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STUDENT SECTION

PREFACE

Welcome to the Southeast Asian Journal of STEM Education (SAJSE), a prominent online platform established by SEAMEO STEM-ED, dedicated to the advancement of STEM education in Southeast Asia. As an open-access publication, SAJSE is an invaluable repository for insights, ideas, and innovations that define the future of STEM education in the region.

At SEAMEO STEM-ED, we believe in the power of collaboration and knowledge exchange to advance STEM education. The articles in SAJSE reflect this belief, offering a wealth of quality knowledge that transcends regional boundaries. Our dedication to openness is demonstrated by our usage of Creative Commons licencing, which allows for the free use, distribution, and replication of our published content with due credit.

We are excited to announce that we are opening up opportunities for teachers and students to share their voices and reflections from the classroom. Teachers are invited to share their innovative practices, challenges, and insights in teaching STEM subjects, providing valuable perspectives that can benefit educators across Southeast Asia. Similarly, students are encouraged to share their experiences and reflections on STEM science projects, highlighting the impact of hands-on learning experiences on their education and personal development.

This initiative aims to echo the voices of teachers and students, providing a platform for them to share their unique perspectives and contribute to the broader conversation on STEM education in Southeast Asia. By amplifying these voices, we hope to inspire others and drive positive change in STEM education practices and policies.

Authors who submit their papers to SAJSE will benefit from the journal's rigorous peer-review process, ensuring the quality and integrity of published articles. Additionally, published papers will be freely accessible to educators, researchers, and policymakers, facilitating the dissemination of innovative practices and ideas in STEM education.

We invite educators, researchers, and innovators from across Southeast Asia to join us in this quest to elevate STEM education. Together, let us construct a cooperative and inclusive learning ecosystem that equips the future generation of innovators and solution seekers, propelling Southeast Asia towards a future characterised by innovation and excellence.

Thank you for being a part of this journey.

Warm regards,

SEAMEO STEM-ED

EDITORIAL

Welcome to SAJSE, the leading platform for advancing STEM education and encouraging innovation in Southeast Asia. Our journal exemplifies the spirit of collaboration, creativity, and capacity building. We are dedicated to making STEM education accessible to all, while also offering chances for educators and students to share their research, teaching techniques, and new ideas. This open-access journal serves as a beacon for researchers, educators, policymakers, and students seeking excellence in STEM education.

A Platform for Diverse Voices

The Southeast Asian Journal on STEM Education transcends its role as a mere repository of information, establishing itself as a vibrant forum that embraces a plurality of perspectives. This journal curates a comprehensive array of contributions, encompassing seminal research articles from seasoned scholars, innovative pedagogical methodologies from educators, and introspective analyses on integrated STEM disciplines authored by students. It operates as a platform that acknowledges and values the diverse viewpoints of all constituents within the educational sphere, thereby facilitating a collective ethos of learning and developmental synergy.

Bridging Policy and Practice

A distinctive feature of this journal is its specialised policy section, designed to stimulate dialogue on the development and enactment of educational policies, with a particular emphasis on STEM disciplines. This section covers a broad spectrum, from theoretical propositions to empirical research and the exchange of best practices. The journal aims to contribute to and impact policy-making processes that determine the trajectory of educational advancement. It represents an effort to reconcile policy with practice, guaranteeing that educational innovations are firmly anchored in the practical landscape and meet the requirements of learners.

Global Perspectives with a Local Focus

Although the journal invites submissions from educators, policymakers, teachers, and students globally, it prioritises local implementations, research, or practices from Southeast Asian countries. This emphasis underscores a dedication to tackling the distinct challenges and seizing the opportunities present in the region, advocating for solutions that are informed by global perspectives yet tailored to local contexts.

A Call to Action

We warmly invite all stakeholders, particularly teachers and students, to contribute to the Southeast Asian Journal on STEM Education. Your contributions to research, practices, and reflections do more than enrich our collective knowledge; they play an active role in sculpting

a future where STEM education is universally accessible, inclusive, and profoundly influential. This journal stands as a testament to the strength of collaborative effort, reinforcing the notion that every contribution, regardless of its size, is instrumental in unlocking the vast potential of STEM

the Southeast Asian Journal on STEM Education serves as a beacon, illuminating the path toward a more enlightened future via the progression of STEM education. It summons all who are dedicated to nurturing scientific thought and leveraging scientific inquiry to elevate the quality of teaching and learning. United in purpose, let us venture forth on this path of exploration and innovation, laying the foundations for future generations to build upon.

Best regards,

SAJSE Editors

POLICY

SECTION

ADVANCING INTEGRATED STEM EDUCATION IN TECHNICAL AND VOCATIONAL EDUCATION AND TRAINING (TVET)

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Abstract

SEAMEO STEM-ED envisions a future-ready workforce in Southeast Asia equipped with STEM (Science, Technology, Engineering, and Mathematics) competencies critical for Industry 4.0, automation, and artificial intelligence (AI). In collaboration with the International Labour Organization (ILO), SEAMEO STEM-ED introduced the Bangkok Statement on Integrated STEM Education in TVET to align Technical and Vocational Education and Training (TVET) systems with evolving labour market demands. At the heart of this initiative is a strong emphasis on curriculum integration, industry collaboration, teacher capacity building, and inclusive STEM education, recognising these as essential pillars for equipping learners with relevant skills. The Bangkok Statement underscores the urgency of harmonising STEM competencies within TVET systems to ensure they remain responsive to workforce needs. Informed by expert discussions, pre-summit webinars, and regional policy frameworks such as the ASEAN Work Plan on Education 2021–2025 and the SEAMEO Strategic Plan 2021–2030, this initiative drives policy alignment, fosters public-private partnerships, and implements innovative pedagogies. Through regional cooperation and best practices, SEAMEO STEM-ED and ILO aim to cultivate a resilient, future-ready workforce that supports sustainable development and economic growth in the digital era.

Keywords: STEM in TVET, STEM Policy in TVET, Policy Recommendations

1. Introduction

The global shift towards automation, artificial intelligence (AI), and the digital economy demands urgent reform in education systems, particularly in Technical and Vocational Education and Training (TVET). Recognising this need, the Bangkok Statement on Integrated STEM Education in TVET presents a comprehensive vision for aligning STEM competencies with industry demands. This article elaborates on the Bangkok Statement's recommendations, supported by insights from pre-summit webinars and expert discussions, to propose actionable strategies for preparing a future-ready workforce in Southeast Asia. These strategies align with key frameworks, including the ASEAN Work Plan on Education 2021–2025 (ASEAN Secretariat, 2021), the SEAMEO Strategic Plan 2021–2030 (SEAMEO Secretariat, 2021), the GEM Report 2023 (UNESCO, 2023), the World Economic Forum's Future of Jobs Report (World Economic Forum, 2023), the World Bank's workforce development initiatives (World Bank, 2023), and SEAMEO VOCTECH's contributions to regional TVET innovation (SEAMEO VOCTECH, 2024).

The ASEAN Secretariat's Work Plan on Education 2021–2025 closely aligns with the Bangkok Statement on STEM Education in TVET (SEAMEO STEM-ED, 2024), which emphasises the integration of STEM (Science, Technology, Engineering, and Mathematics) into TVET to enhance workforce readiness for Industry 4.0. Key initiatives supporting this alignment include the following:

a. **Strengthening Business-Industry Collaboration**:
The ASEAN Future Workforce Council (AFWC), established in 2019, reinforces partnerships between education providers and industries. This directly supports the Bangkok Statement's call for synergising TVET curricula with labour market demands and emerging technologies.

b. **Curriculum Alignment with STEM Competencies**:
The International Labour Organization's (ILO) STEM in TVET Curriculum Guide advances the Bangkok Statement's vision by mapping STEM competencies to TVET programmes. This ensures students gain industry-relevant competencies, fostering regional economic growth and resilience.

c. **Promoting Regional Workforce Mobility**:
The ASEAN-ROK TVET Mobility Programme, funded by the ASEAN-Korea Cooperation Fund, supports the Bangkok Statement by addressing skills gaps and fostering cross-border collaboration. This initiative helps equip learners with digital and STEM skills vital for a dynamic, interconnected labour market.

The World Economic Forum's Future of Jobs Report 2023 (World Economic Forum, 2023) highlights significant shifts in the global labour market, emphasising the critical role of STEM (Science, Technology, Engineering, and Mathematics) competencies in adapting to these changes. The report indicates that technological advancements and the green transition will likely create 69 million new jobs by 2027 while displacing 83 million positions, resulting in a net loss of 14 million jobs.

To navigate this evolving landscape, the report underscores the importance of reskilling and upskilling, noting that 44% of workers' competencies are expected to be disrupted within the next five years (Angela Elzir and Matteo Morgandi, 2024).

This aligns with the Bangkok Statement on STEM Education in TVET by SEAMEO STEM-ED, which advocates for integrating STEM into Technical and Vocational Education and Training (TVET) to equip the workforce with competencies essential for Industry 4.0.

While the World Bank's World Development Report 2023 (World Bank Group, 2024) focuses on migration and its developmental impacts, the World Bank has also addressed the importance of digital literacy and skills in workforce development. A World Bank report (Angela Elzir and Matteo Morgandi, 2024) emphasises that the digital economy is expanding rapidly, necessitating a workforce proficient in digital and STEM skills to meet new job demands.
These insights from the World Economic Forum (2023) and the World Bank (2023) reinforce the objectives of the Bangkok Statement, underscoring the necessity of integrating STEM education into TVET programmes to develop a workforce capable of thriving in a rapidly evolving job market.

2. Insight from Global Perspectives of International Organisation

2.1 STEM Competencies: A Regional Framework for Workforce Readiness

A harmonised understanding of STEM competencies is crucial for effectively integrating them into TVET curricula across ASEAN. Establishing standardised definitions ensures consistency and enhances regional collaboration. The ASEAN Work Plan on Education 2021-2025 emphasises regional cooperation to address skills gaps and foster innovation. Additionally, it underscores the need to harmonise qualifications and skills recognition frameworks across ASEAN to enhance mobility and employability. SEAMEO VOCTECH (SEAMEO VOCTECH,

2024) has been instrumental in developing regional competency standards and conducting baseline studies to identify critical skill gaps, ensuring that STEM education addresses the demands of the Fourth Industrial Revolution. For instance, the ILO's Women in STEM Workforce Readiness and Development Program (International Labour Organization, 2017) demonstrates how targeted capacity-building initiatives can align STEM education with labour market needs.

