Readings/Oldfield1971.pdf

Pettigrew, J. D., & Miller, S. M. (1998). A sticky interhemispheric switch in bipolar disorder? *Proceedings of the Royal society B: Biological sciences, 265,* 2141-2148. https://www.researchgate.net/publication/13416450_A_sticky_Interhemispheric_Switch_in_Bipolar_Disorder

Ribolsi, M., Daskalakis, Z., Siracusano, A., & Koch, G. (2014). Abnormal asymmetry of brain connectivity in schizophrenia. *Frontiers in human neuroscience, 8*(1010). https://www.researchgate.net/publication/270655565_Abnormal_Asymmetry_of_Brain_Connectivity_in_Schizophrenia

Santarnechchi, E., Arista, S., Eqiziano, E., Gardi, C., Petrosino, R., Vatti, G., Reda, M., & Rossi, A.

(2014). Interaction between neuroanatomical and psychological changes after mindfulness-based training. *PLos One*, *9*(10). https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0108359

Schimdt, M. F. (2008). Using both sides of your brain: The case of rapid interhemispheric switching. *PLoS Biology*, *6*(10). https://www.researchgate.net/publication/23427151_Using_Both_Sides_of_Your_Brain_The_Case_for_Rapid_Interhemispheric_Switching

Sha, S., Pepe, A., Schijven, D., Carrion-Castillo, A., Roe, J. M., Westerhausen, R., Joliot, M., Fisher, S. E., Crivello, F., & Franks, C. (2021). Handedness and its genetical influences are associated with structural asymmetries of the cerebral cortex in 31,864 individuals. *PNAS*, *118*(47). https://www.pnas.org/doi/pdf/10.1073/pnas.2113095118

Shannahoff-Kalsa, D. (1993). The ultradian rhythm of alternating cerebral hemispheric activity. *International journal of neuroscience*, *70*, 285-298. https://psycnet.apa.org/record/1994-04675-001

Tang, Y., Lu, Q., Feng, H., Tang, R., & Posner, M. I. (2015). Short-term meditation increases blood flow in anterior cingulated cortex and insula. *Frontiers in psychology*, *6*(212). https://www.frontiersin.org/articles/10.3389/fpsyg.2015.00212/full

Tzourio-Mazoyer, N. (2016). Intra and inter hemispheric connectivity supporting hemispheric specialization. In H. Kennedy, D. C. Van Essen, & Y. Christen (Eds.), *Micro, meso and macro connectomies of the brain* (pp. 129-147). Springer. https://www.ncbi.nlm.nih.gov/books/NBK435763/

Valloritigara, G., & Rogers, L. J. (2005). Survival with an asymmetric brain: Advantages and disadvantages of cerebral lateralization. *Behavioral and brain sciences*, *28*(4), 576-633. https://www.researchgate.net/publication/7555482_Survival_with_an_asymmetrical_brain_Advantages_and_disadvantages_of_cerebral_lateralization

Ypsilanti, A., & Koidou, I. (2013). Laterality explored: Atypical hemispheric dominance in Downs syndrome. In G. Grouios, A._Ypsilanti, & I. Koidou (Eds.), *Downs syndrome* (pp. 209-236). https://www.researchgate.net/publication/300831925_Laterality_Explored_Atypical_Hemispheric_Dominance_in_Down_Syndrome

Zhong, S., He, Y., Shu, H., & Gong, G. (2017). Developmental changes in topological asymmetry between hemispheric brain white matter networks from adolescence to young adulthood. *Cerebral cortex*, *27*(4). https://www.researchgate.net/publication/301640626_Developmental_Changes_in_Topological_Asymmetry_Between_Hemispheric_Brain_White_Matter_Networks_from_Adolescence_to_Young_Adulthood

Zhou, R. & Liu, L. (2017). Eight-week mindfulness training enhances left frontal EEG asymmetry during emotional challenge: A randomized controlled trial. *Mindfulness*, *8*, 181-189. https://link.springer.com/article/10.1007/s12671-016-0591-z

APPENDICES

Table 1 : Demographic data of meditators & non-meditators.

Characteristics	Meditators (n=47)	Non-meditators (n=45)	P-value
Age	39.51+/-20	34.38+/-11	0.854
Females (%)	100	55	

Data are presented as the means +/- SD.
The P value was obtained using the Mann-Whitney U test

Table 2 : Comparison of mindfulness scores between meditators & non-meditators.

Mindfulness scores	Meditators (n=47)	Non-meditators (n=45)	P-value
Mean	3.35+/-0.38	3.2+/-0.33	<0.05
Variance	0.14	0.11	

Data are presented as the mean +/-SD.

The P value was obtained using the Mann-Whitney U test.

Table 3 : Comparison of decile values (cerebral asymmetry scores) between meditators & non-meditators.

Decile values (cerebral asymmetry scores)	Meditators (n=47)	Non-meditators (n=45)	P-value
Mean	7.62+/-2.82	5.89+/-3.37	<0.05
Variance	7.98	11.37	

Data are represented as the means +/-SD.

The P value was obtained using the Mann-Whitney U test.

Table 4 : Comparison of decile values (cerebral asymmetry scores) between non-meditating males & non-meditating females

Decile values (cerebral asymmetry scores)	Non-meditating males (n=19)	Non-meditating females (n=26)	P-value
Mean	4.95+/-3.34	6.58+/-3.29	>0.05
Variance	11.16	10.81	

Data are represented as the means +/-SD.

The P-value was obtained using the Mann-Whitney U test.

Tackling Listeria Monocytogenes in Ready-to-Eat Meats: Promising Strategies with Natural Antimicrobials

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ABSTRACT

The increasing consumer demand for convenient, flavorful, and safe Ready-to-Eat (RTE) meat and poultry products is accompanied by significant public health concerns regarding potential contamination and the growth of Listeria monocytogenes (LM), a pathogenic, intracellular, Gram-positive bacterium. In 2019, the US reported over 25,000 cases of foodborne diseases, leading to 6,164 hospitalizations and 122 fatalities, with LM being a primary causative agent. The safety of RTE meat products is intricately tied to the quality of raw ingredients and the entire production process. Contamination can occur at various stages, from processing to consumption, with post-processing cross-contamination being a common route for LM transmission. Recent research underscores LM's association with RTE meat products, including sausages and deli meats. In response to the challenges posed by LM contamination in RTE-MPPs, natural antimicrobials have emerged as promising solutions. These antimicrobials align with consumer preferences for minimally processed, chemical-free foods. Bacteriocins, ribosomally synthesized peptides, hold potential as safe antimicrobial agents due to their varying molecular weights and antibacterial ranges. Spices and herbs, notably clove oil, exhibit antimicrobial properties attributed to phenolic compounds. Essential oils derived from aromatic plants demonstrate antibacterial effects, albeit with variations in efficacy across bacterial species. Bacteriophages, viruses that infect bacteria have received FDA approval for LM control in RTE products. While natural antimicrobials hold promise, ongoing research is crucial for developing effective technologies and regulatory guidelines. This review aims to explore the occurrence of Listeria in RTE meat products and evaluate potential natural antimicrobial additives for LM control, addressing the pressing need for safer and more flavorful

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RTE foods.

Keywords **- Listeria monocytogenes, RTE meats, Natural antimicrobials**

1. INTRODUCTION

Street foods, as per the classification provided by the World Health Organization (WHO), include consumable food items and drinks that are made and vended by street vendors and hawkers in public spaces and thoroughfares (Andrade et al., 2023). These culinary offerings have considerable importance within several communities. Nevertheless, the safety of ready-to-eat (RTE) meals raises concerns due to their preparation and sale in environments that lack legal regulation and sanitary monitoring. The absence of sufficient management and monitoring exacerbates the potential for foodborne illnesses, hence presenting a significant worldwide public health concern (Abrahale et al., 2019). According to the FoodNet report of 2019, a total of 25,866 instances of foodborne disease were documented, leading to 6,164 hospitalizations and 122 fatalities (Tack et al., 2019). The predominant causative agents of gastrointestinal tract (GIT) foodborne infections in the United States are microorganisms, including Salmonella, Listeria, Escherichia coli, and Campylobacter (Heredia & García, 2018).

The safety of RTE meat products is closely associated with the quality of the raw ingredients used during their production. Across the whole of the production chain, including various stages such as processing, transportation, storage, display, preparation, and consumption, it is possible for food to be exposed to and contaminated with detrimental microorganisms. The contamination in question can be attributed to various factors, such as substandard hygiene practices exhibited by individuals handling food, limited availability of safe drinking water, insufficient infrastructure, improper storage of food at temperatures favorable for microbial proliferation, contact with domestic and other animals, including rodents and insects, and the presence of air pollutants (Andrade et al., 2023).

Animal and animal products are considered integral sources of vital nutrients for human consumption owing to their substantial concentrations of vitamin B groups, protein, essential amino acids, and minerals. Nonetheless, the advantageous nutritional composition of these substances also establishes an optimal setting for the proliferation of diverse bacteria, owing to characteristics such as the correct pH level, nutrient accessibility, and elevated water activity (Kaveh et al., 2023; Pateiro et al., 2021). Microbial contamination is a significant challenge for the meat business, leading to the deterioration of fresh meat and meat products. Bacterial strains including *Salmonella* spp., *Campylobacter jejuni*, *Escherichia coli* O157:H7, *Listeria monocytogenes*, *Clostridium* spp., *Pseudomonas*, *Acinetobacter*, *Brochothrix thermosphacta*, *Lactobacillus* spp., *Enterobacter*, alongside molds and yeasts, have the potential to initiate outbreaks that carry substantial consequences for both public health and the economy (Jayasena & Jo, 2013; Ji et al., 2023).

The challenge arises when addressing this issue, since the available intervention options are constrained by the market preference for chemicals that are classified as "natural." The objective of this study is to investigate the prevalence of *Listeria* in RTE meat products and examine the

possible efficacy of natural antimicrobial additions in the control of *Listeria*.

2. LISTERIA MONOCYTOGENES

In the year 1926, EGD Murray successfully isolated the first officially documented strain of *Listeria monocytogenes* (LM) from rabbits and guinea pigs. In the beginning, EGD Murray designated it as *Bacterium monocytogenes*. In the year 1927, a temporary alteration in nomenclature occurred, resulting in the designation of *Listerella hepatolytica*. In the year 1940, Pirie proposed the designation *L. monocytogenes*, which subsequently became part of the Approved Lists of Bacterial Names (Dortet et al., 2019). Among the taxonomic classification of Listeria, which now has a total of 17 officially acknowledged species (Dhama et al., 2015; Orsi & Wiedmann, 2016), only two are acknowledged as pathogens: *Listeria monocytogenes* and *Listeria ivanovii. L. ivanovii* is mostly recognized as an animal pathogen that is often linked to cases of ruminant abortion (Barbuddhe et al., 2012; Dortet et al., 2019).

LM has been categorized into thirteen distinct serotypes, mostly determined by the presence of somatic and flagellar antigens. Among these serotypes, 1/2a, 1/2b, and 4b have been identified as the most frequently implicated in human infections, whilst serotypes 1/2a and 4b are predominantly connected with infections in animals(den Bakker et al., 2014; Dhama et al., 2015). *Listeria* species have a Gram-positive morphology, characterized by rod-shaped cells with diameters spanning from 0.4 to 0.5 micrometers and lengths ranging from 0.5 to 2 micrometers. The microorganisms in question exhibit characteristics of being non-encapsulated bacilli, lacking the ability to make spores, and displaying both aerobic and facultative anaerobic metabolic capabilities. LM is a bacterium that has the ability to exist both within and outside of cells, known as being facultative intracellular and saprophytic. It is capable of transitioning from a harmless organism in the environment to a potentially dangerous disease (Dhama et al., 2015; Dortet et al., 2019).

The organism has peritrichous flagella, ranging from one to five, which allow tumbling motion within a certain range of temperatures(Dortet et al., 2019). The activity of flagellin is shown to diminish at a temperature of 37°C, resulting in the loss of motility in the bacteria. Organism has notable resilience when exposed to various pH levels and temperature ranges. The organism has a capacity for survival across a temperature range spanning from 1°C to 45°C, while displaying its most favorable growth rates between the temperature range of 30 to 37°C. The process of subjecting dairy products to pasteurization at a temperature of 60°C has been shown to be very effective in eradicating *Listeria.* Furthermore, the substance exhibits resilience against pH fluctuations ranging from 4.5 to 9 and a concentration of 10% sodium chloride (NaCl). However, it demonstrates optimal growth and development under conditions of neutral pH and a NaCl concentration of 0.5% (Bodie et al., 2023; Dhama et al., 2015; Dortet et al., 2019) .

All strains of LM demonstrate the capacity to generate acid from certain sugars, such as L-rhamnose, α-methyl-D-mannoside, glucose, and lactose. However, they are unable to make acid from D-xylose or D-mannitol. When seen under reflected light, colonies of Listeria spp. exhibit

characteristics such as tiny size, smooth texture, mild flattening, and a milky white coloration. Under typical lighting conditions, objects seem to have a bluish-gray color. However, when illuminated by oblique light, a unique blue-green shimmer becomes apparent. *Listeria* species are characterized by their non-fastidious nature, ability to exhibit beta-hemolysis on solid medium with diverse blood sources, and positive reactions for catalase, methyl red, and Voges-Proskauer tests, while showing negative results for oxidase test (Dortet et al., 2019; Ramaswamy et al., 2007).

Listeriosis is a very consequential gastrointestinal infection that arises from the ingestion of meat products that have been tainted with LM. The condition has a notable fatality rate, surpassing 20% in affected persons (Hernandez-Milian & Payeras-Cifre, 2014). Although listeriosis constitutes less than 2% of foodborne diseases in the United States, it is responsible for a significantly disproportionate 40% of fatalities associated with foodborne infections. Furthermore, this phenomenon is associated with the most elevated risk of hospitalization, impacting around 92% of those who have contracted the infection. Each year, the United States has an estimated 1,600 documented cases and roughly 260 fatalities as a result of listeriosis(Tack et al., 2019) . Listeriosis mostly impacts the gastrointestinal tract (GIT), giving rise to symptoms like nausea, diarrhea, vomiting, and headaches (Bodie et al., 2023). LM infection in humans may result in prolonged and asymptomatic bacteremia. It will then spread to the brain or the placenta, causing meningitis or encephalitis in immunocompromised patients, abortions in pregnant mothers, and generalized infections in infected neonates (Dortet et al., 2019).The infective dosage of LM exhibits variability, with estimates indicating a range of 10 to 100 million colony-forming units (CFU) for healthy humans. However, immunocompromised individuals may be susceptible to infection even at lower levels, as low as 0.1 to 10 million CFU(Angelo et al., 2017). The incubation time of listeriosis exhibits variability, depending on the mechanism of transmission and the amount of exposure. It normally ranges from one to four weeks, however in certain cases it may extend to several months. Listeriosis outbreaks have been associated with a wide variety of dietary items. Nevertheless, a substantial majority of instances arise from the ingestion of RTE meat products (see Table 1). It is worth noting that delicatessen meats have been identified as having the greatest potential for causing listeriosis. These particular food products are conducive to the development of LM under normal storage settings and have a longer shelf life compared to other RTE food items(Bodie et al., 2023). The presence of LM in RTE meals has significant economic implications, leading to an average yearly financial loss of USD 2.8 billion in the United States(Hoffmann et al., 2015).

Table 1-Reported cases of listeriosis outbreak from RTE meat products-United stated 2023-2002 https://www.cdc.gov/foodsafety/outbreaks/lists/ outbreaks-list.html, accessed on 30 September 2023.

Study period, year	Food vehicle	Total no of cases	No of hospi-talization	No of deaths
2022	Deli meat	16	13	1
2021	Cooked chicken	3	3	1
2020	Deli meat	12	12	1
2018	Deli ham	4	4	1
2016	Deli sliced meat	10	10	1
2010	Hog head cheese	14	7	2
2002	Deli meat	13	13	1
	Grilled chicken	3	3	0
	Deli meat	54	NA	8

NA- not applicable

3. LM IN RTE MPPS

Ready-to-eat (RTE) foods, which include a wide range of categories such as red meat, chicken, seafood, dairy, and vegetables, have been acknowledged as possible carriers of bacterial infections, hence contributing to the occurrence of foodborne outbreaks. The occurrence of LM in various food items raises significant concerns for public health (Buchanan et al., 2017; Hanning et al., 2008; Ramaswamy et al., 2007). The potential for contamination by LM exists at many points throughout the RTE meat manufacturing chain. It is worth mentioning that the transmission of LM in RTE meat is often linked to cross-contamination that occurs during post-processing stages, even when the meat has been cooked thoroughly (Swaminathan & Gerner-Smidt, 2007). Moreover, LM has the capacity to flourish at conditions of very low temperatures, reaching as low as 2°C. Consequently, this raises concerns over the potential exposure of consumers to this particular pathogen (Dortet et al., 2019). Desai et al., 2019 performed a thorough examination of LM outbreaks documented in ProMED data between 1996 and 2018. The investigation conducted by the researcher's brought attention to the correlation between the transmission of LM and certain (RTE) meat items, including cooked sausages, RTE sausages, and deli meats.

From 1998 to 2019, the United States documented a cumulative count of six instances of listeriosis outbreaks associated with Ready-to-Eat Meat and Poultry Products (RTE-MPPs). These outbreaks resulted in a total of 194 recorded cases, including 28 fatalities and 9 occurrences of stillbirths or miscarriages. One of the notable outbreaks, which occurred in 1998, was deemed noteworthy because to its association with hotdogs and maybe deli meats, leading to a total of 101 reported cases of sickness. In the year 2000, there was an additional occurrence of an

epidemic that was linked to the consumption of turkey deli meats. This particular outbreak affected a total of 10 states, resulting in 29 reported cases of sickness. Tragically, this outbreak also had severe consequences, leading to the unfortunate loss of 19 lives and causing 9 instances of stillbirths or miscarriages. These instances highlight the intermittent yet pervasive characteristics of listeriosis as a significant foodborne illness(Cartwright et al., 2013).

Globally, epidemics of listeriosis have also had a substantial effect. In France, during the year 1992, a significant incident occurred, whereby a total of 279 cases, 22 instances of miscarriage, and 63 fatalities were reported. This epidemic was shown to be associated with the consumption of pig tongue in jelly, a regional ready-to-eat meat product. The presence of contaminated delicatessen goods served to worsen the epidemic. The underlying factors included cross-contamination, insufficient cleaning, and disinfection protocols(Jacquet et al., 1995).

The greatest recorded epidemic of listeriosis on a worldwide scale occurred in South Africa over the period of 2017 to 2018, including a significant total of 1060 reported cases. In their comprehensive study, Thomas et al., 2020 used a range of methodologies including epidemiological research, trace-back investigations, environmental assessments, and Whole Genome Sequencing (WGS) analysis. Their findings provide compelling evidence of a significant correlation between listeriosis illness and the consumption of a regional RTE pork product often referred to as polony.

RTE meat products have the most elevated fatality risk per serving and per year when compared to other food items(Summary et al., 2010). The increased risk mentioned may be ascribed to the frequent and higher levels of LM concentration that occur due to recontamination prior to the final packing stage, as well as during retail handling or home preparation(Bodie et al., 2023). Equipment and surfaces that come into touch with RTE meats after cooking are often identified as the primary sources of cross-contamination (Tadele et al., 2017). The capacity of LM to endure in food processing facilities is enhanced by the development of biofilms on diverse surfaces (Meloni, 2015). Numerous studies have provided substantial evidence indicating that LM has the capability to stick to and form biofilms on various food contact surfaces, such as polyethylene, polyvinyl chloride, glass, and stainless steel(Blackman & Frank, 1996; Di Bonaventura et al., 2008; Doijad et al., 2015).

3. ANTIMICROBIAL AGENTS FOR CONTROLLING LM IN MPPS

The historical use of antimicrobial agents in the preservation of food has been seen throughout a significant period of time, spanning several centuries. Nevertheless, in recent times, consumer attitudes have undergone a transformation, placing more emphasis on products that are seen to be "natural." In recent times, there has been a discernible increase in the prevalence of RTE processed meat items that are free from synthetic additives. The movement in consumer preferences towards food alternatives devoid of artificial preservatives and pesticides is fueled by the increasing demand for perceived safety and

health advantages connected with these choices (Poti et al., 2015).Although thermal processing is widely recognized as the most effective method for consistently inactivating LM and maintaining food safety, it is not exempt from some limitations(Allerberger & Wagner, 2010) . The sensory and nutritional quality of RTE meat products may be negatively impacted by high-temperature treatments. As a result, customers actively pursue options that effectively address microbiological concerns while still preserving the quality of food products. The increasing popularity of natural and organically processed meats may be attributed to their perceived advantages in terms of safety and health, as recognized by consumers. The exclusion of artificial chemicals, preservatives, and pesticides appeals to those who are inclined towards a more organic and comprehensive approach to the intake of food(Burnett-Boothroyd & McCarthy, 2011) . In the realm RTE meat products, an antimicrobial agent refers to a material that fulfills one of two primary roles: either impeding the proliferation of bacteria by slowing their development (known as bacteriostatic), or directly exterminating bacteria (known as bactericidal). These compounds have a crucial function in protecting meat products against the long-term presence of dangerous germs(Summary et al., 2010). The paper titled "Safe and Suitable Ingredients Used in The Production of Meat and Poultry Products" provides a thorough collection of permitted antimicrobials and treatment procedures for use in RTE meat and poultry products. This resource functions as a point of reference for professionals in the industry and regulatory bodies to guarantee adherence to specified safety protocols (Mie et al., 2017). The following section explores the use of natural antimicrobials in the RTE food business as a means to address the difficulties presented by LM. The use of these natural antimicrobial techniques has great potential in improving food safety and meeting customer demands for minimally processed, chemical-free RTE-MPPs.

3.1 Bacteriocins

Bacteriocins are a class of peptides that are generated by ribosomes and exhibit biological activity as proteins or protein complexes. These substances feature antibacterial capabilities, specifically targeting bacterial species that are closely related (Todd, 2015). Bacterial strains that produce these bacteriocins demonstrate immunity via the synthesis of enzymes that provide resistance against these antimicrobial chemicals (Ríos Colombo et al., 2018). It is of significance to note that bacteriocins are considered to be safe for human intake due to their quick digestion by proteases in the gastrointestinal system of humans(Darbandi et al., 2022). Bacteriocins may be classified into three distinct categories according to their composition, molecular weight (MW), and spectrum of antibacterial activity. Class I encompasses a group of antimicrobial peptides known as lantibiotics, which are distinguished by their compact size (<5 kDa) and resistance to high temperatures. Nisin serves as a prominent illustration of this class. Class II consists of non-lantibiotics, which are characterized by their short size (<10 kDa), thermal stability, and high content of common amino acids such as glycine and pediocin. On the other hand, it is worth noting that Class III bacteriocins, such as Enterolysin, have a much greater molecular weight, exceeding

30 kilodaltons (Šušković et al., 2010; Todd, 2015)

The primary mechanism by which bacteriocins exert their effects is via the denaturation of cell membranes (Yang et al., 2014). Cationic bacteriocins often exhibit a preference for the anionic bacterial cell surface as their targe(Rashid et al., 2016)t. The bacteriocins have hydrophobic areas that cross the lipid bilayer of the cellular surface, ultimately creating complexes that include ion-selective pores. This series of events results in the dissipation of the proton motive force, depletion of intracellular adenosine triphosphate (ATP), leakage of intracellular substrates, and ultimately, cellular demise (Christensen & Hutkins, 1992; Shahnawaz & Soto, 2012). Certain bacteriocins use specialized docking molecules, such as lipid II or mannose permease, in order to establish interactions with cellular membranes (Bodie et al., 2023).

The use of the maltose ABC transporter and permease as receptors is shown in Garvicin ML, a bacteriocin with a circular structure that is produced from *Lactococcus garvieae* DCC43 (Gabrielsen et al., 2012) . Lantibiotics, which are classified as Class I bacteriocins, are characterized by the presence of (methyl)lanthionine residues. These residues contribute to the formation of intramolecular thioether rings, leading to the creation of 'wedge-like' apertures inside the cell membrane. On the other hand, Class II bacteriocins induce membrane permeability by means of 'barrel stave' holes (Moll et al., 1999).

Lactic acid bacteria (LAB) are primarily recognized as the principal producers of bacteriocins LAB are present in a wide range of matrices, including decaying plant material, fruits, dairy products, fermented meats and fish, cereals, vegetables, drinks, and several other sources. Significantly, LAB has the ability to colonize hosts of both human and animal origin (Bodie et al., 2023). Bacteriocins originating from food-grade LAB have non-toxic properties towards humans, do not induce any changes in the nutritional attributes of food items, and exhibit notable effectiveness even when present at low concentrations, often as low as 5 mg/kg (Reis et al., 2012).Nisin, which is produced by the bacterium *Lactobacillus lactis,* is widely used as a bacteriocin in meat-based food items(Todd, 2015). Nisin is widely recognized as safe (GRAS) and belongs to the lantibiotic classification. Research has shown the efficacy of this intervention in significantly diminishing populations of Gram-positive bacteria, such as *Listeria*(de Arauz et al., 2009). RTE meat products, including frankfurters and diced turkey, have shown significant decreases in *Listeria* populations after treatment with nisin(Bodie et al., 2023; Ruiz et al., 2010).

Bacteriocins provide a range of possibilities in the field of bioengineering, enabling enhanced bioactivity and targeted action against foodborne pathogens and organisms that cause spoiling. Peptides have the potential to be modified in order to improve their solubility, resistance to proteases, and tolerance to pH variations, hence increasing their antibacterial efficacy (Perez et al., 2014). The concurrent use of several bacteriocins might potentially result in synergistic antibacterial outcomes against LM. Garviecin LG34, bifidocin A, leucocin C-607, pediocin GS4, plantaricin LPL-1, and pediocin PA-1, among other antimicrobial peptides (Gao et al., 2015; Liu et al., 2015; Wang et al., 2019), have

shown significant effectiveness in combating LM by creating hydrophilic holes in the cytoplasmic membrane of Gram-positive pathogens. This process results in the dissipation of the transmembrane electrical potential, depletion of intracellular ATP, and the leakage of ions, amino acids, proteins, and nucleic acids(Wang et al., 2019).

One of the viable strategies for delivering bacteriocins in a practical manner involves the use of edible films that have been impregnated with these antimicrobial agents. This delivery approach allows for a controlled and progressive release of the bacteriocins onto the surface of the meat product during the course of its shelf life (COMA, 2008). However, it has been shown that some strains of LM have acquired resistance to bacteriocins. As an example, it has been shown that LM has the capacity to modify the composition of cellular membranes, specifically the lipid composition and charges of phospholipids. This alteration ultimately leads to the development of resistance to nisin (Demel et al., 1996; Van Kraaij et al., 1998). Nevertheless, the development of resistance may be significantly influenced by the mutation of LM target receptors, such as the mannose phosphotransferase (Man-PTS) receptor, which is associated with Class IIa bacteriocins (Gravesen et al., 2002).

At now, nisin stands as the sole bacteriocin that has obtained approval for its use in food by both the United States Food and Drug Administration (FDA) and the European Union (Lahiri et al., 2022). The product has a long-standing record of safe use, leading to its classification as generally recognized as safe (GRAS) by the Food and Drug Administration (FDA)(Chikindas et al., 1993). Nisin exhibits thermal stability, efficacy at low doses, little modifications in taste or appearance, absence of resistance induction in target microorganisms, lack of influence on the normal gut microbiota, and straightforward detection and measurement(Lahiri et al., 2022). Although there have been extensive studies on various bacteriocins, a significant number of them still need comprehensive characterization and are pending approval for use in the food business.