2.2 Government-Industry Collaboration

Partnerships between governments, educational institutions, and industries play a crucial role in ensuring TVET programmes remain relevant. The World Economic Forum's Future of Jobs Report stresses that partnerships are critical for aligning curricula with emerging skills demands in AI, robotics, and green technologies. SEAMEO VOCTECH's initiatives in establishing public-private partnerships (PPPs) have supported the co-design of training programmes tailored to industry needs, such as apprenticeships and cooperative education models. Work-based learning programmes and internships complement these partnerships by bridging the gap between theoretical knowledge and practical application, thereby enhancing employability (SEAMEO VOCTECH, 2024).

2.3 Teacher Training and Support

Empowering TVET educators through professional development is critical. Teachers must receive continuous training in emerging technologies and pedagogical strategies. Programmes integrating micro-credentials, industry exposure, and mentorship will empower educators to deliver high-quality STEM education. SEAMEO VOCTECH's regional training programmes, which focus on enhancing the digital and pedagogical competencies of TVET trainers, align with the SEAMEO Strategic Plan 2021-2030 and underscore the importance of equipping educators with tools for innovation and inclusion (SEAMEO VOCTECH, 2024).

2.4 Innovative and Inclusive STEM Education

Ensuring equal access to STEM education for disadvantaged groups is essential for inclusivity. Scholarships, gender-sensitive curricula, and targeted mentorship programmes are effective strategies for reducing barriers to participation. The GEM Report 2023 (UNESCO, 2023) highlights the need to address gender disparities in STEM fields through systemic reforms and tailored interventions. SEAMEO VOCTECH's community-based training initiatives (SEAMEO VOCTECH, 2024), which prioritise marginalised groups and underrepresented communities, further underscore the importance of inclusive approaches. Promoting creativity and innovation within TVET curricula enhances students' ability to tackle complex challenges in technology-driven careers. For instance, integrating problem-solving projects and digital simulations promotes innovation while addressing local development challenges.

2.5 Challenges and Best Practices

The 2023 Global Education Monitoring (GEM) Report (UNESCO, 2023) examines the role of technology in education, highlighting both its potential benefits and challenges. The report emphasises that while technology can enhance access to educational resources, particularly for marginalised groups, it also has the potential to exclude individuals from poorer backgrounds if not implemented thoughtfully.

Integrating STEM into TVET presents several challenges, including infrastructure gaps, limited teacher qualifications, and rigid curricula. Addressing these challenges requires:

a. **Infrastructure Development:** Investments in modern facilities, reliable internet access, and advanced equipment are critical for effective STEM training. The World Bank's initiatives on education financing offer valuable insights into overcoming such challenges by focusing on scalable solutions for resource-constrained environments. SEAMEO VOCTECH's support for e-learning platforms and blended learning models provides additional avenues for mitigating infrastructure limitations (SEAMEO VOCTECH, 2024).

b. **Flexible Curricula:** Adaptive curricula that respond to technological changes enable timely updates and skill acquisition. The SEAMEO Strategic Plan also underscores the importance of embedding future-ready skills into curricula (SEAMEO Secretariat, 2023).

c. **Regional Collaboration:** Platforms for sharing best practices foster innovation and cohesion among ASEAN member states. This aligns with the ASEAN Work Plan's emphasis on collaborative capacity-building and shared standards (ASEAN Secretariat, 2023).

In parallel, the International Labour Organization (International Labour Organization, 2016) has released several key messages in 2023:

a. **Global Unemployment Trends**: The ILO reports that global unemployment remained at a historical low of 5% last year and is projected to stay the same through 2025. However, disparities persist, with youth unemployment notably higher at 12.6%. The ILO underscores the need for new approaches to social justice, including investments in education and leveraging migrant remittances to stimulate job creation in developing countries.

b. **Value of Essential Work**: The ILO's "World Employment and Social Outlook 2023" report calls for a revaluation of key workers' roles to better reflect their social contributions. It advocates for increased investment in essential sectors to ensure the sustainability of critical services, especially in light of challenges highlighted by the COVID-19 pandemic.

These insights from the GEM Report and the ILO highlight the importance of integrating technology thoughtfully in education and addressing labour market challenges through comprehensive social policies. Along with the **SEAMEO Strategic Plan 2021–2030** highlights STEM and TVET as critical pillars for regional development. Key statements include:

a. **Programme Excellence and Alignment with SDGs**: The plan emphasises advancing STEM and TVET education to address skills gaps, promote innovation, and align with SDG 4 (Quality Education) and SDG 8 (Decent Work and Economic Growth). This ensures youth are prepared for Industry 4.0 and the rapidly evolving job market.

b. **Digital Transformation for Rapid Change**: The integration of digital technologies into STEM and TVET programmes is prioritised to enhance teaching and learning, bridging the gap between educational outcomes and industry demands.

c. **Strategic Partnerships and Networking**: SEAMEO fosters collaboration with industry, governments, and educational institutions to strengthen STEM and TVET curricula, ensuring they remain relevant to emerging trends and technologies.

SEAMEO STEM-ED and SEAMEO VOCTECH are committed to advancing STEM in TVET to build a future-ready workforce equipped with critical skills for sustainable development and economic growth in Southeast Asia. At the forefront of this effort, SEAMEO STEM-ED and SEAMEO VOCTECH can play a pivotal role by either initiating new programmes or expanding

existing SEAMEO VOCTECH initiatives such as: a) **Regional TVET Leadership** which drives STEM integration into TVET by offering specialised training, research, and consultancy services tailored to the needs of Southeast Asian countries; and b) **SEA-VET.NET** as this platform consolidates best practices and innovations in TVET, emphasising STEM education's role in fostering regional collaboration and knowledge-sharing among policymakers and educators.

This aligns with the SEAMEO Strategic Plan 2021–2030 and directly supports the Sustainable Development Goals (SDGs), ensuring that regional education and workforce development contribute to global sustainability efforts. Key connections include:

SDG 4 – Quality Education:

- SEAMEO STEM-ED's emphasis on integrating STEM into TVET fosters equitable access to quality education that equips learners with the technical and digital skills needed for Industry 4.0.
- SEAMEO VOCTECH's training programmes and SEA-VET.NET platform enhance capacity-building for educators, ensuring inclusive and quality education across Southeast Asia.

SDG 8 – Decent Work and Economic Growth:

- By aligning TVET curricula with labour market demands, SEAMEO supports youth employability and lifelong learning, addressing skills gaps critical for economic growth.
- STEM-focused TVET promotes entrepreneurship and innovation, fostering job creation in emerging sectors such as green technologies and digital economies.

SDG 9 – Industry, Innovation, and Infrastructure:

- SEAMEO VOCTECH and SEAMEO STEM-ED facilitates the development of STEM competencies that drive innovation and industrial advancement in Southeast Asia.
- Digital transformation in TVET aligns with sustainable infrastructure development, ensuring students are prepared for technologically advanced industries.

SDG 17 – Partnerships for the Goals:

- SEAMEO STEM-ED and SEAMEO VOCTECH actively engage in cross-sectoral partnerships with industries, governments, and international organisations to advance STEM in TVET and achieve regional and global education goals.

2.6 The Way Forward

The Bangkok Statement's recommendations (SEAMEO STEM-ED, 2024) provide a roadmapfor advancing integrated STEM education in TVET. Key actions include:

a. Developing a joint regional strategic plan that incorporates baseline research, curriculum development, and resource allocation, reflecting the goals outlined in the SEAMEO Strategic Plan and ASEAN Work Plan. This includes sector-specific plans targeting industries like green energy and ICT.

b. Establishing regional guidelines for STEM competencies to standardise and harmonise practices across ASEAN, consistent with global trends highlighted in the World Economic Forum's Future of Jobs Report. SEAMEO VOCTECH's ongoing efforts in developing competency frameworks provide valuable reference points.

c. Enhancing teacher training programmes and expanding industry partnerships to support the integration of cutting-edge technologies in TVET curricula. Leveraging digital platforms for training delivery ensures wider access and scalability.

d. Promoting inclusive policies to ensure underrepresented groups, particularly women, have access to STEM opportunities, addressing equity concerns noted in the GEM Report 2023 and the ASEAN Work Plan. SEAMEO VOCTECH's community-based initiatives further this goal by delivering tailored training programmes.

3. Conclusion

Integrating STEM into TVET is essential for equipping Southeast Asia's workforce with the skills needed for the Fourth Industrial Revolution. Collaborative efforts among governments, industries, and educational institutions are crucial to overcoming challenges and achieving sustainable development. By implementing the recommendations of the Bangkok Statement and aligning with frameworks such as the ASEAN Work Plan, the SEAMEO Strategic Plan, and global reports, ASEAN countries can build resilient, inclusive, and future-ready TVET systems that drive regional growth and innovation.

Embedding STEM in TVET empowers Southeast Asian learners with future-ready skills, promotes lifelong learning, and strengthens regional resilience in alignment with the SDGs. This strategic focus ensures that education serves as a catalyst for sustainable economic and social development.

Bangkok Statement on Science, Technology, Engineering and Mathematics (STEM) Education in Technical Vocational Education

Section 1: Preamble

1. We, the participants from academic institutions and government agencies across Malaysia, the Philippines, and Thailand, convened at Rajamangala University of Technology Lanna in Chiang Mai, Thailand, from February 5-7, 2024. This collaboration between SEAMEO STEM-ED and SEAMEO VOCTECH, supported by the International Labour Organization, focused on the integration of STEM (Science, Technology, Engineering, and Mathematics) into Technical Vocational Education and Training (TVET). Additionally, a follow-up webinar held on May 29, 2024 and Integrated STEM Leadership Summit held on June 11-12, 2024, showcased and validated our STEM in TVET recommendations with leaders from development partners, government, academia, and industry.
2. **We recognise** the transformative potential of STEM competencies, both in traditional and expansive definitions, to meet the demands of the Fourth Industrial Revolution and to empower the workforce in Southeast Asia with the skills necessary for future challenges.
3. **We acknowledge** the tradition of TVET to include STEM knowledge in technology and engineering but often with a limited scope.
4. **We highlight** the urgent need to adequately prepare our students for current and future demands by enhancing the integration of STEM into the TVET curriculum.