3.2 SPICES AND HERBS

Spices and herbs are botanical components well recognized for their capacity to enhance the sensory qualities of many culinary preparations. Spices comprise a wide variety of botanical components, such as roots, rhizomes, stems, leaves, bark, flowers, fruits, and seeds. On the other hand, herbs are often obtained from plants that do not possess a woody structure (Bodie et al., 2023). Several research have been conducted to investigate the antibacterial properties of clove oil and other plant extracts against foodborne pathogens, namely LM (Cressy et al., 2003; Mytle et al., 2006; Zhang et al., 2009). Zhang et al., 2009 undertook a series of research to demonstrate the inhibitory effects of clove, rosemary, cassia bark, and licorice extracts on LM. The antibacterial activity shown by the combination of rosemary and licorice extracts was notably significant. Significant decreases in LM development were seen when rosemary and licorice extracts were administered to RTE ham slices infected with LM at dosages of 2.5, 5, and 10 mg/mL. During a 28-day storage period at a temperature of 4°C, decreases of 2.5-, 2.6-, and 3-log colony-

forming units per square centimeter (CFU/cm²) were detected.

The antimicrobial effects of spices and herbs are ascribed to distinct bioactive components, including flavonoids, phenolic acids, lignans, and polymeric tannins (Cueva et al., 2010; Cushnie & Lamb, 2005; Moreno et al., 2006). The antimicrobial activities of these chemicals are achieved by their interaction with the cell membranes of bacteria, which leads to the facilitation of pore formation and subsequent enhancement of membrane permeability. This method has notable efficacy in combating Gram-positive bacteria, specifically targeting LM (Nohynek et al., 2006). Phenolic acids, such as benzoic acid, play a substantial role in the antibacterial properties shown by spices and herbs. The induction of hyper-acidification occurs at the interface of the plasma membrane, resulting in changes to both cell membrane potential and permeability. Furthermore, phenolic acids have an effect on the activity of the Na^+/K^+ ATPase pump, which is an essential element in the process of ATP generation (Vattem et al., 2005).

3.3 ESSENTIAL OILS (EOS)

The study of aromatic plants and their constituents has attracted significant interest in the pursuit of natural agents that may limit bacterial development. The antibacterial effects of these plants have been ascribed to essential oils (EO) and other secondary metabolites present in them(Chouhan et al., 2017; O'Bryan et al., 2015). Essential oils are composed of a diverse array of naturally occurring volatile molecules, obtained from different plant sources including bark, leaves, flowers, and seeds (Nazzaro et al., 2013). The aforementioned substances include terpenes, aldehydes, alcohols, esters, phenolics, ethers, and ketones (Chouhan et al., 2017). It is worth mentioning that EOs exhibit a distinct feature wherein they include two or three primary constituents in significant proportions, although a multitude of additional constituents are present in minimal quantities. As an example, the essential oil derived from origanum mostly consists of carvacrol (30%) and thymol (27%)(Bilia et al., 2021) .

It is important to acknowledge that the effects of essential oils on bacterial species might exhibit variability. Gram-positive bacteria, characterized by their unique cell wall composition, exhibit greater susceptibility to essential oils. Hydrophobic compounds have the ability to easily infiltrate Gram-positive cells, hence exerting their effects on both the cell wall and cytoplasm. In contrast, Gram-negative bacteria often demonstrate heightened resistance to essential oils (Nazzaro et al., 2013; Swamy et al., 2016). The primary factor contributing to the antibacterial effectiveness of EOs is the presence of phenolic chemicals contained within them (Bachir & Benali, 2012). EOs use diverse strategies to impede the proliferation of bacteria, including the impairment of cytoplasmic membranes, the denaturation of proteins, the coagulation of cytoplasm, and the disruption of the proton motive force(Swamy et al., 2016).

A considerable body of research has provided evidence supporting the inhibitory effects of EOs on LM. Ghasemi Pirbalouti et al., 2010 conducted a study to examine the effects of EOs derived from *Thymus daenensis Celak*, *Thymbra spicata*, and *Satureja bachtiarica* on chicken

frankfurters. The results of their study demonstrated a decrease in LM populations when frankfurters were subjected to EO treatment during storage at a temperature of 4°C (Bachir & Benali, 2012). In their study, Vrinda Menon & Garg, 2001 conducted an investigation into the antibacterial properties of clove oil in minced mutton at various temperature conditions. Their findings revealed a noteworthy inhibition of LM development when concentrations of 0.5% and 1% of clove oil were used. In their study, Awaisheh, 2013 provided evidence that Eos ,extracted from fir and qysoom, had inhibitory effects on the growth rates of LM during storage at a temperature of 4°C. This observation was made using a meat luncheon model.

The use of sensory assessment has been of great significance in the evaluation of consumer acceptability in the context of exploring the potential of EO and related chemicals as natural antibacterial additives. Although EOs possess notable antibacterial characteristics, they do have significant constraints when it comes to their use in the food industry.

The limitations arise from the robust organoleptic profile, restricted solubility in water, and vulnerability to degradation (Bodie et al., 2023). In order to address negative sensory impacts, it may be required to use mixtures of EOs that may work together to enhance antimicrobial effectiveness. This approach enables the use of lower quantities of individual compounds.

3.4 Bacteriophages

Bacteriophages, often known as phages, are a distinct category of viruses that possess a remarkable capacity to selectively infect bacterial cells. Every bacteriophage demonstrates selectivity towards a given species, serotype, or strain of bacteria(Petty et al., 2007). These viral organisms have a remarkable presence in the natural world, as they have been extensively detected in a wide range of settings, including soil, water (Petty et al., 2007), and numerous food sources such as meat, dairy, and vegetables (Atterbury et al., 2003; Binetti & Reinheimer, 2000; Hsu et al., 2002) . The clearance for the use of two separate bacteriophage preparations, which include the phages P100 and LMP-102, as dietary components intended to address LM, has been given by the United States dietary and Drug Administration (FDA) (Bodie et al., 2023). The investigation conducted by Guenther et al., 2009 revealed a significant decrease in the populations of LM bacteria by up to five logarithmic units in a range of food items, such as hot dogs, sliced turkey meat, and smoked salmon. Chibeu et al., 2013 revealed equally noteworthy results, demonstrating that the use of LISTEX™P100 resulted in considerable decreases in LM levels during the cold storage of cooked turkey and roast beef. The observed decreases, which equated to nearly a two-log decrease in colony-forming units per square centimeter (CFU/cm2), provide evidence for the effectiveness of therapies using bacteriophages.

Remarkably, the Listeria bacteriophage A511 demonstrated remarkable efficacy against LM, both externally and inside within a vacuum-sealed cooked meat simulation (Ahmadi et al., 2020). Upon direct application to the surface of the meat, the counts of LM decreased to levels that were undetectable, and these counts were consistently lower than the control samples for a prolonged refrigerated storage period

of 20 days. Nevertheless, the efficacy of A511 in lowering pathogenic counts was shown to be less significant when LM was intentionally introduced into the meat (Bodie et al., 2023). The aforementioned results highlight the potential benefits of using multi-hurdle strategies, which include the combination of several antimicrobial treatments with phages, in order to achieve the most effective reduction of LM in various types of meat.

One unique approach is using immobilized phage cocktails on cellulose membranes to address the presence of *Listeria* and *Escherichia coli* in RTE meat products across different storage conditions and packaging styles. The aforementioned methodology presents a more reliable mechanism for controlling the presence of Listeria in packaged goods, while concurrently safeguarding the integrity of non-*Listeria* microbial communities. It is important to acknowledge that the utilization of phages alone may not provide a comprehensive resolution for the control of LM contamination in food. The effectiveness of phages is significantly augmented when they are utilized in conjunction with other anti-listerial agents (Anany et al., 2011).

Further investigation is required in order to fully explore the possibilities of bacteriophages in ready-to-eat beef products. A crucial research target is to identify further anti- bacteriophages that exhibit excellent antimicrobial activity under the specific circumstances often seen in meat processing and sale, particularly refrigeration. Furthermore, it is important to do research on the compatibility between bacteriophages and other antimicrobials, like as essential oils or organic acids, in order to explore their potential for many practical applications. There are many ongoing issues associated with the use of bacteriophages in the context of food. The problems discussed are the selectivity of bacteriophages towards their target species, the possibility of bacterial resistance emergence through time, thorough assessments of phage effects on human health, animal well-being, and environmental factors. In addition, the issue of consumer acceptability regarding phages, whether they are seen as natural creatures or genetically engineered organisms, is a crucial topic that warrants careful consideration (Li et al., 2022; Połaska & Sokołowska, 2019)

3. CONCLUSION

The demand from consumers for RTE meat and poultry products that are convenient, appetizing, and safe has been increasing. Nonetheless, the ongoing vulnerability RTE products to contamination and proliferation of LM continues to be a chronic issue of concern for the well-being of the general population. The food sector is actively seeking novel methods to efficiently address the issue of LM in RTE meat products. The vulnerability mentioned is further exacerbated by the widespread prevalence of LM, the extended durability of RTE meats, and the possibility of customers mishandling or incorrectly storing such items.

The present study provides a detailed examination of recent research discoveries and offers valuable perspectives on the current state of natural anti-listerial chemicals. The use of these biological antimicrobial agents serves as a financially feasible and highly beneficial approach to intervention.

However, it is crucial to continue striving for progress in this ever-evolving area of study. The main goal is to innovate new technologies and implement relevant regulatory protocols to provide the utmost degree of safety in the distribution of RTE goods to customers. With the advent of sophisticated diagnostic techniques, such as 16S rRNA gene sequencing, there exists the ability to not only evaluate the effectiveness of natural antimicrobials against *Listeria*, but also to assess any potential unintended impacts on the wider microbial communities found in RTE meat products during the storage process. Unintended consequences have the potential to influence economic results, specifically in relation to the shelf life of RTE-MPPs. In addition, the use of whole-genome sequencing for the examination of LM populations enables the identification of distinct strain variants and their respective reactions to antimicrobial interventions. With this acquired information, it becomes possible to develop multi-hurdle strategies that exhibit enhanced efficacy and broader applicability to various strains of LM.

In closing, the effort to improve LM control in RTE meat products is a continuous and essential endeavor. The collaboration between academics, food industry experts, and regulatory agencies is crucial in order to meet the changing customer expectations and maintain the convenience and safety of RTE products.

REFERENCES

Abrahale, K., Sousa, S., Albuquerque, G., Padrão, P., & Lunet, N. (2019). Street food research worldwide: a scoping review. Journal of Human Nutrition and Dietetics, 32(2), 152–174. https://doi.org/10.1111/jhn.12604

Ahmadi, H., Barbut, S., Lim, L. T., & Balamurugan, S. (2020). Examination of the Use of Bacteriophage as an Additive and Determining Its Best Application Method to Control Listeria monocytogenes in a Cooked-Meat Model System. Frontiers in Microbiology, 11(May), 1–11. https://doi.org/10.3389/fmicb.2020.00779

Allerberger, F., & Wagner, M. (2010). Listeriosis: A resurgent foodborne infection. Clinical Microbiology and Infection, 16(1), 16–23.

Bilia, A. R., Guccione, C., Isacchi, B., Righeschi, C., Firenzuoli, F., & Bergonzi, M. C. (2021). Retraction: Essential oils loaded in nanosystems: A developing strategy for a successful therapeutic approach (Evidence-Based Complementary and Alternative Medicine (2014) 2014 (651593) DOI: 10.1155/2014/651593). Evidence-Based Complementary and Alternative Medicine, 2021(2), 2088–2097.

Binetti, A. G., & Reinheimer, J. A. (2000). Thermal and chemical inactivation of indigenous Streptococcus thermophilus bacteriophages isolated from Argentinian dairy plants. Journal of Food Protection, 63(4), 509–515. https://doi.org/10.4315/0362-028X-63.4.509

Blackman, I. C., & Frank, J. F. (1996). Growth of Listeria monocytogenes as a biofilm on various food- processing surfaces. Journal of Food Protection, 59(8), 827–831. https://doi.org/10.4315/0362-028X-59.8.827

Bodie, A. R., O'Bryan, C. A., Olson, E. G., & Ricke, S. C. (2023). Natural Antimicrobials for Listeria monocytogenes in Ready-to-Eat Meats: Current Challenges and Future Prospects. Microorganisms, 11(5), 1–16. https://doi.org/10.3390/microorganisms11051301

Buchanan, R. L., Gorris, L. G. M., Hayman, M. M., Jackson, T. C., & Whiting, R. C. (2017). A review of Listeria monocytogenes: An update on outbreaks, virulence, dose-response, ecology, and risk assessments. Food Control, 75, 1–13. https://doi.org/10.1016/j.foodcont.2016.12.016

Burnett-Boothroyd, S. C., & McCarthy, B. J. (2011). Antimicrobial treatments of textiles for hygiene and infection control applications: an industrial perspective. Textiles for Hygiene and Infection Control, 196209.https://doi.org/10.1533/9780857093707.3.196

Cartwright, E. J., Jackson, K. A., Johnson, S. D., Graves, L. M., Silk, B. J., & Mahon, B. E. (2013). Listeriosis outbreaks and associated food vehicles, United States, 1998-2008. Emerging Infectious Diseases, 19(1), 1–9. https://doi.org/10.3201/eid1901.120393

Chibeu, A., Agius, L., Gao, A., Sabour, P. M., Kropinski, A. M., & Balamurugan, S. (2013). Efficacy of bacteriophage LISTEXTMP100 combined with chemical antimicrobials in reducing Listeria monocytogenes in cooked turkey and roast beef. International Journal of Food Microbiology, 167(2), 208–214. https://doi.org/10.1016/j.ijfoodmicro.2013.08.018

Chikindas, M. L., Garcia-Garcera, M. J., Driessen, A. J. M., Ledeboer, A. M., Nissen- Meyer, J., Nes, I.

F., Abee, T., Konings, W. N., & Venema, G. (1993). Pediocin PA-1, a bacteriocin from Pediococcus acidilactici PAC1.0, forms hydrophilic pores in the cytoplasmic membrane of target cells. Applied and Environmental Microbiology, 59(11), 3577–3584.https://doi.org/10.1128/aem.59.11.35 77-3584.1993

Chouhan, S., Sharma, K., & Guleria, S. (2017). Antimicrobial Activity of Some Essential Oils—Present Status and Future Perspectives. Medicines, 4(3), 58. https://doi.org/10.3390/medicines4030058

Christensen, D. P., & Hutkins, R. W. (1992). Collapse of the proton motive force in Listeria monocytogenes caused by a bacteriocin produced by Pediococcus acidilactici. Applied and Environmental Microbiology, 58(10), 3312–3315. https://doi.org/10.1128/aem.58.10.3312-3315.1992

COMA, V. (2008). Bioactive packaging technologies for extended shelf life of meat-based products. Meat Science, 78(1–2), 90–103. https://doi.org/10.1016/j.meatsci.2007.07.035

Cressy, H. K., Jerrett, A. R., Osborne, C. M., & Bremer, P. J. (2003). A novel method for the reduction of numbers of Listeria monocytogenes cells by freezing in combination with an essential oil in bacteriological media. Journal of Food Protection, 66(3), 390–395. https://doi.org/10.4315/0362-028X-66.3.390

Cueva, C., Moreno-Arribas, M. V., Martín-Álvarez, P. J., Bills, G., Vicente, M. F., Basilio, A., Rivas, C. L., Requena, T., Rodríguez, J. M., & Bartolomé, B. (2010). Antimicrobial activity of phenolic acids against commensal, probiotic and pathogenic bacteria. Research in Microbiology, 161(5), 372–382. https://doi.org/10.1016/j.resmic.2010.04.006

Cushnie, T. P. T., & Lamb, A. J. (2005). Antimicrobial activity of flavonoids. International Journal of Antimicrobial Agents, 26(5), 343–356. https://doi.org/10.1016/j.ijantimicag.2005.09.002

Darbandi, A., Asadi, A., Mahdizade Ari, M., Ohadi, E., Talebi, M., Halaj Zadeh, M., Darb Emamie, A., Ghanavati, R., & Kakanj, M. (2022). Bacteriocins: Properties and potential use as antimicrobials. Journal of Clinical Laboratory Analysis, 36(1). https://doi.org/10.1002/jcla.24093

de Arauz, L. J., Jozala, A. F., Mazzola, P. G., & Vessoni Penna, T. C. (2009). Nisin biotechnological production and application: a review. Trends in Food Science and Technology, 20(3–4), 146–154.
https://doi.org/10.1016/j.tifs.2009.01.056

Demel, R. A., Peelen, T., Siezen, R. J., De Kruijff, B., & Kuipers, O. P. (1996). Nisin Z, mutant nisin Z and lacticin 481 interactions with anionic lipids correlate with antimicrobial activity: A monolayer study. European Journal of Biochemistry, 235(1–2), 267–274. https://doi.org/10.1111/j.1432-1033.1996.00267.x

den Bakker, H. C., Warchocki, S., Wright, E. M., Allred, A. F., Ahlstrom, C., Manuel, C. S., Stasiewicz, M. J., Burrell, A., Roof, S., Strawn, L. K., Fortes, E., Nightingale, K. K., Kephart, D., & Wiedmann, M. (2014). Listeria floridensis sp. nov., Listeria aquatica sp. nov., Listeria cornellensis sp. nov., Listeria riparia sp. nov. and Listeria grandensis sp. nov., from agricultural and natural environments. International Journal of Systematic and Evolutionary Microbiology, 64(PART 6), 1882–1889.https://doi.org/10.1099/ijs.0.052720-0

Desai, A. N., Anyoha, A., Madoff, L. C., & Lassmann, B. (2019). Changing epidemiology of Listeria monocytogenes outbreaks, sporadic cases, and recalls globally: A review of ProMED reports from 1996 to 2018. International Journal of Infectious Diseases, 84, 48–53. https://doi.org/10.1016/j.ijid.2019.04.021

Dhama, K., Karthik, K., Tiwari, R., Shabbir, M. Z., Barbuddhe, S., Malik, S. V. S., & Singh, R. K. (2015). Listeriosis in animals, its public health significance (food-borne zoonosis) and advances in diagnosis and control: a comprehensive review. Veterinary Quarterly, 35(4), 211–235.https://doi.org/10.1080/01652176.2015.1063023

Di Bonaventura, G., Piccolomini, R., Paludi, D., D'Orio, V., Vergara, A., Conter, M., & Ianieri, A. (2008). Influence of temperature on biofilm formation by Listeria monocytogenes on various food-contact surfaces: Relationship with motility and cell surface hydrophobicity. Journal of Applied Microbiology, 104(6), 1552–1561. https://doi.org/10.1111/j.1365-2672.2007.03688.x

Doijad, S. P., Barbuddhe, S. B., Garg, S., Poharkar, K. V., Kalorey, D. R., Kurkure, N. V., Rawool, D. B., & Chakraborty, T. (2015). Biofilm-forming abilities of listeria monocytogenes serotypes isolated from different sources. PLoS ONE, 10(9), 1–14. https://doi.org/10.1371/journal.pone.0137046

Dortet, L., Radoshevich, L., Veiga, E., & Cossart, P. (2019). Listeria monocytogenes. In Encyclopedia of Microbiology (4th ed., Issue July 2014). Elsevier Inc. https://doi.org/10.1016/B978-0-12-801238-3.02297-2

Gabrielsen, C., Brede, D. A., Hernández, P. E., Nes, I. F., & Diep, D. B. (2012). The maltose ABC transporter in Lactococcus lactis facilitates high-level sensitivity to the circular bacteriocin garvicin ML. Antimicrobial Agents and Chemotherapy, 56(6), 2908–2915. https://doi.org/10.1128/AAC.00314-12

Gao, Y., Li, D., Liu, S., & Zhang, L. (2015). Garviecin LG34, a novel bacteriocin produced by Lactococcus garvieae isolated from traditional Chinese fermented cucumber. Food Control, 50, 896–900. https://doi.org/10.1016/j.foodcont.2014.10.040

Ghasemi Pirbalouti, A., Rahimi, E., & Ali Moosavi, S. (2010). Antimicrobial activity of essential oils of three herbs against Listeria monocytogenes on chicken frankfurters. Acta Agriculturae Slovenica, 95(3), 219–223. https://doi.org/10.2478/v10014-010-0013-1

Gravesen, A., Ramnath, M., Rechinger, K. B., Andersen, N., Jänsch, L., Héchard, Y., Hastings, J. W., & Knøchel, S. (2002). High-level resistance to class IIa bacteriocins is associated with one general mechanism in Listeria monocytogenes. Microbiology, 148(8), 2361–2369. https://doi.org/10.1099/00221287-148-8-2361

Guenther, S., Huwyler, D., Richard, S., & Loessner, M. J. (2009). Virulent bacteriophage for efficient biocontrol of listeria monocytogenes in ready-to-eat foods. Applied and Environmental Microbiology, 75(1), 93–100. https://doi.org/10.1128/AEM.01711-08

Hanning, I. B., Johnson, M. G., & Ricke, S. C. (2008). Precut prepackaged lettuce: A risk for listeriosis? Foodborne Pathogens and Disease, 5(6), 731–746. https://doi.org/10.1089/fpd.2008.0142

Heredia, N., & García, S. (2018). Animals as sources of food-borne pathogens: A review. Animal Nutrition, 4(3), 250–255. https://doi.org/10.1016/j.aninu.2018.04.006

Hernandez-Milian, A., & Payeras-Cifre, A. (2014). What is new in Listeriosis? BioMed Research International, 2014. https://doi.org/10.1155/2014/358051

Hoffmann, S., Maculloch, B., & Batz, M. (2015). Economic burden of major foodborne illnesses acquired in the United States. Economic Cost of Foodborne Illnesses in the United States, 140, 1–74.

Hsu, F. C., Shieh, Y. C. C., & Sobsey, M. D. (2002). Enteric bacteriophages as potential fecal indicators in ground beef and poultry meat. Journal of Food Protection, 65(1), 93–99. https://doi.org/10.4315/0362-028X-65.1.93

Jacquet, C., Catimel, B., Brosch, R., Buchrieser, C., Dehaumont, P., Goulet, V., Lepoutre, A., Veit, P., & Rocourt, J. (1995). Investigations related to the epidemic strain involved in the French listeriosis outbreak in 1992. Applied and Environmental Microbiology, 61(6), 2242–2246. https://doi.org/10.1128/aem.61.6.2242-2246.1995

Jayasena, D. D., & Jo, C. (2013). Essential oils as potential antimicrobial agents in meat and meat products: A review. Trends in Food Science and Technology, 34(2), 96–108.

https://doi.org/10.1016/j.tifs.2013.09.002

Ji, J., Shankar, S., Royon, F., Salmieri, S., & Lacroix, M. (2023). Essential oils as natural antimicrobials applied in meat and meat products—a review. Critical Reviews in Food Science and Nutrition, 63(8), 993–1009.
https://doi.org/10.1080/10408398.2021.1957766

Kaveh, S., Hashemi, S. M. B., Abedi, E., Amiri, M. J., & Conte, F. L. (2023). Bio-Preservation of Meat and Fermented Meat Products by Lactic Acid Bacteria Strains and Their Antibacterial Metabolites. Sustainability (Switzerland), 15(13), 1–17. https://doi.org/10.3390/su151310154

Lahiri, D., Nag, M., Dutta, B., Sarkar, T., Pati, S., Basu, D., Abdul Kari, Z., Wei, L. S., Smaoui, S., Wen Goh, K., & Ray, R. R. (2022). Bacteriocin: A natural approach for food safety and food security. Frontiers in Bioengineering and Biotechnology, 10(October), 1–19. https://doi.org/10.3389/fbioe.2022.1005918

Li, J., Zhao, F., Zhan, W., Li, Z., Zou, L., & Zhao, Q. (2022). Challenges for the application of bacteriophages as effective antibacterial agents in the food industry. Journal of the Science of Food and Agriculture, 102(2), 461–471. https://doi.org/10.1002/jsfa.11505

Liu, G., Ren, L., Song, Z., Wang, C., & Sun, B. (2015). Purification and characteristics of bifidocin A, a novel bacteriocin produced by Bifidobacterium animals BB04 from centenarians' intestine. Food Control, 50, 889–895.
https://doi.org/10.1016/j.foodcont.2014.10.049

Meloni, D. (2015). Presence of listeria monocytogenes in mediterranean-style dry fermented sausages. Foods, 4(1), 34–50. https://doi.org/10.3390/foods4010034

Mie, A., Andersen, H. R., Gunnarsson, S., Kahl, J., Kesse-Guyot, E., Rembiałkowska, E., Quaglio, G., & Grandjean, P. (2017). Human health implications of organic food and organic agriculture: A comprehensive review. Environmental Health: A Global Access Science Source, 16(1), 1–22. https://doi.org/10.1186/s12940-017-0315-4

Moll, G. N., Konings, W. N., & Driessen, A. J. M. (1999). Bacteriocins: Mechanism of membrane insertion and pore formation. Antonie van Leeuwenhoek, International Journal of General and Molecular Microbiology, 76(1–4), 185–198. https://doi.org/10.1023/A:1002002718501

Moreno, S., Scheyer, T., Romano, C. S., & Vojnov, A. A. (2006). Antioxidant and antimicrobial activities of rosemary extracts linked to their polyphenol composition. Free Radical Research, 40(2), 223–231. https://doi.org/10.1080/10715760500473834

Mytle, N., Anderson, G. L., Doyle, M. P., & Smith, M. A. (2006). Antimicrobial activity of clove (Syzgium aromaticum) oil in inhibiting Listeria monocytogenes on chicken frankfurters. Food Control, 17(2), 102–107. https://doi.org/10.1016/j.foodcont.2004.09.008

Nazzaro, F., Fratianni, F., De Martino, L., Coppola, R., & De Feo, V. (2013). Effect of essential oils on pathogenic bacteria. Pharmaceuticals, 6(12), 1451–1474. https://doi.org/10.3390/ph6121451

Nohynek, L. J., Alakomi, H. L., Kähkönen, M. P., Heinonen, M., Helander, I. M., Oksman-Caldentey, K. M., & Puupponen-Pimiä, R. H. (2006). Berry phenolics: Antimicrobial properties and mechanisms of action against severe human pathogens. Nutrition and Cancer, 54(1), 18–32. https://doi.org/10.1207/s15327914nc5401_4

O'Bryan, C. A., Pendleton, S. J., Crandall, P. G., & Ricke, S. C. (2015). Potential of plant essential oils and their components in animal agriculture - in vitro studies on antibacterial mode of action. Frontiers in Veterinary Science, 2(SEP), 1–8. https://doi.org/10.3389/fvets.2015.00035

Orsi, R. H., & Wiedmann, M. (2016). Characteristics and distribution of Listeria spp., including Listeria species newly described since 2009. Applied Microbiology and Biotechnology, 100(12), 5273–5287. https://doi.org/10.1007/s00253-016-7552-2

Pateiro, M., Munekata, P. E. S., Sant'Ana, A. S., Domínguez, R., Rodríguez-Lázaro, D., & Lorenzo, J. M. (2021). Application of essential oils as antimicrobial agents against spoilage and pathogenic microorganisms in meat products. International Journal of Food Microbiology, 337, 108966. https://doi.org/10.1016/j.ijfoodmicro.2020.108966

Perez, R. H., Zendo, T., & Sonomoto, K. (2014). Novel bacteriocins from lactic acid bacteria (LAB): Various structures and applications. Microbial Cell Factories, 13(Suppl 1), 1–13. https://doi.org/10.1186/1475-2859-13-S1-S3

Petty, N. K., Evans, T. J., Fineran, P. C., & Salmond, G. P. C. (2007). Biotechnological exploitation of bacteriophage research. Trends in Biotechnology, 25(1), 7–15. https://doi.org/10.1016/j.tibtech.2006.11.003

Połaska, M., & Sokołowska, B. (2019). Review bacteriophages—a new hope or a huge problem in the food industry. AIMS Microbiology, 5(4), 324–347. https://doi.org/10.3934/microbiol.2019.4.324

Poti, J. M., Mendez, M. A., Ng, S. W., & Popkin, B. M. (2015). Is the degree of food processing and convenience linked with the nutritional quality of foods purchased by US households? American Journal of Clinical Nutrition, 101(6), 1251–1262. https://doi.org/10.3945/ajcn.114.100925

Ramaswamy, V., Cresence, V. M., Rejitha, J. S., Lekshmi, M. U., Dharsana, K. S., Prasad, S. P., & Vijila, H. M. (2007). Listeria - Review of epidemiology and pathogenesis. Journal of Microbiology, Immunology and Infection, 40(1), 4–13.