Section 2: Recommendations

To enhance TVET through STEM Education, we recommend:

1. Harmonise Understanding of STEM Competency: Develop common regional guidelines and definitions of STEM competencies specific to TVET.
2. Focus on Outcomes and Sustainability: Emphasise skilled training outcomes and sustainable practices within TVET programmes.
3. Adapt to Local Contexts: Customise STEM education programmes to the unique needs and contexts of each Southeast Asian country.
4. Foster Government-Industry Collaboration: Strengthen partnerships to integrate STEM more deeply into industrial training and cooperative education programmes.
5. Enhance Teacher Training and Support: Provide professional development opportunities for teachers to effectively integrate and interpret STEM in the educational process.
6. Implement Holistic Assessment Methods: Utilise innovative assessment methodologies to monitor student progress effectively.
7. Promote Innovation and Creativity: Support the creation of innovation centres and makerspaces to foster creativity and practical skills.
8. Share Best Practices and Collaborate Regionally: Establish platforms for sharing successful practices and enhancing regional collaboration on STEM in TVET.
9. Develop a Joint Regional Strategic Plan: Address baseline research, learning resources, and curriculum development to enhance STEM integration.

Section 3: Ways forward

1. Develop further action plans based on the provided recommendation.
2. Share the recommendations and action plan with the ASEAN TVET Council.
3. Continue to identify and engage partners to implement these strategies.
4. Monitor and report on the progress of these initiatives regularly.

References

Angela Elzir & Matteo Morgandi (2024). Building Digital Literacy and Skills to Reflect the Needs of the Job Market. *World Bank.* https://documents1.worldbank.org/curated/en/099714205022428058/pdf/IDU18de6d0dd130d5146e2181b51803ab8411275.pdf

ASEAN Secretariat. (2021). ASEAN Work Plan on Education 2021-2025. Retrieved from the ASEAN website. https://asean.org/wp-content/uploads/2022/04/Public-Release-ASEAN-Work-Plan-on-Education-2021-2025.pdf

International Labour Organization (ILO). (2017). ILO Women in STEM Workforce Readiness and Development Program. Reports and Frameworks (2017-2019). https://www.ilo.org/projects-and-partnerships/projects/women-stem-workforce-readiness-and-development-programme

SEAMEO STEM-ED. (2024). Bangkok Statement on Integrated STEM Education in Technical Vocational Education and Training (TVET). https://www.seameo-stemed.org/research-publication/summary-report/

SEAMEO STEM-ED. (2024). Pre-Summit Webinar Report: Integrated STEM Leadership Summit. International Labour Organization (ILO). (2016). ASEAN Jobs in Transformation. https://www.ilo.org/sites/default/files/wcmsp5/groups/public/@ed_dialogue/@act_emp/documents/publication/wcms_579553.pdf

SEAMEO Secretariat. (2021). SEAMEO Strategic Plan 2021-2030. https://www.seameo.org/Main_programme/419

SEAMEO VOCTECH. (2024). Regional Initiatives in TVET Innovation. https://voctech.org/training/innovative-projects-and-initiatives/

UNESCO. (2023). Global Education Monitoring (GEM) Report. https://www.google.co.th/books/edition/Global_Education_Monitoring_Report/te7UEAAAQBAJ?hl=en&gbpv=1&printsec=frontcover

World Bank. (2023). Education and Workforce Development Initiatives. https://www.worldbank.org/en/topic/education

World Bank Group. (2024). World Development Report 2024. https://www.worldbank.org/en/publication/wdr/wdr-archive?utm_source=chatgpt.com

World Economic Forum. (2023). Future of Jobs Report. https://www.weforum.org/publications/series/future-of-jobs/

TEACHER

SECTION

TEACHING SCIENCE WITH GAMIFICATION: ACTION RESEARCH WITH CLASS SEVEN STUDENTS

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ABSTRACT

This study explored how gamification affects learning outcomes in science education, specifically among seventh-grade students. Using a quasi-experimental research design, the research compared instruction based on gamification (Sheppard Software) with traditional teaching (Chalk and Board) in the science unit on Living Things and the Environment. A pre-test was conducted to assess the students' prior knowledge and inform intervention strategies. Over a period of five weeks, gamification techniques were applied to the Experimental Group (EG), while the Control Group (CG) received traditional instruction. The post-test results showed a significant improvement in academic performance for both groups, with the EG achieving a 36% greater improvement compared to the CG. This reduction in performance variability within the experimental group highlights the potential of gamification to promote equity. However, factors such as scalability, resource needs, and teacher readiness are important to consider for wider implementation.

Keywords: gamification, performance variability, learning outcome, intervention strategies

1. Introduction

1.1 Background

Education is a constantly evolving process that has always adapted to the needs of learners and the requirements of the modern world. In recent years, educators have become increasingly interested in innovative teaching methods that can engage students more effectively and improve their learning experience (Baeten et al., 2013). One effective approach is gamification, which incorporates game elements and mechanics into non-game settings, such as classrooms, to boost student motivation and enhance learning outcomes (Dicheva et al., 2015; Papadakis et al., 2020; Carrillo et al., 2019; Reichelt, 2015).

Gamification leverages one of the core attractions of games: competition, achievement, rewards, and progression. By incorporating elements like points, badges, leaderboards, and challenges, gamification has the potential to transform traditional teaching and learning methods, making them more engaging (Reichelt, 2015; Bal, 2019). This approach is especially relevant in science education, where abstract concepts and complex theories can be challenging for many students to grasp (Papadakis et al., 2018; Loganathan et al, 2019).

The science curriculum includes both theoretical and practical components that encourage students to engage actively and tackle problems. While traditional teaching methods can be somewhat effective, they often fail to address the varied interests and learning styles of students. Science subjects, with their perceived complexity and abstract nature, can be

intimidating for middle schoolers. However, gamification has been shown to boost motivation, encourage collaboration, and enhance understanding of scientific concepts (Vidakis et al., 2020; Papadakis et al., 2018; Arnold, 2014; Morris et al., 2013).

Teaching science to middle school students has proven to be quite difficult for researchers. Many students struggle with abstract or theoretical scientific concepts, and conventional teaching methods often do not capture their interest or ignite their curiosity. As a result, students may become disengaged from lessons or fail to grasp the material fully, leading to decreased motivation and lower academic performance in science.

To address this challenge, integrating gamification into the classroom has emerged as a promising approach. Nevertheless, there is still a lack of research on its specific application within the science curriculum for seventh-grade students in the context of Bhutanese education. This study aimed to fill this gap by exploring the impact of gamified learning strategies on science education, specifically looking at how these activities influence students' academic performance in the subject. The following objective and the question guided the course of this study:

1.2 Objective

Examine the relationship between gamification and academic performance in science.

1.3 Question

What is the effect of gamification on academic performance in science?

2. Review of Literature

2.1 Definition

Gamification refers to the application of game design elements in contexts that are not games (Deterding et al., 2011; Groh, 2012; Simões et al., 2012; Prince, 2013). This approach involves incorporating features and mechanics from games—like points, rewards, levels, challenges, and leaderboards—into non-game environments to boost motivation and engagement in tasks that might otherwise feel dull or repetitive (Bozkurt and Genc, 2024; Werbach and Hunter, 2012). In recent years, this growing field has gained traction, focusing on enhancing user motivation and involvement with non-gaming activities (Stocco et al., 2017). The idea first emerged in the digital media sector around 2008 but saw widespread adoption by 2010 (Deterding et al., 2011). Gamification can be understood as a process that embeds game elements into non-game contexts, leading to gamic features (Yohannis et al., 2014). While it differs from serious games and playful interactions, the term is still debated within the industry (Deterding et al., 2011). Thus, gamification represents a modern strategy that employs game mechanics in educational settings to foster student motivation and improve academic performance. By integrating essential gaming components such as points, badges, levels, challenges, and instant feedback, it turns conventional learning into an engaging, dynamic, and enjoyable experience.

2.2 Gamification in Education

Gamification, which involves incorporating game elements into non-game settings, has become increasingly popular in education due to its ability to boost student engagement and motivation (Suh et al., 2018; Borges et al., 2014). Studies show that gamification can enhance student attendance, participation, and overall learning experiences in both schools and

universities (Rashid and Suganya, 2017). By using various game-related features like points, badges, and leaderboards, educators can create a more enjoyable and motivating learning atmosphere (Rashid and Suganya, 2017; Avsar, 2017). Additionally, combining computational thinking techniques with gamification has been proposed to help students tackle intellectual challenges in their courses (Huang et al., 2019; Avsar, 2017). A review of 120 papers published between 2011 and 2014 highlights the growing popularity of gamification across different educational contexts, from primary schools to higher education, and indicates a developing consensus on its definition and use in the field (Caponetto et al., n.d.).

2.3 The use of Gamification in Science

Gamification in science has produced varied outcomes regarding student performance and engagement. Some research indicates a positive link between gamification and higher test scores, with features like leaderboards, badges, and points boosting student involvement and achievement in physics and other STEM disciplines (Rose et al., 2016; Tiria and Caballes, 2019). Incorporating gamification into mathematics and science education can aid in developing higher-order cognitive skills, including problem-solving and critical thinking (Incikabi et al., 2020). The use of technology-driven gamification in science classrooms has proven particularly effective in capturing students' attention and enhancing their understanding of concepts (Loganathan et al., 2019; Arnold, 2014; Morris et al., 2013). These features can enhance motivation and participation beyond the basic course requirements (Rose et al., 2016). On the other hand, some studies suggest that gamification might negatively impact intrinsic motivation, satisfaction, and academic performance in certain situations (Hanus and Fox, 2015). The effects of gamification seem to differ across various STEM areas, with most research concentrating on computer science-related subjects (Ortiz et al., 2016). Nonetheless, successful implementation demands careful planning and execution. Some challenges, such as unreliable internet connections and possible demotivation stemming from competitive aspects, have been identified (Loganathan et al., 2019). Despite these obstacles, gamification continues to be a promising strategy for educators aiming to engage digital-native students and improve their learning experiences in science education.