Rashid, R., Veleba, M., & Kline, K. A. (2016). Focal targeting of the bacterial envelope by antimicrobial peptides. Frontiers in Cell and Developmental Biology, 4(JUN), 1–13. https://doi.org/10.3389/fcell.2016.00055

Reis, J. A., Paula, A. T., Casarotti, S. N., & Penna, A. L. B. (2012). Lactic Acid Bacteria Antimicrobial Compounds: Characteristics and Applications. Food Engineering Reviews, 4(2), 124–140. https://doi.org/10.1007/s12393-012-9051-2

Ríos Colombo, N. S., Chalón, M. C., Navarro, S. A., & Bellomio, A. (2018). Pediocin-like bacteriocins: new perspectives on mechanism of action and immunity. Current Genetics, 64(2), 345–351. https://doi.org/10.1007/s00294-017-0757-9

Ruiz, A., Williams, S. K., Djeri, N., Hinton, A., & Rodrick, G. E. (2010). Nisin affects the growth of Listeria monocytogenes on ready-to-eat turkey ham stored at four degrees Celsius for sixty-three days. Poultry Science, 89(2), 353–358. https://doi.org/10.3382/ps.2008-00503

Shahnawaz, M., & Soto, C. (2012). Microcin amyloid fibrils A are reservoir of toxic oligomeric species. Journal of Biological Chemistry, 287(15), 11665–11676. https://doi.org/10.1074/jbc.M111.282533

Sirsat, S. A., Muthaiyan, A., & Ricke, S. C. (2009). Antimicrobials for foodborne pathogen reduction in organic and natural poultry production. Journal of Applied Poultry Research, 18(2), 379–388. https://doi.org/10.3382/japr.2008-00140

Summary, E., Meats, P. D., & Service, I. (2010). FSIS Comparative Risk Assessment for Listeria monocytogenes in Ready-to- eat Meat and Poultry Deli Meats Report FSIS Comparative Risk Assessment for Listeria monocytogenes in Ready-to- eat Meat and Poultry Deli Meats Report. May, 1–2.

Šušković, J., Kos, B., Beganović, J., Pavunc, A. L., Habjanič, K., & Matoć, S. (2010). Antimicrobial activity - The most important property of probiotic and starter lactic acid bacteria. Food Technology and Biotechnology, 48(3), 296–307.

Swaminathan, B., & Gerner-Smidt, P. (2007). The epidemiology of human listeriosis. Microbes and Infection, 9(10), 1236–1243. https://doi.org/10.1016/j.micinf.2007.05.011

Swamy, M. K., Akhtar, M. S., & Sinniah, U. R. (2016). Antimicrobial properties of plant essential oils against human pathogens and their mode of action: An updated review. Evidence-Based Complementary and Alternative Medicine, 2016. https://doi.org/10.1155/2016/3012462

Tack, D. M., Marder, E. P., Griffin, P. M., Cieslak, P. R., Dunn, J., Hurd, S., Scallan, E., Lathrop, S., Muse, A., Ryan, P., Smith, K., Tobin-D'Angelo, M., Vugia, D. J., Holt, K. G., Wolpert, B. J., Tauxe, R., & Geissler, A. L. (2019). Preliminary incidence and trends of infections with pathogens transmitted commonly through food — Foodborne Diseases Active Surveillance Network, 10 U.S. sites, 2015–2018. American Journal of Transplantation, 19(6), 1859–1863. https://doi.org/10.1111/ajt.15412

Tadele, Y., Profile, S. E. E., Cogan, T. A., Slader, J., Bloomfield, S. F., Humphrey, T. J., R.H.O., Sandilands, V., Hocking, P. M., Pradeep, M. A., Sharma, S. R. K., Bohl, J. L., Zakhem, E., Bitar,

K. N., DVS, Herolzer, R., Patent, U. S., Chambers, J. R., Zaheer, K., … Chouchane, H. (2017). Vaccination Procedure Guide COBB COntents. Egg Innovations and Strategies for Improvements, 85(4), 73–84. http://dx.doi.org/10.1016/j.ecolind.2017.02.022%0Ahttps://doi.org/10.1016/j.jclepro.2018.02.274%0Ahttp://dx.doi.org/10.1016/B978-1-78242-275-4.00012-5%0Ahttp://dx.doi.org/10.1016/B978-0-444-52707-3.50008-2%0Ahttps://osha.europa.eu/sites/default/files/publ

Thomas, J., Govender, N., McCarthy, K. M., Erasmus, L. K., Doyle, T. J., Allam, M., Ismail, A., Ramalwa, N., Sekwadi, P., Ntshoe, G., Shonhiwa, A., Essel, V., Tau, N., Smouse, S., Ngomane, H. M., Disenyeng, B., Page, N. A., Govender, N. P., Duse, A. G., … Blumberg, L. H. (2020). Outbreak of Listeriosis in South Africa Associated with Processed Meat. New England Journal of Medicine, 382(7), 632–643.

https://doi.org/10.1056/nejmoa1907462

Todd, L. (2015). Accepted manuscript Development Accepted manuscript. June.

Van Kraaij, C., Breukink, E., Noordermeer, M. A., Demel, R. A., Siezen, R. J., Kuipers, O. P., & De Kruijff, B. (1998). Pore formation by nisin involves translocation of its C-terminal part across the membrane. Biochemistry, 37(46), 16033–16040. https://doi.org/10.1021/bi980931b

Vattem, D. A., Lin, Y. T., Ghaedian, R., & Shetty, K. (2005). Cranberry synergies for dietary management of Helicobacter pylori infections. Process Biochemistry, 40(5), 1583–1592. https://doi.org/10.1016/j.procbio.2004.06.024

Vrinda Menon, K., & Garg, S. R. (2001). Inhibitory effect of clove oil on Listeria monocytogenes in meat and cheese. Food Microbiology, 18(6), 647–650. https://doi.org/10.1006/fmic.2001.0430

Wang, Y., Qin, Y., Zhang, Y., Wu, R., & Li, P. (2019). Antibacterial mechanism of plantaricin LPL-1, a novel class IIa bacteriocin against Listeria monocytogenes. Food Control, 97, 87–93. https://doi.org/10.1016/j.foodcont.2018.10.025

Yang, S. C., Lin, C. H., Sung, C. T., & Fang, J. Y. (2014). Antibacterial activities of bacteriocins: Application in foods and pharmaceuticals. Frontiers in Microbiology, 5(MAY), 1–10. https://doi.org/10.3389/fmicb.2014.00241

Zhang, H., Kong, B., Xiong, Y. L., & Sun, X. (2009). Antimicrobial activities of spice extracts against pathogenic and spoilage bacteria in modified atmosphere packaged fresh pork and vacuum packaged ham slices stored at 4 °C. Meat Science, 81(4), 686–692. https://doi.org/10.1016/j.meatsci.2008.11.011

Advances of Molecular Diagnosis for the Detection of Human Leishmaniasis in Sri Lanka

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ABSTRACT

Human leishmaniasis is one of the neglected tropical parasitic diseases. Sri Lanka reports a large focus of cutaneous leishmaniasis (CL) caused by Leishmania donovani which is usually the cause for fatal visceral leishmaniasis (VL). Few cases of VL and mucosal leishmaniasis (MCL) have also been detected recently within the country. Therefore, an enhanced case detection, early treatment, and understanding of sequalae of the infection are required to contain the spread of this new clinical entity. This study aimed at identifying currently available molecular diagnostic tools for leishmaniasis in Sri Lanka and recent advances of the field. Usefulness of the *parasitological diagnostic methods, i.e., light microscopy and in vitro culture in case detection is limited in chronic, atypical or treated lesions. However, timely and accurate investigation of all light microscopy, in vitro culture negative cases for all forms of leishmaniasis is preferred prior to treatment. Molecular detection of leishmaniasis using polymerase chain reaction (PCR) is the most sensitive method used currently for diagnosis of leishmaniasis. Conventional single-step PCR, quantitative real-time PCR, nested PCR and PCR-restriction fragment length polymorphism (PCR-RFLP) are widely used to detect different genetic sequences of Leishmania such as kinetoplastid DNA, small subunit ribosomal RNA and internal transcribed spacer region. Also low sensitive loop-mediated isothermal amplification (LAMP) has been tested locally by several research groups. Although several PCR techniques are used for diagnosis of leishmaniasis in different local settings, recently developed nested PCR methods are useful in detecting leishmaniasis with high accuracy in the minority of cases that go undetected by first line investigations. Future research activities focus on further development of molecular detection of leishmaniasis in Sri Lanka by using an advanced technique, multiplex LAMP test and validating a new diagnostic kit.*

Keywords - LAMP, Leishmaniasis, Diagnosis

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1. INTRODUCTION

Leishmaniasis is a neglected, zoonotic parasitic disease caused by parasites of the genus Leishmania. There are more than 20 different types of Leishmania species affect for infection in humans (Dedet and Pratlong, 2002). Leishmania parasite is related to the kingdom Protista, the order Kinetoplastida, the family Trypanosomatidae, and the genus Leishmania (Akhoundi et al., 2016). Now it is a globally important disease that is found in parts of the tropics, subtropics, and southern Europe. Leishmaniasis has recently been categorized in to the group of neglected tropical diseases (NTD) by World Health Organization (WHO) which is especially common in low-income populations in developing regions of Africa, Asia and America (WHO, 2010).

Species of genus *Leishmania* causes multifactorial based three main clinical forms [i.e., visceral leishmaniasis (also known as kala-azar, VL), cutaneous leishmaniasis (CL), and muco-cutaneous leishmaniasis (MCL)]. Resultant type of immunity is known to be species dependant (Chang et al., 2002). All three forms of the disease are associated with great morbidity and also with mortality in case of VL and MCL (Dedet and Pratlong, 2002). Skin lesions of CL usually occur at the site of sandfly bite while MCL and VL occur as metastatic sequelae of initial skin inoculations on mucosal tissue (i.e., skin, mouth or nose) and viscera (i.e., enlarged liver/spleen) respectively.

*Leishmania*sis spreads across 98 countries in Europe, Africa, Asia, and America *(*Alvar et al., 2012). However, over 90% of new cases occur in Afghanistan, Algeria, Bangladesh, Bolivia, Brazil, Columbia, Ethiopia, India, Iran, Peru, South Sudan, Sudan, and Syria. There are about 0.9 to 1.7 million people newly infected every year and 20,000–30,000 deaths occur annually (WHO, 2016). Bangladesh, Brazil, Ethiopia, India, South Sudan, and Sudan record over 90% of VL cases while more than 70% of CL cases occurred in Afghanistan, Algeria, Brazil, Colombia, Costa Rica, Ethiopia, the Islamic Republic of Iran, Peru, Saudi Arabia, and the Syrian Arab Republic (WHO, 2010). Almost 90% of MCL cases occur in the Plurinational State of Bolivia, Brazil, and Peru (WHO, 2010).

Sri Lanka is a new focus of human leishmaniasis in the South-Asian region. First autochthonous case of CL was reported from Ambalantota, Southern Sri Lanka in 1992 (Athukorale et al., 1992). Since year 2001 local cases of leishmaniasis are being continuously reported and leishmaniasis is an established parasitic disease in Sri Lanka at present.

Interestingly, *Leishmania donovani*, the usually visceralizing species is caused for CL in Sri Lanka. Strains of *L. donovani* from Sri Lanka were typed as zymodeme MON-37 by multilocus enzyme electrophoresis (MLEE) (Karunaweera et al., 2003). This finding was further confirmed by true genetic based gene sequencing and microsatellite loci studies (Siriwardana et al., 2007).

Conventional parasitological methods, i.e., light microscopy (LM), *in vitro* culturing (IVC) and molecular method, i.e., PCR on lesion materials (slit-skin scrapings or lesion aspirates), splenic and bone marrow aspirates are usually used for diagnosis of local leishmaniasis (Ihalamulla et al., 2008; Deepachandi et al., 2019). Confirmation of the disease is important since non-pathognomonic symptoms of leishmaniasis, expensive treatments, and significant toxicity of drugs. It is therefore crucial to have tools that enable prompt definitive diagnosis of leishmaniasis in endemic areas to initiate appropriate treatments and better patient management.

Therefore, this study aimed at identifying molecular diagnostic methods of leishmaniasis in Sri Lanka and recent advances of the field.

2. MOLECULAR METHODS USED IN LEISHMANISIS ENDEMIC SETTINGS OF THE WORLD

PCR is the most widely used molecular method for diagnosis of leishmaniasis. Molecular detection of *Leishmania* using PCR is the most sensitive method to date albeit it requires experts to handle, extremely expensive, complex, and cannot be performed in the field (Reithinger and Dujardin, 2007; Szargiki et al., 2009; Sundar and Rai, 2002). The specificity of the PCR can be adapted to specific needs by targeting conserved region of the gene. Different PCR methods have been used as a diagnostic tool for leishmaniasis which involved different genetic targets and primer sequences designed against full or partial *Leishmania* genome of relevance. Among them conventional single-step PCR, real-time PCR, nested PCR, and PCR-RFLP are widely used techniques which are designed for targeting different genetic sequences of *Leishmania*, e.g., 18s-rRNA (ribosomal ribonucleic acid), small subunit ribosomal RNA (SSU rRNA), a repetitive genomic sequence of DNA (deoxyribonucleic acid), miniexon (spliced ladder) gene repeat, β-tubulin gene region, gp63 gene locus, internal transcribed spacer (ITS) regions, and micro-satellite DNAs (e.g., maxi- and minicircles of kinetoplast DNA) (Salam et al., 2010; Yehia et al., 2012; Toz et al., 2013; Hossain et al., 2017; Mohammadiha et al., 2017; Leon et al., 2017; Galluzzi et al., 2018; Teimouri et al., 2018).

3. MOLECULAR METHODS ESTABLISHED IN LOCAL SETTING

Different PCR protocols and loop-mediated isothermal amplification (LAMP) have been tested locally (Kothalawala and Karunaweera, 2016; Ranasinghe et al., 2015). LAMP is a relatively less complex method that is cost-effective and requires a lower performance time (Kothalawala and Karunaweera, 2016). However, the low sensitivity rate of LAMP limits its use as a diagnostic tool.

Furthermore, *Leishmania* genus-specific kDNA (kinetoplast DNA) and ITS1 PCR assays have demonstrated 92% sensitivity, while the sensitivity level of *L. donovani* species-specific kDNA assay is only 71% in local settings (Ranasinghe et al., 2015).

4. RECENT ADVANCES IN MOLECULAR DIAGNOSTIC METHODS OF LEISHMANIASIS IN SRI LANKA

Recently established modified single-tube nested PCR (Mo-STNPCR) produced a highly sensitive diagnostic assay to detect leishmaniasis while enabling exclusion of *Crithidia* spp. and *Leptomonas* spp. which are non-leishmanial pathogens that can complicate detection of *Leishmania* spp. in IVCs as well as in some widely used CPCR methods (Lachaud et al., 2002; Deepachandi et al., 2019). Results showed high sensitivity, specificity and therefore a high accuracy for diagnosis of leishmaniasis (Deepachandi et al., 2019). New Mo-STNPCR test can easily replace conventional PCR with better results and may be used as a useful second line assay for detection of all LM and IVC negative leishmaniasis cases in Sri Lanka and other leishmaniasis endemic settings.

5. FUTURE PERSPECTIVES

The use of advanced LAMP techniques in *Leishmania* detection offers distinct advantages over traditional PCR practices, particularly in discerning endemic variations among different *Leishmania* species (Duthie et al., 2018; Bualert et al 2015).

LAMP utilizes multiple primers to target several regions within the DNA sequence of interest. This multi-primer design significantly enhances the specificity of LAMP, reducing the chances of cross-reactivity with closely related species,

which can be a challenge with traditional PCR methods. Also, LAMP operates under isothermal conditions, which means it amplifies DNA rapidly at a constant temperature (Verma et al., 2013; Dikhit et al., 2012).

In contrast, traditional PCR involves temperature cycling, making it a more time-consuming process (Teoh et al., 2015). LAMP's quick turnaround time is advantageous in detecting *Leishmania* species promptly, allowing for earlier diagnosis and treatment initiation (Verma et al., 2013; Dikhit et al., 2012). Moreover, LAMP is less prone to inhibitors present in complex biological samples, making it robust and reliable even in resource-limited settings where the quality of extracted DNA may not be optimal. This feature is particularly relevant in endemic regions where diagnostic facilities may be limited. Advanced LAMP methods can incorporate multiplexing, allowing the simultaneous detection of different *Leishmania* species and strains in a single reaction. This is particularly valuable for assessing endemic variations and co-infections in *Leishmania*-endemic regions. Advanced LAMP techniques offer a highly sensitive, specific, and rapid approach for *Leishmania* detection, making them well-suited for discerning endemic variations among *Leishmania* species. The combination of these advantages positions LAMP as a valuable tool in understanding and managing *Leishmania* infections in diverse geographic regions.

REFERENCES

Akhoundi, M., Kuhls, K., Cannet, A. et al. (2016). A historical overview of the classification, evolution,
and dispersion of *Leishmania* parasites and sandflies. *PLOS Neglected Tropical Diseases*, 10(3), e0004349.

Alvar, J., Velez, I.D., Bern, C., et al. (2012). *Leishmania*sis worldwide and global estimates of its incidence. *PLoS One*, 7(5), e35671.

Athukorale, D.N., Seneviratne, J.K., Ihalamulla, R.L., Premaratne, U.N. (1992). Locally acquired cutaneous leishmaniasis in Sri Lanka. *Journal of Tropical Medicine and Hygiene*, 95(6), 432-3.

Bualert L., Charungkiattikul W., Thongsuksai P., Mungthin M., and Siripattanapipong S. (2015). *Leishmania*sis Tropica: The Role of PCR in the Detection of *Leishmania* Donovani in Domestic Dogs (Canis familiaris). Experimental Parasitology, 154, 73-80.

Chang, K.P., McGwire, B.S. (2002). Molecular determinants and regulation of *Leishmania* virulence. *Kinetoplastid Biology and Disease*, 1(1).

Dedet, J.P., Pratlong, F. (2002). *Leishmania*sis. In: Cook G and Zumala A, eds. Manson's tropical diseases, 21st edition, 1339-64.

Deepachandi, B., Weerasinghe, S., Soysa, P., Karunaweera, N., Siriwardana, Y. (2019). A highly sensitive modified nested PCR to enhance case detection in leishmaniasis. *BMC Infectious Diseases*, 19, 623.

Dikhit M.R., Kumar A., Das S., Dehury B., Parida P.K. (2012). Development and evaluation of loop-mediated isothermal amplification assay for detection of *Leishmania* donovani infection. Diagnostic Microbiology and Infectious Disease, 74(2), 151-157.

Duthie M.S., Reed S.J., Piazza F.M., Bull N.C., Marovich M.A., Sundaresh P.S., et al. (2018). Development and pre-clinical analysis of a LAMP-based assay for the detection of *Leishmania* parasites in clinical samples. PLoS Negl Trop Dis, 12(3), e0006205.

Galluzzi, L., Ceccarelli, M., Diotallevi, A., Menotta, M., Magnani, M. (2018). Real-time PCR applications for diagnosis of leishmaniasis. *Parasites & Vectors*, 11, Article no 273.

Hossain, F., Ghosh, P., Khan, M.A.A., et al. (2017), Real-time PCR in detection and quantitation of *Leishmania donovani* for the diagnosis of visceral leishmaniasis patients and the monitoring of their response to treatment. *PLoS One*, 12(9), e0185606.

Ihalamulla, R.L., Siriwardana, Y.D., Karunaweera, N.D. (2008). Efficacy of RPMI 1640 and M199 mediain the isolation of *Leishmania* from cutaneous lesions. *Annals of Tropical Medicine and Parasitology*, 102(2), 173-5.

Karunaweera, N.D., Pratlong, F., Siriwardana, H.V.Y.D., Ihalamulla, R.L., Dedet, J.P. (2003). Sri Lankan
cutaneous leishmaniasis is caused by Leishmania donovani zymodeme MON-37. Transactions of

the Royal Society of Tropical Medicine and Hygiene, 97(4), 380-1.

Kothalawala, H.S., Karunaweera, N.D. (2016). Loop-mediated isothermal amplification assay as a sensitive diagnostic tool for *Leishmania donovani* infections in Sri Lanka. *Ceylon Medical Journal*, 61(2), 68-70.

Lachaud, L., Marchergui-Hammami, S., Chabbert, E., Dereure, J., Dedet, J.P., Bastien, P. (2002). Comparison of six PCR methods using peripheral blood for detection of canine visceral leishmaniasis. *Journal of Clinical Microbiology*, 40(1), 210-5.

Leon, C.M., Munoz, M., Hernandez, C. et al. (2017). Analytical performance of four polymerase chain reaction (PCR) and real time pcr (qPCR) assays for the detection of six *Leishmania* Species DNA in Colombia. *Frontiers in Microbiology*, 8, 1907.

Mohammadiha, A., Dalimi, A., Mahmoodi, M.R., Parian, M., Pirestani, M., Mohebali, M. (2017), The PCR RFLP-based detection and identification of the *Leishmania* species causing human cutaneous leishmaniasis in the Khorasan-Razavi province, Northeast of Iran. *Journal of Arthropod-Borne Diseases*, 11(3), 383-92.

Ranasinghe, S., Wickremasinghe, R., Hulangamuwa, S. et al. (2015). Polymerase chain reaction detection of *Leishmania* DNA in skin biopsy samples in Sri Lanka where the causative agent of cutaneous leishmaniasis is *Leishmania donovani*. *Memorias do Instituto Oswaldo Cruz*, 110(8), 1017-23.

Reithinger, R., Dujardin, J,C. (2007). Molecular diagnosis of leishmaniasis: current status and future applications. *Journal of Clinical Microbiology*, 45(1), 21-5.

Salam, M.A., Mondal, D., Kabir, M., Ekram, A.R.M.S., Haque, R. (2010). PCR for diagnosis and assessment of cure in kala-azar patients in Bangladesh. *Acta Tropica*, 113(1), 52-5.

Siriwardana, H.V.Y.D., Noyes, H.A., Beeching, N.J., Chance, M.L., Karunaweera, N.D., Bates, P.A. (2007).
Leishmania donovani and cutaneous leishmaniasis, Sri Lanka. *Emerging Infectious Diseases*, 13(3), 476-8.

Sundar, S., Rai, M. (2002). Laboratory diagnosis of visceral leishmaniasis. *Clinical and Diagnostic Laboratory Immunology*, 9(5), 951-8.

Szargiki, R., de Castro, E.A., Luz, E., Kowalthuk, W., Machado, A.M., Thomaz-Soccol, V. (2009). Comparison of serological and parasitological methods for cutaneous leishmaniasis diagnosis in the State of Parana, Brazil. Brazilian *Journal of Infectious Diseases*, 13(1), 47-52.

Teimouri, A., Mohebali, M., Kazemirad, E., Hajjaran, H. (2018), Molecular identification of agents of human cutaneous leishmaniasis and canine visceral leishmaniasis in different areas of Iran using internal transcribed spacer 1 PCR-RFLP. *Journal of Arthropod-Borne Diseases*, 12(2), 162-71.

Teoh B.T., Sam S.S., Tan K.K., Danlami M.B., Shu M.H., Johari J., Hooi P.S., Brooks D., Piepenburg O., Nentwich O., Wilder-Smith A., and Franco L. (2015). Early Detection of Dengue Virus by Use of Reverse Transcription–Recombinase Polymerase Amplification. Journal of Clinical Microbiology, 53(3), 830-837.

Toz, S.O., Culha, G., Zeyrek, F.Y., et al. (2013). A realtime ITS1-PCR based method in the diagnosis and species identification of *Leishmania* parasite from human and dog clinical samples in Turkey. *PLOS Neglected Tropical Diseases*, 7(5), e2205.

Verma S., Avishek K., Sharma V., Negi N.S., Ramesh V., Salotra P. (2013). Application of loop-mediated isothermal amplification assay for the sensitive and rapid diagnosis of visceral leishmaniasis and post-kala-azar dermal leishmaniasis. Diagn Microbiol Infect Dis. 75(4), 390-395.

World Health Organization. (2010). Control of the leishmaniasis. Report of a meeting of the WHO expert committee, Technical report series 949. WHO, Geneva. https://apps.who.int/iris/bitstream/handle/10665/44412/WHO_TRS_949_eng.pdf?sequence=1

World Health Organization. *Leishmania*sis. (2016). World Health Organization fact sheet. http://www.who.int/mediacentre/factsheets/fs375/en/

Yehia, L., Adib-Houreih, M., Raslan, W.F., et al. (2012). Molecular diagnosis of cutaneous leishmaniasis and species identification: analysis of 122 biopsies with varied parasite index. *Journal of Cutaneous Pathology*, 39(3), 347-55.

Harnessing Auxin and Cytokinin Signaling Pathways for Enhanced Seedling Growth and Crop Production: Advances, Challenges, and Future Prospects

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Abstract

Growth, development, and response to the surrounding environmental conditions of plants are hugely governed by plant hormones. Among the several plant hormones, auxins and cytokinin play a key role in controlling the development and growth of a plant while also regulating its immunity. Since cytokinin and auxins work together, the ratio between these two hormones affects the growth throughout a plant's lifecycle, from the beginning of seed germination to the growth of roots, leaves, and stems, plant flowering, fruiting, seed development, seed filling, seed dormancy, and ultimately the death of the plant. Though they are naturally occurring in plants, some specific hormones can be made synthetically to improve crop production. In contrast to grown plants, seedlings can be affected largely by the surrounding environmental conditions, such as biotic and abiotic factors. These conditions can be a heavy burden for a newly emerging seedling, which can ultimately result in the death of the plant. At that time, the plant hormones in seedlings interact with different complex networks and pathways to govern the response to developmental and environmental issues, thereby limiting stressful conditions for the seedlings. Through the current review, we focus on the regulatory roles of auxin and cytokinin with respect to the seedling growth and developmental processes of seedlings.