3. Methodology

A quasi-experimental research design was adopted for this study analysing Pre-Test and Post Test scores of Control Group (CG) and Experimental Group (EG) as indicated in table 1. The control and experimental groups were randomly determined.

Table 1: Experimental Design

Groups	Pre-Test	Experimental Manipulation	Post-Test
Experimental Group	Academic achievement test	Gamification (Sheppard Games)	Academic achievement test
Control Group	Academic achievement test	Chalk and Board approach	Academic achievement test

3.1 Participants

The study group consisted of fifty-five seventh-grade students. The participants for both the experimental and control groups were selected randomly. In this study, class 7C (n=28) was designated as the Control Group, while class 7B (n=27) was selected as the Experimental Group.

3.2 Instrument

The study used academic test scores from a specific science unit as its main data source. To address the research question, both Pre-Test and Post-Test assessments were conducted. A total of 50 multiple-choice questions were developed, with four answer options for each question, aimed at evaluating knowledge related to the science unit on "Living Things and the Environment." A pre-test was used to establish a baseline measure of the participants' existing knowledge, giving insight into their prior understanding of the unit. After analysing the pre-test data, the intervention strategies were implemented.

3.3 Intervention Strategies

The intervention strategies were carried out based on the analysis of the baseline data. The study included a Control Group (CG) and an Experimental Group (EG) to evaluate the effects of different teaching methods. The control group was instructed using the traditional Chalk and Board approach, covering all topics in the "Living Things and Environment" unit. In contrast, the experimental group experienced a gamification treatment known as Sheppard Software, aimed at teaching the same topics. The activities for both the teaching methods lasted for five weeks. After implementing the respective teaching methods, a post-test was conducted to measure the impact of the interventions on student performance. To analyse the data, descriptive statistics—such as frequencies, means, percentages, and standard deviations—were used to present and interpret quantitative results clearly and meaningfully.

Sheppard Software is an online platform that offers a wide range of educational games covering various subjects. The platform incorporates gamification elements like rewards, interactivity, and progressive challenges to enhance learning outcomes. Users can earn points for correct answers through a point-based scoring system. Immediate feedback is provided to indicate whether the answers are correct. Upon completing levels or achieving high scores, learners receive badges, stars, or congratulatory messages as rewards.

The Chalk and Board method is a traditional teaching style where the instructor uses a blackboard or whiteboard along with chalk or markers to deliver lessons. This method focuses on direct, teacher-led instruction, guiding students through the material step-by-step. Teachers engage students by asking questions, inviting them to solve problems on board, or encouraging group discussions. Assessments are carried out through in-class exercises, quizzes, or oral questioning, which allows for real-time feedback.

4. Results and Discussion

4.1 Pre-intervention: Baseline result

The baseline data, derived from the pre-test on the unit "Living Things and Environment," provided the foundational reference for later analysis. The mean scores and standard deviations of EG and CG summarised in Table 2 served as critical benchmarks informing the design and implementation of targeted intervention strategies.

Table 2: Pre-test result

Group	Mean	SD
EG	7.76	2.30
CG	8.34	2.51

As indicated in table 2, the mean score for EG is 7.76, and for CG, it is 8.34. These values indicate the average pre-test performance for the respective groups. EG has a standard

deviation of 2.30, while CG has a slightly higher SD of 2.51. This shows more variability in CG's pre-test scores compared to EG.

4.2 Post-intervention Findings

Following a five-week implementation of intervention strategies with the experimental group (EG), a post-test was administered to evaluate the effectiveness of gamification. The differences between the pre-test and post-test scores for both groups were analysed to assess the impact of the intervention. A summary of the test results is provided in Table 3.

Table 3: Comparative result of pre-test and post-test performance.

Groups	**Pre-test**		**Post-test**		**Difference**
	Mean	SD	Mean	SD	Mean
EG	7.76	2.30	11.40	1.70	3.64
CG	8.34	2. 51	11.01	2.76	2.67

The EG's mean increased from 7.76 to 11.40, with a difference of +3.64 and the CG's mean increased from 8.34 to 11.01, with a difference of +2.67. Both groups have an indication of improved performance, but EG showed a larger improvement (mean difference of 3.64) compared to CG (mean difference of 2.67). This suggests that the intervention strategies applied to the experimental group had a more substantial impact on their performance compared to the control group. The Post-test SD decreased for EG (from 2.30 to 1.70), suggesting a more consistent performance in the experimental group after intervention, while for CG, post-test SD increased slightly (from 2.51 to 2.76), showing more variability in post-test performance.

The greater improvement in the experimental group suggests the intervention was effective in enhancing performance. The reduction in variability (SD) for EG implies that the intervention not only improved scores on average but also helped bring participants to a more uniform level of achievement. The EG's improvement (mean difference of 3.64) is approximately 36% greater than CG's improvement (mean difference of 2.67). This is a notable advantage favoring the experimental group's intervention. Table 2 provides compelling evidence that the intervention applied to the EG was effective in improving both average performance and consistency of outcomes. In contrast, the CG showed improvement, but it was less pronounced and more variable. These results highlight the value of the intervention and its potential for broader application or further investigation.

The findings align with existing literature emphasising the motivational and cognitive benefits of gamification in education. For instance, Gibson et al., (2015), Faghihi et al., (2014), MacKinnon et al., (2015) and Turan et al., (2016) highlight that gamified learning environments foster greater engagement, which, in turn, enhances knowledge retention and application. Similarly, the recent studies (Huang et al., 2019; Kim et al., 2018; Marín et al., 2018) note that the inclusion of game-like elements such as rewards, challenges, and feedback mechanisms can stimulate intrinsic motivation and improve learning outcomes. In this study, the use of Sheppard Games provided similar benefits by transforming the learning process into an interactive and enjoyable experience.

The EG's improvement, approximately 36% greater than CG's, demonstrates gamification's potential to drive significant academic gains. This aligns with research by Khan et al., (2017) and Yıldırım (2017), who found that gamification strategies were particularly effective in promoting active learning and collaboration. The consistent performance gains within EG also support findings by Buckley and Doyle (2014) and Hanus and Fox (2015), which indicate that gamification reduces learning disparities by catering to diverse student needs.

The decrease in performance variability within the experimental group underscores the potential of gamification to promote equity in education. By creating an engaging and supportive learning atmosphere for all students, gamification can help close achievement gaps, especially in diverse classrooms. This aligns with the work of Domínguez et al. (2013) and Hamari and Koivisto (2014), who support gamification to encourage inclusive education. Nevertheless, there are still questions about whether this effect is more beneficial for certain learner profiles and how it might apply to different subjects or contexts. Gamification may particularly advantage students who thrive in competitive or interactive settings, possibly leaving those with other learning preferences less catered to.

The findings of the study carry significant implications for how curricula are designed and how instruction is delivered. The notable improvement observed in the experimental group highlights the need for innovative teaching methods that focus on engaging students. By incorporating gamified elements into traditional curricula, we can not only boost academic performance but also enrich the overall learning experience. However, while gamification appears promising, implementing it on a larger scale presents challenges in the current educational landscape, including limited infrastructure and resources, inconsistent internet access, the necessity for teacher training in gamified approaches, and the diverse learning needs of students. Nevertheless, with appropriate strategies, training, and resource distribution, gamification could greatly enhance the educational experience in Bhutanese schools, fostering active participation, collaboration, and critical thinking.

4.3 Limitations

While the study demonstrates the effectiveness of gamification, it is important to acknowledge certain limitations. The sample size (n=55) is small, and the study focuses on a single science unit. Future research could explore the long-term effects of gamification across diverse subjects and larger student populations.

5. Conclusion

This study highlights the significant impact of gamification on improving science education outcomes for seventh-grade students. By contrasting gamification-based instruction with traditional teaching methods, the research found that gamification not only boosts academic performance but also leads to more consistent learning results, as shown by the reduced variability in the experimental group.

The experimental group demonstrated a 36% greater improvement in test scores compared to the control group, showcasing the effectiveness of gamification. These results are consistent with existing literature that points to the motivational, cognitive, and equity-enhancing advantages of gamified learning. Additionally, the study emphasises the need for innovative teaching methods to meet the diverse learning needs of students. While the

research validates the benefits of gamification, it also highlights areas for further investigation. Practical challenges such as scalability, resource availability, and teacher readiness require additional attention. Future research should explore the long-term effects of gamification and its relevance in various educational contexts.

In summary, gamification serves as a powerful tool for transforming science education, closing achievement gaps, and creating a more inclusive and engaging learning environment. As educators and policymakers aim to update curricula, this study supports the thoughtful integration of gamification to nurture a generation of motivated, confident, and scientifically literate learners.

References

Arnold, B. J. (2014). Gamification in education. *Proceedings of the American society of Business and Behavioral Sciences*, *21*(1), 32-39.

Avsar, E. K. (2017). Analysis of gamification of education. *The Online Journal of New Horizons in Education*, *7*(1), 20-23.

Bal, M. (2019). Use of Digital Games in Writing Education: An Action Research on Gamification. *Contemporary Educational Technology*. *10*(3), 246-271.

Baeten, M., Struyven, K., & Dochy, F. (2013). Student-Centred Teaching Methods: Can They Optimize Students' Approaches to Learning in Professional Higher Education? *Studies in Educational Evaluation*, *39*(1), 14-22.

Borges, S.D., Durelli, V.H., Reis, H.M., & Isotani, S. (2014). A systematic mapping on gamification applied to education. *Proceedings of the 29th Annual ACM Symposium on Applied Computing*.

Caponetto, I., Earp, J., & Ott, M. (n.d.). Gamification and Education: Literature.

Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to game: Defining "gamification". *In Proceedings of the 2011 Annual Conference Extended Abstracts on Human Factors in Computing Systems.*

Dicheva, D., Dichev, C., Agre, G., & Angelova, G. (2015). Gamification in Education: A Systematic Mapping Study. *Journal of educational technology & society*, *18*(3), 75-88.