Keywords **- Plant hormones, regulation, auxin, cytokinin, seedlings**

1. INTRODUCTION

Chemical compounds present naturally in plants have a governing role rather than a nutritional role. The chemical compounds that are usually produced at smaller concentrations are identified as plant hormones or phytohormones (Mukherjee et al., 2022). They are also known as plant growth substances or as plant growth regulators (George et al., 2008; Porcel et

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al., 2014). As sessile organisms, plants cannot go away from harmful environments. Plants should have various adaptive mechanisms to withstand and survive these harmful and stressful conditions (Li et al., 2021). At that point, plant hormones play a key role.

Research studies related to plant hormones started at the beginning of the nineteenth century with the identification of auxin, which was the first plant hormone identified (Yamaguchi et al., 2010). Still, there was no exact definition for a plant hormone due to the fact that the chemical compounds found as phytohormones often vary with the definition that is considered. However, plant hormones are types of chemical messengers that can influence the capability of plants to react to their environment. Unlike humans, in plant cells, specific hormone secretion glands cannot be seen. However, there are naturally present chemical compounds that are effectively functioning at very low concentrations (Mukherjee et al., 2022). Mostly, they are synthesized in certain parts of the plant, i.e., roots, shoots, seeds, flowers, etc., and transported to another location where they are acting or functioning (Yamaguchi et al., 2010).

With the evaluation of hormone biosynthesis, transport, signaling pathways, and modes of action in the last two decades, rapid progress has been observed in the plant science and agriculture fields. Research studies conducted in the field of hormone signaling pathways have revealed that rather than acting as a single hormone itself, they interact with different factors and form a network to function well (Vishal and Kumar, 2018).

Although these phytohormones are naturally present in plants, some soil bacteria are also known to produce them. There are hormone receptors in plants that can respond to hormones (Miransari and Smith, 2014). Interestingly, prokaryotes can also use similar molecules, which can act as receptors for hormones. Plant growth-promoting rhizobacteria (PGPR) are a well-known group of bacteria that can be associated with plant hormone production. They secrete various plant hormones such as abscisic acid, Indole-3-acetic acid, gibberellins, cytokinins, and ethylene (Murthy et al., 2021). Azospirillum, Pseudomonas, Bacillus, Enterobacter, Pantoea, Streptomyces, Rhizobium, Alcaligenes,s, and Azotobacter-like bacterial genera are reported through several research studies as bacteria that can produce phytohormones (Mukherjee et al., 2022).

The production and functions of phytohormones are assisted by the various genes and their expression levels in the genome of plant cells. Thereby, the plant's genetic component determines differences in the germination seed and growth of seedlings. Plant hormones can influence physiological activities like growth, differentiation, defense, senescence, and development. The phytohormones, including auxin, cytokinins, abscisic acid, ethylene, and gibberellins, are identified as the key regulators of plants, while auxin and cytokinin are critical in plant growth and development (Liu et al., 2007). They are usually present within the plant

throughout the season at different concentrations, and their presence and activities are different from the other hormones. Further, they act as a switch to the relevant function and are present only at a specific time (Yamaguchi et al., 2010).

The current review focuses on and discusses recent progress on the role of two well-known phytohormones called auxin and cytokinin involved in seedling growth and development processes and how upcoming research in the field of agriculture may use this emerging knowledge to improve the growth of seedlings, ultimately affecting crop production.

2. SEED GERMINATION, EMERGENCE OF SEEDLINGS AND SEEDLING GROWTH

Plant hormones govern different activities of a plant, including seed germination, the emergence of seedlings, and seedling growth (Graeber et al., 2012; Miransari and Smith, 2014). There are some stages of seed that need to be completed before germination, such as food storage in order to supply the necessary nutrients required for germination. Usually, this food storage contains sources of starch, lipids, proteins, and other micronutrients that are needed for the development of embryos through the activation of specific enzymes and signaling pathways. Seed germination is a natural phenomenon in which changes in morphological and physiological attributes result in the activation of the embryo. Once the seeds absorb water, elongation and expansion of the seed embryo take place. Then the rupturing happens, a radicle emerges out of the seed, and with that, the seed germination process is finished (Hermann et al., 2007). Abiotic factors such as light, soil temperature, pH, shading, and soil moisture are well-known factors that affect seed germination. Further, the burial depth of the seeds also influences seed germination and the emergence of seedlings (Kogel et al., 2004). A large number of studies have been conducted and evaluated on the plant hormones involved in seed germination and their impact on germination using different plant families (Hermann et al., 2007; Muller et al., 2006). Controlling seedling growth occurs with the support of plant growth regulators at the cellular level. Those derivative cells start the process of vacuolation and enlargement with the disappearance of the meristem region (Miransari and Smith, 2014).

Auxin

Primarily auxins are produced in the areas that are experiencing rapid growth such as developing seeds, developing flowers, young leaves, and shoot tips.

Synthesis of auxins

IAA is the most active auxin present in plants. The biosynthesis of auxin usually happens through two major pathways: the tryptophan-dependent pathway and the tryptophan-independent pathway. Indole-3-acetic acid (IAA) is produced from L-tryptophan through indole-3-pyruvate using flavin-containing mono-oxygenases tryptophan aminotransferases (Jiang and Asami, 2018). Further to this, β-oxidation of indole-3-butyric acid, indole-3-acetamide, hydrolyzing IAA conjugates, tryptamine, and indole-3-acetaldoxime pathways are also known as tryptophan-dependent IAA synthesis pathways and have been explained in several research

studies. Not only the plants, but a few bacteria are also able to produce IAA through indole-3-acetamide, indole-3-pyruvate, and indole-3-acetonitrile pathways (Keswani et al., 2020). Among those bacterial species, 80% of the rhizosphere microbial populations are functioning as producers of IAA. Agrobacterium spp., Erwinia spp., and Pseudomonas spp. are some bacterial genera that can produce IAA (Denancé et al., 2013). Interestingly, increased root amplification is happening due to bacterial IAA biosynthesis. The plant-associated microbes also produced IAA via l-tryptophan-dependent and independent pathways. L-tryptophan is a precursor for IAA production. Most of these microbes utilize l-tryptophan secreted as root exudates. In contrast to the bacteria, the biosynthesis of auxin in fungal pathogens is restricted to a few species, such as Ustilago maydis, U. scitaminea, and U. esculenta (Reineke et al., 2008). Additionally, Tsavkelova et al. (2012 reported that some other fungi, such as Colletotrichum spp., also have enzymatic pathways to produce auxins. However, the production of auxins through fungal pathogens has not been clearly demonstrated. As synthetic auxins, 1-naphthalacetic acid (NAA) and 2- and 4-D-related combinations can be used. These two plant growth substances show auxin-like activity. For auxin experiments, the NAA provides poor acidic control while employing the active 1-NAA. As a 2,4-D derivative, 2,4-dichlorophenoxybutyric acid contains two additional methylene groups in the side chain. However, this acts as an analogy to the structural relationship between IBA and IAA. Nowadays, 2-D itself is heavily used as an herbicide (Woodward and Bartel, 2005). Though IAA, 2, 4-D, NAA, and other synthetic compounds of auxins can result in similar physiological behaviors in bioassays, those molecules cause-specific and overlapping changes in gene expression, differences in transport and metabolism, and interactions with the signal transduction pathways.

Role in growth and development

Auxin plays a vital role in governing the below-mentioned functions: enhancing cell and vascular tissue differentiation, root tip initiation, formation of pollen, stimulating the production of ethylene, the development of seedless fruits, resistance to disease, and the development of other plant parts. Particularly, the growth and development of the embryo, leaf, and root-like plant parts may be governed by auxin transport (Miransari and Smith, 2014). However, auxin itself may not be a requirement for seed germination while it is needed for the growth of newly emerged seedlings (Hentrich et al., 2013; Bialek et al., 1992). The IAA acquired in the cotyledon is the main source of IAA for an emerging seedling. According to the study by Bialek et al. (1992, mature seeds of legume plants used amide products as the major source of IAA. Further, this study has shown both tracers of IAA biosynthesis are incorporated into IAA isolated from bean seedlings. Because of that, the relative level of IAA synthesis increases with the time of germination (Bialek et al., 1992). Further, the study has revealed that, in the early stages of bean germination, auxin conjugates might be a valuable source of IAA production and release the IAA needed

for growth at later stages. Through this, we can understand that not only are bean seedlings' shoots competent for IAA biosynthesis, but they also produce IAA biosynthetically in the first days of germination. Hence, the availability of IAA conjugates as a good source of free IAA in a young seedling may influence not only their chemical attributes but also how readily they can be moved from the storage tissue to the axes. During and after seed germination, the radicle tip of the seed contains auxin. Due to the presence of microRNA 60, auxin response factor (ARF) is inhibited during seed germination, and thereby the seed can germinate without any doubt. This is also a requirement for the different growth phases related to seed maturation and late developmental processes. Using microRNA-resistant mutants, researchers determine the biological functions of ARFs. Those studies have shown that the downregulation of this auxin response factor is required for the growth and development of roots, leaves, and flowers. The significance of microRNA's and auxin response factors affecting the interaction between auxin and absicic acids during the early and post stages of germination was also clarified (Liu et al., 2007). The plants exposed longer to IAA have a highly developed root system, which provides higher access to nutrients. With this root system of a plant, which will help to absorb more nutrients, the overall growth of the plant will be improved (Murthy et al., 2021).

Cytokinin

Cytokinin is another well-known plant growth regulator that occurs naturally in plants and synthetically in the environment. Cytokinin is produced in root tissues and developing leaves. However, a high amount of cytokinin is produced within the root tissue and then transported to the top of the shoots. Nutrients also transport and accumulate in plant tissues where high levels of cytokinin are expressed (Barciszewski et al., 2000).

Biosynthesis of cytokinin

Biosynthesis of cytokinin also occurs through two pathways: isopentenyladen-independent pathways and isopentenyladenine-independent pathways. In the isopentenyladenine-dependent pathway, the formation of isopentenyl adenine nucleotide (iPRDP) with the support of adenosine phosphate isopentenyl transferase (iPRTP) initiates the production of tZ cytokinin. It may utilize ATP, ADP, or AMP as substrate while utilizing dimethylallyl pyrophosphate or hydroxymethylbutenyl pyrophosphate as phenyl donors. Additionally, CYP735A catalyzed the conversion of iPRDP and iPRTP into the tZ nucleotide, and phosphoribohydrolase converted this inactive tZ into the active form of tZ (Jiang and Asami, 2018). In the isopentenyladenine-dependent pathway, the hydroxylated side chain of hydroxymethylbutenyl pyrophosphate is moving to the adenine ring, and tZ-type cytokinin is produced (Fr´ebort et al., 2011). Cytokinin can also be produced in bacteria through recycled tRNAs (Miyawaki et al., 2004; Hwang and Sakakibara, 2006). The enzyme is opentenyl transferase, which is nucleotide specific. And it will not develop affinity

with adenine or adenosine. This enzyme has been derived from Dictyostelium discoideum, which is a slime mold.

In higher plants and in bacteria, zeatin is the most widely distributed and abundant natural cytokinin present. The name zeatin was given since it was taken from immature corn grains in pure crystalline form. It was chemically identified as 6-aminopurine (4-hydroxy-3-methylbut-trans-2-enyl). In addition to zeatin, substitutions of amino acids are also identified as natural cytokinin obtained from higher plants and from some bacteria. As examples, dihydrozeatin (DZ) and N6-adenine (Δ2-isopentenyl or iP) can be named, which somewhat differ from original zeatin in the nature of their side chains.

Role in growth and development

The function of cytokinins is more or less similar to that of IAA (Goswami et al., 2015). Derivatives of N6-substituted adenine were the first cytokinins identified. 40 years ago, they were identified as necessary compounds needed for plant cell division. Further studies revealed their role in assisting enzyme activation.

Cytokinin found in plants functions not only in cell division but also in organogenesis, cell culture elongation, and differentiation. Further, many biological processes, such as apical dominance, nutrient mobilization, leaf expansion, chloroplast differentiation, senescence, and activation of the shoot meristem, are also governed by cytokinin. Additionally, the formation of nutritional signaling, branching of roots and shoots, meristem activities such as root growth, chlorophyll production, embryo vasculature, promotion of seed germination, and delaying ofsenescence, are also highly affected by cytokinins (Wong et al., 2015). Moreover, cytokines activate DNA replication, transcription, translation, signal transduction, and the control of the cell cycle. It is also known that cytokinin is needed for morphogenesis in plants. However, deficiency of cytokine causes little apical meristem and stunted growth of the shoot. When concerning signal transduction ability, different environmental and abiotic stressful conditions such as salinity, heat, and drought are also governed by cytokonin (Li et al., 2021). provide the ability for plants to withstand various forms of stress, especially drought and delaying senescence (Li et al., 2021). Moreover, during developmental stages, they are involved in some metabolic activities, the capacity of the sink, and the transportation of stored products to the different parts of leguminous and non-leguminous plants.Some studies have shown that the expression of genes increases with cytokinin, and it is not a single result of cytokinin itself but is controlled by other components such as other plant hormones. Denancé et al. (2013 observed synergistic, antagonistic, and additive interactions among cytokinins and other plant hormones. Further studies reported that Pseudomonas savastanoi, Agrobacterium tumefaciens, and Corynebacteriumfascians, like plant pathogens, also encoded cytokinin biosynthetic genes. Although cytokinin-binding proteins can be found in plants, their activities are still not well understood. However, the mechanisms that govern the responses to cytokinins and their

effects on plants have not been fully established (Denancé et al., 2013).