Domínguez, A., Saenz-de, N., de-Marcos, L., Fernández-, S., Pagés, C., & Martínez, H. (2013). Gamifying learning experiences: Practical implications and outcomes. *Computer & Education, 63*, 380-392.

Faghihi, U., Brautigam, A., Jorgenson, K., Martin, D., Brown, A., Measures, E., & Maldonado Bouchard, S. (2014). How gamification applies for educational purposes, specially with college algebra. *Procedia Computer Science*, 41, 182–187.

Gibson, D., Ostashewski, N., Flintoff, K., Grant, S., & Knight, E. (2015). Digital badges in education. *Education and Information Technologies*, 20, 403–410.

Groh, F. (2012). Gamification: State of the art definition and utilization. *Institute of Media Informatics Ulm University*, *39*, 31.

Hamari, J., & Koivisto, J. (2014). Measuring flow in gamification: Dispositional flow scale-2. *Computers in Human Behavior*, 40, 133-143.

Hanus, M. D., & Fox, J. (2015). Assessing the effects of gamification in the classroom: A longitudinal study on intrinsic motivation, social comparison, satisfaction, effort, and academic performance. *Computers & education, 80*, 152-161.

Huang, B., Hew, K., & Lo, C. (2019). Investigating the effects of gamification-enhanced flipped learning on undergraduate students' behavioral and cognitive engagement. *Interactive Learning Environments*, 27(8), 1106–1126. https://doi.org/10.1080/10494820.2018.1495653

Hursen, C., & Bas, C. (2019). Use of gamification applications in science education. *International Journal of Emerging Technologies in Learning (Online)*, *14*(1), 4-23.

Incikabi, L., Kepceoglu, I., & Pektas, M. (2020). Gamification of Middle School Mathematics and Science. *Advances in Educational Technologies and Instructional Design*.

Khan, A., Ahmad, F., & Malik, M. (2017). Use of digital game-based learning and gamification in secondary school science: The effect on student engagement, learning and the effect on student engagement, learning and gender difference. *Education and Information Technologies, 22, 2767–2804.* https://doi.org/10.1007/s10639-017-9622-1

Kim, E., Rothrock, L., & Freivalds, A. (2018). An empirical study on the impact of lab gamification on engineering students' satisfaction and learning. *International Journal of Engineering Education*, 31(1), 201–216.

Loganathan, P., Talib, C., Thoe, N., Aliyu, F., & Zawadski, R. (2019). Implementing technology infused gamification in science classroom: A systematic review and suggestions for future research. *Sci. Math*, 14, 60–73.

López Carrillo, D., Calonge García, A., Rodríguez Laguna, T., Ros Magán, G., & Lebrón Moreno, J. A. (2019). Using gamification in a teaching innovation project at the University of Alcalá: A new approach to experimental science practices. *Electronic Journal of E-learning*, *17*(2), 93-106.

MacKinnon, R. J., Stoeter, R., Doherty, C., Fullwood, C., Cheng, A., Nadkarni, V., ... & Chang, T. P. (2015). Self-motivated learning with gamification improves infant CPR performance, a randomised controlled trial. *BMJ Simulation & Technology Enhanced Learning*, *1*(3), 71-76.

Marín, B., Frez, J., Cruz-Lemus, J., & Genero, M. (2018). An empirical investigation on the benefits of gamification in programming courses. *ACM Transactions on Computing Education (TOCE)*, 19(1), 1–22.

Morris, B. J., Croker, S., Zimmerman, C., Gill, D., & Romig, C. (2013). Gaming science: the "Gamification" of scientific thinking. *Frontiers in psychology*, 4, 607.

Ortiz Rojas, M. E., Chiluiza, K., & Valcke, M. (2016). Gamification in higher education and stem: A systematic review of literature. In *8th International Conference on Education and New Learning Technologies (EDULEARN)* (pp. 6548-6558). Iated-int Assoc Technology Education A& Development.

Papadakis, S., Marios Trampas, A., Barianos, A., Kalogiannakis, M., & Vidakis, N. (2020). Vidakis, N. Evaluating the Learning Process: The "ThimelEdu" Educational Game Case Study. In Proceedings of the 12th International Conference on Computer Supported Education, (2), 290–298.

Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2018). The effectiveness of computer and tablet assisted intervention in early childhood students' understanding of numbers. An empirical study conducted in Greece. *Education and Information Technologies*, *23*, 1849-1871.

Prince, J. D. (2013). Gamification. *Journal of Electronic Resources in Medical Libraries*, 10(3), 162-169. https://doi.org/10.1080/15424065.2013.820539

Rashid, M. B., & Suganya, P. (2017). Gamification: An initiative to increase engagement and performance in education. *International Journal of Advance Research, Ideas and Innovations in Technology*, *3*(3), 7-16.

Reichelt, A.L. (2015). Effects of gamification: analyzing student achievement, mastery, and motivation in science classrooms.

Rose, J. A., O'Meara, J. M., Gerhardt, T. C., & Williams, M. (2016). Gamification: using elements of video games to improve engagement in an undergraduate physics class. *Physics Education*, *51*(5), 055007.

Simões, J., Redondo, R. D., & Vilas, A. F. (2013). A social gamification framework for a K-6 learning platform. *Computers in human behavior*, *29*(2), 345-353. https://doi.org/10.1016/j.chb.2012.06.007

Stocco, M., Ganaba, M., Tondello, G. F., & Nacke, L. E. (2017, May). Defining Gamification Video. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, 472-472.

Suh, A., Wagner, C., & Liu, L. (2018). Enhancing user engagement through gamification. *Journal of Computer Information Systems*, *58*(3), 204-213.

Tiria, R. A., & Caballes, D. G. (2019). The Role of Gamification on Students Academic Performance in Senior High School Physical Science Course. *Automation and Autonomous Systems*, *11*(3), 41-44.

Turan, Z., Avinc, Z., Kara, K., & Göktas, Y. (2016). Gamification and education: Achievements, cognitive loads, and views of students. *Int. J. Emerg. Technol. Learn.*, *11*(7), 64-69.

Vidakis, N., Barianos, A., Trampas, A., Papadakis, S., Kalogiannakis, M., & Vassilakis, K. (2020). Game Raw Data Collection and Visualization in the Context of the "ThimelEdu" Educational Game. In Computer Supported Education, 1220.

Werbach, K., & Hunter, D. (2012). *For the win: How game thinking can revolutionize your business*. Wharton Digital Press.

Werbach, K., & Hunter, D. (2020). *For the win, revised and updated edition: The power of gamification and game thinking in business, education, government, and social impact*. University of Pennsylvania Press.

Yıldırım, İ., & Şen, S. (2019). The effects of gamification on students' academic achievement: A meta-analysis study. *Interactive Learning Environments*, 1-18.

Yohannis, A. R., Prabowo, Y. D., & Waworuntu, A. (2014, November). Defining gamification: From lexical meaning and process viewpoint towards a gameful reality. In *2014 International Conference on Information Technology Systems and Innovation (ICITSI)* (pp. 284-289). IEEE.

GENETIC LINKAGE ANALYSIS OF INCOMPLETE DOMINANT PAIR IN COMMON BEAN CULTIVARS (*PHASEOLUS VULGARIS*) BY USING DIRECT CALCULATION AND MAXIMUM LIKELIHOOD ESTIMATE CALCULATION METHODOLOGY

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ABSTRACT

In this study, the vine cultivar. “Haibushi” had a normal purple stem and red flower colour crossed with a vine-less cv. “Morocco” had a short green stem and white flower colour. 1) The objective of this study was to explain how to use the maximum likelihood estimate calculation compared with direct calculation methodology on the result of the common bean cross (F_2) for higher school biology education. 2) To analyse the recombinant pair of common bean genes. First, the expected genotypes constructed value of F_2 characteristics linkage was calculated by the direct calculation method. Then the Maximum Likelihood Estimate (MLE) method was used to calculate the reliability of the direct calculation method. Results showed that F_1 had a normal mixed stem and pink flower colour. F_2 populations obtained from all F_1 self-fertilised plants have the ratio 1:2:1 in purple: mixed: green in stem colour and red: pink: white in flower colour with p-value>0.05. The results of the chi-square tests of genetic linkage in stem colour and flower colour characteristics showed no significant differences between observed and expected values. The result indicated that genetic linkage and map distance calculation was 9.7% to 21.6% of incomplete dominance characteristics pair, stem colour, and flower colour. The result of the MLE calculation method showed that four of five of the F_2 populations did not detect significant differences between observed and expected values because r-*values* from the direct calculation and MLE methods resembled. Thus, the genetic linkage calculated by direct calculation used in this study was acceptable. The proportion 9:7 caused by gene epistasis from this research was suited to explainability. Students use Punnett’s table to produce the genotypes proportion then use the Excel software to construct the recombinant genotypes instead of MLE which is complicated for high school students.

Keywords: genetic linkage, Phaseolus vulgaris, direct calculation method, Maximum Likelihood Estimate, high school biology education.

1. Introduction

Genetic factors responded to phenomena expression as the flower colour, and seed coat colour in F_2 offspring generation (Herniter et al., 2024). Non-Mendelian inheritance is proposed as other concepts are not described in Mendel’s law which is that it is not more popular for high school students to practicum their learning. Those non-Mendel’s laws included incomplete dominance, codominance, multiple alleles, sex-linkage traits, and multigene trait events (Strome et al., 2024). Thomas Hunt Morgan found the genetic linkage, using the backcross population of fruit flies. The fruit fly has no di-phenotype male and female, and there was no self-fertilisation. In high school, using fruit flies for the general study was difficult because teachers had to keep parents trained by feeding them. It was easy to use self-

fertilisation in plants to produce an F_2 population (Morgan T. H., 1911), but in genetic linkage, calculating the recombination value was very difficult due to the dominance characteristic involved in both homozygous and heterozygous genotypes, and it was also difficult to separate the homozygous and heterozygous on observation phenotypes. The incomplete dominance was described in Cambodian high school textbooks and students learned that the hetero type should be an intermediate characteristic. A direct calculation method was introduced to calculate the genetic linkage mathematically. The direct calculation method was used in any research field in terms of different calculation parameters, such as estimating the ecosystem levels (Vogt et al., 1998), and the expected genetic parameter of the Turkey common bean (Bilir et al., 2019), mating ecology (Gardner and Ross, 2014), and mathematical approach (Pupeikis, 2000). Two allele probabilities of the F_2 diploid population could be the individual shared (Lipatov et al., 2015), they can also be calculated by directly expecting the genotype value to be reconstructed. In the other report, Joseph 1973 assumed the minimum-steps method verified by Maximum Likelihood Estimation (Josep F., 1973). In this case, there were no reports that direct calculation methods were largely explained in high school biology education. Thus, in this study, two incomplete dominance characteristics were found from crossing between two cultivars in the common bean (*Phaseolus vulgaris* L.). By the way, this segregation did not follow Mendelian 3rd law. Therefore, the use of common beans with incomplete dominance characteristics in the genetic linkage for education material tried to develop for biology experimental classes in high school education.

The Maximum Likelihood Estimation (MLE) is a method used to estimate the parameters of a mathematical model (Allard R.W, 1956). Allard 1956 reported this MLE method to estimate recombination value heredity in the F_2 population. He proposed the expected genotype value from an incomplete dominance gene pair by using the probability of recombination rate (r) as the parameter. However, this formula made it difficult for high school students to practice their calculations. Using MLE here aimed to verify whether the direct calculation method used in this study is reliable or not.

2. Methods and Materials

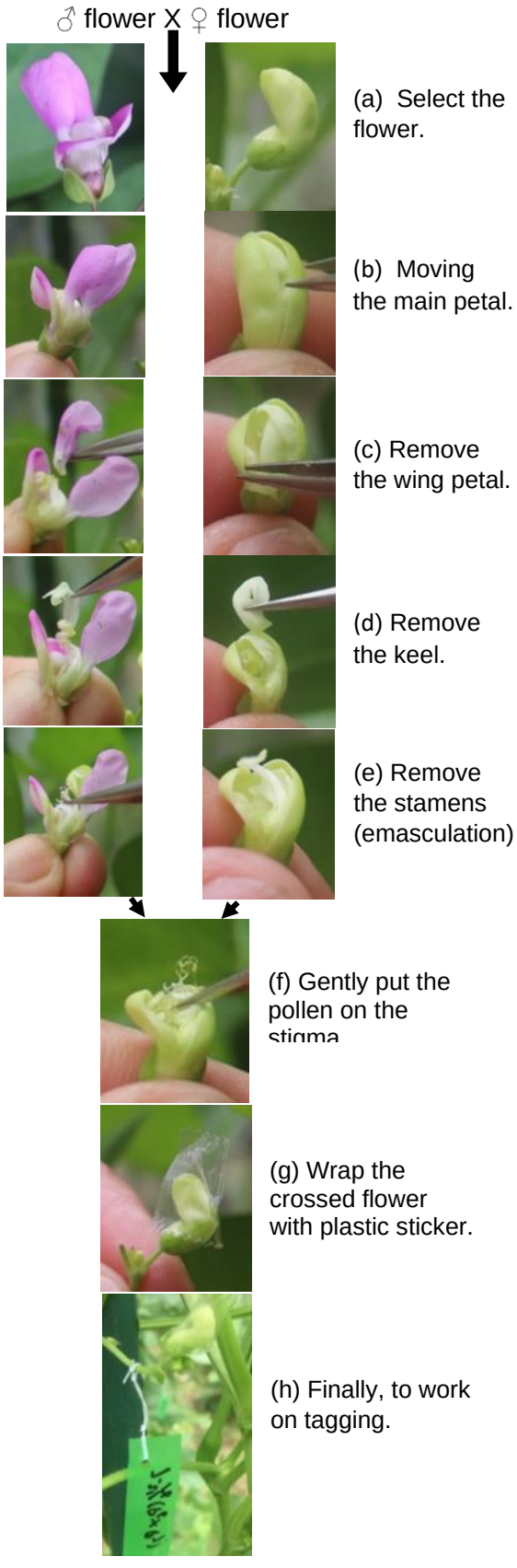
2.1 Plant Materials Selection

The crossing chose the commercial common bean vine cultivar Haibushi as a male parent and a vine-less cultivar Morocco as the female parent. The cultivar Haibushi has normal purple stems, red flowers, and black seed phenomena. The cultivar Morocco had a short green stem colour, white flowers, and white seeds phenomena. These two different parental phenomena are simple to recognise and perform cross techniques.

2.2 Crossing Method

The crossing method used in this study was adapted from techniques of bean crossing performed by Steve Temple et al., 1987. They established two ways of hand pollination: (1) pollination without the emasculation of a female flower and (2) pollination with the emasculation of a female flower. The crossing technique in this study used pollination with the emasculation of the female flower to ensure that self-fertilising is blocked. First, a flower bud (before the flower opened stage) was selected from the Morocco cultivar as a female flower, and an opened flower was selected from the Haibushi cultivar as a male flower (Figure 1a). The techniques of female flower emasculation and collection of pollen from male flowers were done in the same steps (Figure 1b-e). The emasculation of female flowers was done very carefully. The female flower was emasculated by gently holding the flower between the thumb and index finger, then using the forceps' tip to open the petal and wing petal and fold it out direction until the keel is found (Figure 1bc). Gently removed the keel which covered the free stigma, then used forceps to cut all stamens from the part around the stigma (Figure 1d). Then use a pressure plastic bottle with cleaning water to spray on the stigma to ensure that all pollen is removed. For the male parent flower, a forceps' tip collects the stamen and then attaches to the female emasculated stigma (Figure 1f). Finally, fold the female's petal to close the crossed pistil, then cover the pistil with a plastic sticker to keep the moisture inside the flower for fertilisation support and to protect the crossing flower from insect attaching (Figure1g). Finally, the crossed flower was labelled (Figure 1h).

Figure 1: The crossing



2.3 The F_2 Genotype Construction Methods

In the meiosis phase, the F_1 genotype was designed as $\frac{st^{pig}-fl^{pig}}{g-w}$ Where st^{pig} and fl^{pig} represented the purple stem colour and red flower colour alleles, while the *g* and *w* represented the green stem colour and white flower colour alleles, respectively. Then, four

chromosome phenomena were produced, in which two (st^{pig}-fl^{pig}) and (*g*-*w*) were parental genotypes, and two other (st^{pig}-*w*) and (*g*-fl^{pig}) were linked genotypes. The construction of phenotypes and genotypes was produced by using the Punnet square (Table 1).

Table 1: The F_2 phenotypes and genotypes construction.

F_1 gamete		♀ pistil			
		st^{pig}-fl^{pig}	***st^{pig}-w***	***g-fl^{pig}***	***g-w***
♂ pollen	***st^{pig}-fl^{pig}***	$\frac{st^{pig}-fl^{pig}}{st^{pig}-fl^{pig}}$ purple-red	$\frac{st^{pig}-w}{st^{pig}-fl^{pig}}$ purple-pink	$\frac{g-fl^{pig}}{st^{pig}-fl^{pig}}$ mixed-red	$\frac{g-w}{st^{pig}-fl^{pig}}$ mixed-pink
	st^{pig}-w	$\frac{st^{pig}-fl^{pig}}{st^{pig}-w}$ purple-pink	$\frac{st^{pig}-w}{st^{pig}-w}$ purple-white	$\frac{g-fl^{pig}}{st^{pig}-w}$ mixed-pink	$\frac{g-w}{st^{pig}-w}$ mixed-white
	g-fl^{pig}	$\frac{st^{pig}-fl^{pig}}{g-fl^{pig}}$ mixed-red	$\frac{st^{pig}-w}{g-fl^{pig}}$ mixed-pink	$\frac{g-fl^{pig}}{g-fl^{pig}}$ green-red	$\frac{g-w}{g-fl^{pig}}$ green-pink
	g-w	$\frac{st^{pig}-fl^{pig}}{g-w}$ mixed-pink	$\frac{st^{pig}-w}{g-w}$ mixed-white	$\frac{g-fl^{pig}}{g-w}$ green-pink	$\frac{g-w}{g-w}$ green-white

From Table 1, the sixteen F_2 offspring have been produced by self-fertilisation from four F_1's gametes (pistil and pollen gametes). Thus, those offspring were designed as: one purple-red, two purple-pink, two mixed-red, one purple-white, four mixed-pinks, two mixed-white, one green-red, two green-pink, and one green-white. The "*mixed"* here represented the new stem colour of F_2 offspring phenomena which stands in the middle of parental stem colour (purple and green) and "*pink*" represented the middle flower colour between red and white phenomena (Incomplete dominance characteristic).

2.4 Calculation Recombination Rate (*r*) from Observed Population

In Table 1, the expected genotypes and phenotypes were designed using the Punnet square model. The recombination rate was calculated by observing the F_2 characteristic segregation population by using Excel software as the total number of chromosome linkage/total number of chromosomes by the formula: $r = \frac{Total\ Number\ of\ Recombination\ Chromosome}{Total\ Number\ of\ Observed\ Chromosome}$. Where *r* is the recombination rate. Then, $r = \frac{(st^{pig}-w)+(g-fl^{pig})}{(st^{pig}-fl^{pig})+(g-w)+(st^{pig}-w)+(g-fl^{pig})}$. By using the theoretical proportion, the Total proportion of all four-chromosome genotype $st^{pig}-fl^{pig}, g-w, st^{pig}-w$, and $g-fl^{pig}$ equal to 1. Since there are two (st^{pig}-fl^{pig}) and (*g*-*w*) parental genotypes, and two $st^{pig}-w=$ and $g-fl^{pig}$ were linked genotypes. Therefore, the genes of $st^{pig}-w=$ gene of $g-fl^{pig}=\frac{r}{2}$, and genotype of $st^{pig}-fl^{pig} = gene\ of\ \ g-w=\frac{1-r}{2}$.

2.5 Direct Calculation Method for Reconstruction of the Expected Genotypes from Phenotypes Value by using Recombination Rate (*r*)

The expected genotype value = ♀genotype × ♂genotype × number of F_2 population (n). All the expected F_2 genotype value formulas are shown in *Table 2*, sixteen genotypes and nine phenotypes of the F_2 population were produced. To solving genetic linkage, the study directly calculated the expected genotypes from the observed phenotypes using recombination rate (*r*).