Synergism of cytokinin and auxin

Interestingly, cytokinins and auxins are working together, and the balance between these two hormones affects the growth and development of a plant throughout its lifecycle. Further, the concentration of both hormones is relatively similar in plants. However, if cytokinin levels are lower than auxin levels, the plants are in the vegetative growth phase, while if cytokinin levels are higher than auxin levels, the plants change into the reproductive growth stage (Li et al., 2021). However, high levels of cytokinin cause negative effects and tend to inhibit auxin signaling even. If concentrations of both cytokinin and auxin are high, the antagonistic relationship between them is not prominent (Kurepa et al., 2019). During cell division and differentiation, cytokinin and auxin work together to regulate it. Auxins promote cell elongation, while cytokinins stimulate cell division (Hurný et al., 2020). The balance between these hormones influences the development of various plant tissues, including roots, shoots, and leaves (Zu et al., 2011). During the root-growing period, cytokinins influence root development by promoting lateral root formation and elongation, while auxins play a role in primary root growth and root hair development. Together, they coordinate the root system architecture (Grieneisen et al., 2007). Moreover, auxins and cytokinins play key roles during shoot apical meristem development and maintenance. Especially in seedlings, leaf initiation, leaf shape, and the size of the leaf are also determined by these two hormones (Wu et al., 2021). Auxins and cytokinins interact to regulate vascular tissue differentiation. Auxins promote xylem differentiation, while cytokinins play a role in phloem development. Their coordination ensures proper transport and nutrient distribution throughout the plant (Grieneisen et al., 2007). As auxin and cytokinin work against each other, the activities of meristem cells that are differentiating and multiplying keep the root and shoot apical meristem activity in balance. Further to this, auxins are responsible for apical dominance, which inhibits lateral bud growth. Cytokinins counteract this effect by promoting lateral bud outgrowth, leading to increased branching and bushier plant architecture (Zu et al., 2011). To understand the auxin-cytokinin interaction in the development and function of the apical meristem, significant progress has been made to date (Kurepa et al., 2019). However, the significance and depth of these interactions during the development of organs initiated by apical meristems are less or less known. Kurepa et al. (2019 also reported that plants should have an additional mechanism that can govern auxin and cytokinin signaling interactions. However, further studies need to be done to prove this hypothesis.

3. CONCLUSION AND FUTURE DIRECTIONS

Germination of seeds and seedling growth are important stages of plants that affecting crop production and the final yield. These are depending on a range of factors, i.e. environmental conditions, seed's conditions and availability of growth hormones. In fact, growth hormones produced naturally by both plants and bacteria, can largely

impact on seed germination and seedling growth. Not only as a hormone itself, but also as a combination too. During the stages such as cell division, cell differentiation, cell proliferation, formation of root and shoot, reproduction and senescence, synergism effect of both the hormones were well documented. Therefore, it is clear that auxin and cytokinin are acting together and the ratio between these two hormones affects for throughout plant's lifecycle which will ultimately affect for the better crop production.

However, the specific studies are still required to fill the gaps of synergism impact of both the hormones on seed germination and seedling growth.

Although, the functions of auxin and cytokinin are clearly established in plants, little amount of studies have been conducted to test the effect of these growth hormones in seedling growth. Therefore, more research studies are required to understand the hormonal effect on seedling growth of plants. Hence, future research should largely narrow down to the way of individual and combine application of auxins and cytokinin can provide optimum conditions for the seed germination and growth of seedlings under the various environmental conditions such as stresses. However, more details need to be evaluated regarding the signaling pathways of auxins and cytokinins, including how these hormones are synthesized, transported, perceived, and transduced within plant cells as well as how they integrate with other hormonal networks.

Genetic influence for them during seed germination and seedling growth need to be assessed. Study the genetic regulation of hormone biosynthesis and signaling components and identification key genes and transcription factors involved in controlling auxin and cytokinin responses during seedling development will be significant. Utilize genetic engineering techniques to modulate hormone-related gene expression and achieve desirable seedling traits, such as enhanced growth, stress tolerance, and nutrient utilization. Explore epigenetic modifications (e.g., DNA methylation, histone modifications) that influence the expression of genes related to auxin and cytokinin signaling and investigate how epigenetic changes affect seedling growth and development will be timely needed.

Further to this, examine the interplay between auxins, cytokinins, and nutrient-uptake/availability. Investigate how these hormones influence nutrient acquisition, transport, and allocation in seedlings and develop strategies to optimize nutrient management and fertilizer application based on the interactions between hormone signaling and nutrient metabolism will be important.

Study the role of plant-associated microbes in modulating auxin and cytokinin levels, investigate how microbiome interactions affect seedling growth and nutrient acquisition, explore the potential of using beneficial microbes to enhance hormone production, uptake, and utilization for improved seedling vigor will be needed for further understanding of auxin and cytokinin relationship. Examine how auxins and cytokinins contribute to seedling responses to various abiotic and biotic

stresses (e.g., drought, salinity, pathogens) and develop strategies to enhance stress tolerance through hormone-based interventions can be done accordingly. Investigate the role of auxins and cytokinins in phytoremediation, the process of using plants to remove pollutants from the environment; specially by exploring how these hormones can enhance the efficiency of phytoremediation strategies for contaminated soils need to be directed.

Develop sustainable agricultural practices that harness the potential of auxins and cytokinins to improve soil health, reduce environmental impact, and promote resource-efficient crop production need to be addressed.

Integrate emerging knowledge about hormone signaling into precision agriculture technologies and sensor- based approaches to monitor hormone levels and seedling growth in real-time need to be developed. Designing of automated systems for precise hormone application, enabling tailored treatments to optimize seedling growth and crop performance and tailor research efforts to specific crop speciesand their growth stages need to be done. Moreover, the uniqueresponses of different crops to auxin and cytokinin treatments, considering both agronomic and horticultural contexts need to be investigated.

Finally, the economic feasibility and practicality of implementing hormone-based strategies for seedling growth enhancement in diverse agricultural systems need to be evaluated while considering the potential socio-economic impacts of adopting these strategies, including implications for farmers, markets, and food security.

REFERENCES

Barciszewski, J., Siboska, G., Clark,B. F., & Rattan, S. I. (2000).Cytokinin formation by oxidative metabolism. Journal of plant physiology, 157(5), 587-588.

Bialek, K., Michalczuk, L., & Cohen,J. D. (1992). Auxin biosynthesis during seed germination in Phaseolus vulgaris. Plant Physiology, 100(1), 509-517.

Denancé, N., Sánchez-Vallet, A., Goffner, D., & Molina, A. (2013).Disease resistance or growth: the role of plant hormones in balancing immune responses and fitness costs. Frontiers in plant science, 4,155.

Emamverdian, A., Ding, Y., Mokhberdoran, F., & Ahmad, Z. (2021). Mechanisms of selected plant hormones under heavy metal stress. Pol. J. Environ. Stud, 30, 497-507.

Frebort, I., Kowalska, M., Hluska, T., Frébortová, J., & Galuszka, P. (2011). Evolution of cytokinin biosynthesisand degradation. Journal of Experimental Botany, 62(8), 2431-2452.

George, E. F., Hall, M. A., & Klerk,G. J. D. (2008). Plant growth regulators I: introduction; auxins, their analogues and inhibitors. In Plant Propagation by Tissue Culture: Volume 1. The Background (pp. 175-204). Dordrecht: Springer Netherlands.

Goswami, D.,Parmar, S.,Vaghela, H., Dhandhukia, P., & Thakker, J. N. (2015). Describing Paenibacillus mucilaginosus strain N3 as an efficient plant growth promoting rhizobacteria (PGPR). Cogent Food & Agriculture, 1(1), 1000714.

Graeber, K. A. I., Nakabayashi, K.,Miatton, E., Leubner-Metzger, G. E. R. H. A. R. D., & Soppe, W. J. (2012). Molecular mechanisms of seed dormancy. Plant, cell & environment, 35(10), 1769-1786.

Grieneisen, V. A., Xu, J., Marée, A. F., Hogeweg, P., & Scheres, B. (2007). Auxin transport is sufficientto generate a maximum and gradient guiding root growth. Nature, 449(7165), 1008-1013.

Hentrich, M., Böttcher, C., Düchting, P., Cheng, Y., Zhao, Y., Berkowitz, O. & Pollmann, S. (2013). The jasmonic acid signaling pathway is linked to auxin homeostasis through the modulation of YUCCA 8 and YUCCA 9 gene expression. The Plant Journal, 74(4), 626-637.

Hermann, K., Meinhard, J., Dobrev, P., Linkies, A., Pesek, B., Heß, B., ... & Leubner-Metzger, G. (2007). 1-Aminocyclopropane-1-carboxylic acid and abscisic acid during the germination of sugar beet (Beta vulgaris L.): a comparative study of fruits and seeds. Journal of Experimental Botany, 58(11), 3047-3060.

Hurný, A., Cuesta, C., Cavallari, N., Ötvös, K., Duclercq, J., Dokládal, L., ... & Benková, E. (2020). Synergistic on auxin and cytokinin 1 positively regulates growth and attenuates soil pathogen resistance. Nature Communications, 11(1), 2170.

Hwang, I., & Sakakibara, H. (2006). Cytokinin biosynthesis and perception. Physiologia Plantarum, 126(4), 528-538.

Jiang, K., & Asami, T. (2018). Chemical regulators of plant hormones and their applications in basic research and agriculture. Bioscience, biotechnology, and biochemistry, 82(8), 1265-1300.

Keswani, C., Singh, S. P.,Cueto, L., García-Estrada, C., Mezaache-Aichour, S., Glare, T. R.,... & Sansinenea, E. (2020). Auxins of microbial origin and their use in agriculture. Applied Microbiology and Biotechnology, 104, 8549-8565.

Koger, C. H., Reddy, K. N., & Poston, D. H. (2004). Factors affecting seed germination, seedling emergence, and survival of texasweed(Caperoniapalustris). Weed science, 52(6), 989-995.

Kurepa, J., Shull, T. E., & Smalle, J. A. (2019). Antagonistic activity of auxin and cytokinin in shoot and root organs. Plant Direct, 3(2), e00121.

Li, N., Euring, D., Cha, J. Y., Lin, Z., Lu, M., Huang, L. J., & Kim, W. Y. (2021). Plant hormone-mediated regulation of heat tolerance in response to global climate change. Frontiers in Plant Science, 11, 627969.

Liu, P. P., Montgomery, T. A., Fahlgren, N., Kasschau, K. D., Nonogaki, H., & Carrington, J. C. (2007). Repression of auxin by microRNA160 is critical for seed germination and post-germination stages. The Plant Journal, 52(1), 133-146.

Miransari, M., & Smith, D. L.(2014). Plant hormones and seed germination. Environmental and experimental botany, 99, 110-121.

Miyawaki, K., Matsumoto-Kitano, M., & Kakimoto, T. (2004). Expression of cytokinin biosynthetic isopentenyltransferase genes in Arabidopsis: tissue specificity and regulation by auxin, cytokinin, and nitrate. The plant journal, 37(1), 128-138.

Mukherjee, A., Gaurav, A. K., Singh, S., Yadav, S., Bhowmick, S.,Abeysinghe, S., & Verma, J. P.(2022). The bioactive potential of phytohormones:review. Biotechnology Reports, 35, e00748.

Müller, K., Tintelnot, S., & Leubner-Metzger, G. (2006). Endosperm-limited Brassicaceae seed germination: abscisic acid inhibits embryo-induced endosperm weakening of Lepidium sativum (cress) and endosperm rupture of cress and Arabidopsis thaliana. Plant and Cell Physiology, 47(7), 864-877.

Murthy, K. N., Soumya, K., Udayashankar, A. C., Srinivas, C., & Jogaiah, S. (2021). Biocontrol potential of plant growth-promoting rhizobacteria (PGPR) against Ralstonia solanacearum: current and future prospects. In Biocontrol Agents and Secondary Metabolites (pp. 153- 180). Woodhead Publishing.

Porcel, R., Zamarreño, Á. M., García-Mina, J. M., & Aroca, R. (2014). Involvement of plant endogenous ABA in Bacillus megaterium PGPR activity in tomato plants. BMC plant biology, 14(1), 1-12.

Raspor, M., Motyka, V., Kaleri, A. R., Ninković, S., Tubić, L., Cingel, A., & Ćosić, T. (2021). Integrating the roles for cytokinin and auxin in de novo shoot organogenesis: from hormone uptake to signaling outputs. International Journal of Molecular Sciences, 22(16), 8554.

Reineke, G., Heinze, B., Schirawski, J., Buettner, H., Kahmann, R., & Basse, C. W. (2008). Indole-3-acetic acid (IAA) biosynthesis in the smut fungus Ustilago maydis and its relevance for increased IAA levels in infected tissue and host tumour formation. Molecular plant pathology, 9(3), 339-355.

Su, Y. H., Liu, Y. B., & Zhang, X. S. (2011). Auxin–cytokinin interaction regulates meristem development. Molecular plant, 4(4), 616-625.

Tsavkelova, E., Oeser, B., Oren-Young, L., Israeli, M., Sasson, Y., Tudzynski, B., & Sharon, A. (2012). Identification and functional characterization of indole-3-acetamide-mediated IAA biosynthesis in plant-associated Fusarium species. Fungal Genetics and Biology, 49(1), 48-57.

Vishal, B., & Kumar, P. P. (2018). Regulation of seed germination and abiotic stresses by gibberellins and abscisic acid. Frontiers in Plant Science, 9, 838.

Wong, W. S., Tan, S. N., Ge, L., Chen, X., & Yong, J. W. H. (2015). The importance of phytohormones and microbes in biofertilizers. Bacterial metabolites in sustainable agroecosystem, 105-158.

Woodward, A. W., & Bartel, B. (2005). Auxin: regulation, action, and interaction. Annals of botany, 95(5), 707-735.

Wu, W., Du, K., Kang, X., & Wei, H. (2021). The diverse roles of cytokinins in regulating leaf development. Horticulture Research, 8.

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