Table 2: The formula used to calculate the expected value of genotype characteristics linkage pair, stem colour and flower colour by using the Punnett square.

F_1 gametes		*purple-red*	*purple-white*	*green-red*	*green-white*
		$\frac{1-r}{2}$	$\frac{r}{2}$	$\frac{r}{2}$	$\frac{1-r}{2}$
purple-red	$\frac{1-r}{2}$	$(\frac{1-r}{2})^2 n$	$\frac{r(1-r)}{4}n$	$\frac{r(1-r)}{4}n$	$(\frac{1-r}{2})^2 n$
purple-white	$\frac{r}{2}$	$\frac{r(1-r)}{4}n$	$(\frac{r}{2})^2 n$	$(\frac{r}{2})^2 n$	$\frac{r(1-r)}{4}n$
green-red	$\frac{r}{2}$	$\frac{r(1-r)}{4}n$	$(\frac{r}{2})^2$	$(\frac{r}{2})^2 n$	$\frac{r(1-r)}{4}n$
green-white	$\frac{1-r}{2}$	$(\frac{1-r}{2})^2 n$	$\frac{r(1-r)}{4}n$	$\frac{r(1-r)}{4}n$	$(\frac{1-r}{2})^2 n$

Using the Punnett square model in Table 2, the reconstructed genotypes from nine phenotypes frequency given as formula below:

$Purple-d = \frac{st^{pig}-fl^{pig}}{st^{pig}-fl^{pig}} = \frac{(1-r)^2}{4}n,$

$Purple-Pink = \frac{st^{pig}-fl^{pig}}{st^{pig}-w} + \frac{st^{pig}-w}{st^{pig}-fl^{pig}} = \frac{r(1-r)}{2}n,$

$Purple-White = \frac{st^{pig}-w}{st^{pig}-w} = \frac{r^2}{4}n,$

$Mixed-d = \frac{st^{pig}-fl^{pig}}{g-fl^{pig}} + \frac{g-fl^{pig}}{st^{pig}-fl^{pig}} = \frac{r(1-r)}{2}n,$

$Mixed-Pink = \frac{st^{pig}-fl^{pig}}{g-w} + \frac{g-w}{st^{pig}-fl^{pig}} + \frac{st^{pig}-w}{g-fl^{pig}} + \frac{g-fl^{pig}}{st^{pig}-w} = \frac{r^2+(1-r)^2}{2}n,$

$Green-d = \frac{g-fl^{pig}}{g-fl^{pig}} = \frac{r^2}{4}n,$

$|Green-Pink = \frac{g-fl^{pig}}{g-w} + \frac{g-w}{g-fl^{pig}} = \frac{r(1-r)}{2}n$

$Green-White = \frac{g-w}{g-w} = \frac{(1-r)^2}{4}n.$

Then use the expected genotypes and observed phenotypes value to calculate in chi-square test by Chi-square formula:

$$Chi-square = \sum \frac{(Observed\ Value-Expected\ Value)^2}{Expected\ Value}.$$

2.6 Maximum Likelihood Estimate Calculation Method

Maximum Likelihood Estimate methods were used to estimate the recombination rate from the F_2 population (Allard R.W., 1956). This calculation showed probability. Using the *r* parameter, *the r*-value producing the highest probability was the most reliable, and the chi-square value using this *r*-value could show the minimum value and *the p*-value as highest. The probability function of observed genotypes can be expressed from a multinomial distribution. The probability of frequencies of appearance of observed phenotype number of F_2 is as: $P(r) = \frac{n!\prod_{i=1}^{m}\left(f_{k_i}\right)^{k_i}}{\prod_{i=1}^{m} k_i!}$. Where *m* is the number of observed phenotypes, *n* is the population values $(n = k_1 + k_2 + \ldots + k_m)$, k_i is the observed value and f_{k_i}: the frequency phenotype with recombination rate value.

Note: (*i*) $n! = n(n-1)\ldots.2.1,$

(*ii*) $\prod_{i=1}^{m} \quad k_i! = k_1!\,k_2!\ldots!\,k_m!$

(*iii*) $\prod_{i=1}^{m} \quad \left(f_{k_i}\right)^{k_i} = \left(f_{k_1}\right)^{k_1}\left(f_{k_2}\right)^{k_2}\ldots.\left(f_{k_m}\right)^{k_m}.$

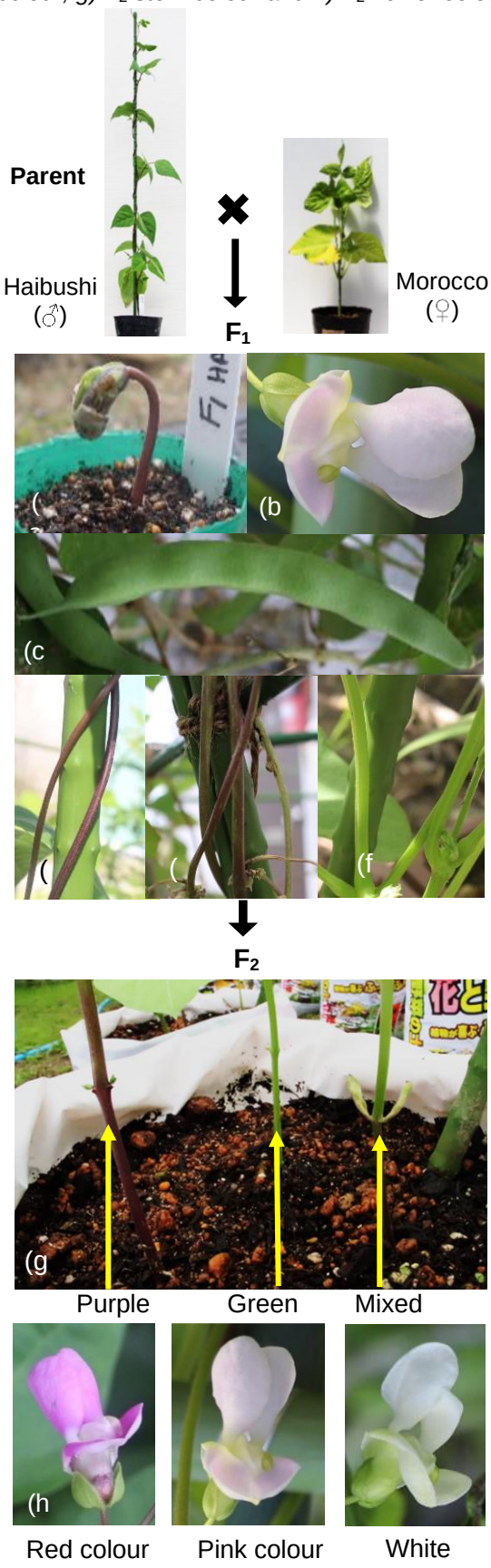
3. Result and Discussion

In the cross between the "Haibushi cultivar" with long and purple stems and the "Morocco cultivar" with short and green stems, all F_1 offspring were long and colour stem plants (Figure 2a-e*)*. The long stem characteristic of F_1 plants looked completely dominant on short stem characteristics because all F_1 progenies showed long stems. The mixed stem colour characteristics of F_1 plants showed the incomplete dominance of purple stem and green stem. The cross between the red flower Haibushi cultivar and the white flower Morocco cultivar, F_1 offspring were all pink flower plants (Figure 2b). Pink flower characteristics are incompletely dominant between red and white flower characteristics. The F_2 population was segregated into nine different phenotypes, including purple-red, purple-pink, purple-white, mixed-red, mixed-pink, mixed-white, green-red, green-pink, and green-white plants in the characteristics pair of stem colour *(*Figure 2g) and flower colour *(*Figure 2h*)*. The term Mixed colour here refers to the colour of the offspring stem in the middle between the green and purple parents' colour. The phenotype frequency from observed data of F_2 rejected Mendel's proportions 9:3:3:1 and 1:2:1: 2:4:2: 1:2:1, thus, the genetic linkage was hypothesised.

3.1 Incomplete Dominant of F_2 Characteristics Segregation Pair, Stem Colour and Flower Colour

F_2 characteristics stem colour and flower colour were statistics analysed by chi-square test among 263 F_2 plants obtained from six F_1 populations (Table 3). The stem colour characteristics, the F_2 plants were segregated into three different phenotypes purple, mixed (immediate colour), the green stem colour (*Figure:2g*), and flower colour (Figure:2h). The segregation ratios were 1:2:1 in purple, mixed, and green in stem colour with p-value > 0.05, 2 degrees of freedom (Table 4). The flower characteristics, F_2 populations were also segregated into

Figure 2: F_1 and F_2 characteristics. a) Young F_1, b) F_1 flower, c) fruit, d) Haibushi stem colour, e) F_1 stem colour, f) Moroco stem colour, g) F_2 stem colour and h) F_2 flower colour.



three different phenotypes included red, pink (immediate colour), and white flower colour, and the segregation ratio was 1:2:1 of red: pink: white colour flowers with p-value > 0.05, 2 degrees of freedom (Table 5). This ratio of 1:2:1 followed Mendel's incomplete dominance inheritance characteristics.

Table 3: F_2 phenotypes segregation and frequency.

F_1 code	*F_2 phenotypes*								
	purple-red	purple-pink	purple-white	mixed-red	mixed - pink	mixed-white	green-red	green-pink	green-white
14-HAI	3	4	0	5	13	0	2	1	12
11-HAI	1	8	0	5	16	1	0	3	7
12-HAI	2	3	0	2	17	1	0	1	8
15-HAI	7	1	0	6	24	0	0	4	15
8-HAI	9	1	0	7	15	2	0	3	17
10-HAI	7	5	0	3	8	1	1	5	7
independent frequency	*1/16*	*2/16*	*1/16*	*2/16*	*4/16*	*2/16*	*1/16*	*2/16*	*1/16*

Table 4: The incomplete dominance of F_2 characteristics in stem colour.

F_1 code	*n*	*x^2*	*deg. of freedom*	*p-value*	*proportion*
14-HAI	40	3.60	2	0.165	1:2:1
11-HAI	41	0.26	2	0.874	1:2:1
12-HAI	34	2.0	2	0.367	1:2:1
15-HAI	57	4.40	2	0.110	1:2:1
8-HAI	54	4.37	2	0.112	1:2:1
10-HAI	37	4.62	2	0.099	1:2:1

Table 5: The incomplete dominance of F_2 characteristic in flower colour.

F_1 code	n	x^2	deg. of freedom	p-value	proportion
14-HAI	40	0.55	2	0.757	1:2:1
11-HAI	41	4.31	2	0.115	1:2:1
12-HAI	34	3.35	2	0.187	1:2:1
15-HAI	57	0.15	2	0.924	1:2:1
8-HAI	54	5.07	2	0.079	1:2:1
10-HAI	37	0.51	2	0.773	1:2:1

3.2 Expected Genotypes from Observed Phenotypes by Direct Calculation Method

F_2 populations obtained from five F_1 plants, 11-HAI (n=41), 12-HAI (n=34), 15-HAI (n=57), 8-HAI (n=54) and 10-HAI (n=37) were used in this study. All plant phenotype was inputted into an Excel database, and each plant's data observed in both colour characteristics were changed to estimated genotype combinations on the chromosome by using recombination (*r*) value. From these estimated genotype combinations on the chromosome, the r-value is calculated by the total recombinant chromosome number/total observed chromosome number. The results of the gene linkage study of stem colour and flower colour characteristics significantly differ between the expected number and observed number of F_2 plants because all p-values>0.05 from the chi-square test (Table 4, and Table 5*).* Each r-value calculated for each population was 0.2125, 0.1029, 0.0965, 0.1204, and 0.2162, respectively. The chi-square test between the observed value and reconstructed expected value of genotypes using r-value indicated that only observed population 11-HAI deviated from the expected value and

other populations did not have significant differences, so these recombinant values were acceptable. Two weak points of these calculations were imaged; (1) to change from phenotype to genotype, a couple of heterozygosis genotypes, mixed-pink, could not divide between parent pair of chromosomes, *st*^{pig}-*fl*^{pig} and *g*-*w*, and recombinant pair of chromosomes, *st*^{pig}-*w* and *g*-*fl*^{pig}. In this study, the number of plants in each population was not so many, the expected value of F_2 plants with both different recombinant chromosome pairs, calculated by $\frac{r^2}{2}n$ was about 1 or 2 when r=0.1. So, students could be ignoring this value. If the *r*-value is too big or the number of F_2 plants is also big, then consideration is needed. (2) this method, the *r*-value was different by each population, thus teachers have to explain to the students this reason. However, the differences depended on the observed value, so when F_2 populations obtained from the same F_1 plants cultivated repeat, it looked like the same *r*-value may be present. The results of linked incompletely dominant characters will be good materials used in high school genetic education because students could image genotypes on a chromosome from phenotype. Gene-linkage inheritance, which confirmed two loci involved during gene expression event, (Herniter et al., 2024). Nevertheless, mostly backcross populations were used in the linkage study, students understood linkage calculation as several individuals with recombinant phenotypes per total number of individuals and no chromosome images. Common bean stem colour and flower colour results are based on F_2 population results; thus, it is important to have chromosome images for students to calculate genotypes to phenotypes procedure. Frank 2010 demonstrated the calculation methods for biology and biotechnology (Frank H. S., 2010). In Chapter 10, he suggested a formula to calculate the expected value, but those formulas seemed so difficult for the students at the high school level.

3.3 Confirmation of recombination value by MLE calculation in segregation between incomplete dominant pair, stem, and flower colour

A couple of incomplete dominant characters were then detected r-value by the MLE calculation method to verify the direct calculation method. This MLE calculation aimed to find out the differences between the parameter r-value in the direct calculation method and the r-value in MLE (Table 6 and Table 7). Results showed that in a population of 10-HAI, 8% of differences were presented between direct calculation methods and MLE, while other populations were less than 4.5% (Table 6). These results suggested that detecting a recombination value of nearly 0.5 as the nearly equal independent value was unstable for a small number of individuals in populations. Thus, it could not decide whether the recombination value obtained from the direct calculation method could be used. However, understanding MLE methods to calculate recombinant value might be too tricky for high school students (Allard, 1956). So, the comparison of detection recombinant value between the direct calculation method and MLE should be calculated by the smaller recombinant value as 30%-40% of other coupled characters.

Table 6: chi-square test of expected genotypes by direct calculation method.

F_1 code	n	r	x^2	degree of freedom	p-value
11-HAI	41	0.21	14.50	7	0.01<p<0.05
12-HAI	34	0.10	5.63	7	0.5<p<07
15-HAI	57	0.10	12.36	7	0.05<p<0.1
8-HAI	54	0.12	14.03	7	0.05<p<0.1
10-HAI	37	0.22	6.10	7	0.3<p<0.5

Table 7: Comparison between r-value of the direct calculation method and the r-value of MLE method.

F_1 code	n	r(x^2)	r(MLE)	X^2	degree of freedom	p-value
11-HAI	41	0.21	0.24	14.49	7	0.07
12-HAI	34	0.10	0.11	5.63	7	0.69
15-HAI	57	0.09	0.1	12.36	7	0.136
8-HAI	54	0.12	0.13	14.03	7	0.13
10-HAI	37	0.21	0.13	6.93	7	0.54

4. The Applicability for High School Biology Education

The estimating genotype was considered essential to recognise the recombinant genotype for the student by meiosis. In this estimation, students could consider that recombination occurred on a chromosome. In F_2 segregation, students learned Punnett square methods in independence. An independent case could be considered a recombination value at 0.5. The four kinds of coupled genotype frequency were the same as 1/4 in each gamete-coupled genotype. Thus, to introduce recombinant value, four types of coupled genotypes were described using the r-value. The formula of expected value was described by r-value. All recombinant chromosomes could be estimated in incomplete dominance character pairs, and the recombinant value was calculated by directly calculating methods as r=total recombinant chromosomes/total estimated chromosomes. In the confirmation of the reliability of r-value calculating of direct calculated methods by Maximum Likelihood Estimation methods, two r-values were similar to each other. To produce an experimental genetic class that included both Mendel's laws and genetic linkage, the independent colour of the stem and flower was considered a better material. Here, it was proposed that the new experimental class, which was docking between plant hormone content and whole genetic study, could be produced by using common beans. Although these contents are divided into other grades, a curriculum reconstructed could be needed as likely contents accumulate.

5. Conclusion

For these common bean cultivars could be concluded the recombination rate was ranked 9% to 21% representing genetic linkage in incomplete dominance pair, stem colour, and flower colour. The method to calculate the expected number of F_2 genotypes and phenotypes by direct calculation introduced in this study is useful for high school biology education in common bean genetic linkage. The result of this genetic linkage in incomplete dominance pairs, stem colour, and flower colour of common beans are suitable reference materials for further genetic linkage research. In the class, teachers can use the data of F_2 offspring from this research to teach students. Teachers can lead students to design the experiment as project-based learning. Students can do ground-based practicals on the common bean crossing technique. Through this ground-based practical, they investigated the handling work and recognised the phenomena of pollen and pistils possible to cross-fertilise. The MLE method should be difficult for high school students to use to calculate the genetic recombinant of common beans. Thus, the direct calculation method using Excel software is introduced as a crucial simple calculation for students. Using Punnett's square to produce the genotype's proportion and then using the Excel software to construct the recombinant genotypes could be used for simple handling calculations by high school students.

References

Allard, R. W. (1956*).* Formulas and tables to facilitate the calculation of recombination values in heredity. *Journal of Agricultural Science* Published by the California Agricultural Experiment Station (Vol. 24).

Bilir, Ö., Özmen, C. Y., Özcan, S., & Kibar, U. (2019). Genetic analysis of Turkey common bean (Phaseolus vulgaris L.) genotypes by simple sequence repeats markers. *Russian Journal of Genetics*, *55*(1), 61-70.

Frank H. S. (2010). *Calculations for Molecular Biology and Biotechnology*. *The Real-Time Polymerase Chain Reaction (RT-PCR)*, 2nd Edition, 212–214.

Gardner, A., & Ross, L. (2014). Mating ecology explains patterns of genome elimination. *Ecology Letters*, *17*(12), 1602-1612. https://doi.org/10.1111/ele.12383

Herniter, I. A., Muñoz-Amatriaín, M., Lo, S., Guo, Y. N., Lonardi, S., & Close, T. J. (2024). Identification of candidate genes controlling red seed coat color in cowpea (Vigna unguiculata [L.] Walp). *Horticulturae*, *10*(2), 161. https://doi.org/10.3390/horticulturae10020161

Felsenstein, J. (1973). Maximum likelihood and minimum-steps methods for estimating evolutionary trees from data on discrete characters. *Systematic Biology*, *22*(3), 240-249. http://www.jstor.org/stable/2412304

Lipatov, M., Sanjeev, K., Patro, R., & Veeramah, K. R. (2015). Maximum likelihood estimation of biological relatedness from low coverage sequencing data. *BioRxiv*, 023374. https://doi.org/10.1101/023374

Morgan, T. H. (1911). Random segregation versus coupling in Mendelian inheritance. *Science*, *34*(873), 384-384.

Pupeikis, R. (2000). Closed-loop robust identification using the indirect approach. *Informatica*, *11*(3), 297-310.

Strome, S., Bhalla, N., Kamakaka, R., Sharma, U., & Sullivan, W. (2024, July 1). Clarifying Mendelian vs non-Mendelian inheritance. *Genetics*, Vol. 227. Oxford University Press. https://doi.org/10.1093/genetics/iyae078

Vogt, K. A., Vogt, D. J., & Bloomfield, J. (1998). Analysis of some direct and indirect methods for estimating root biomass and production of forests at an ecosystem level. *Plant and Soil*, 200(1), 71-89.

ASSESSING STEM INTEGRATION AND TEACHER MOTIVATION: INSIGHTS FROM THE 'STRENGTHENING TEACHING EDUCATION PROGRAM' SURVEY

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ABSTRACT

This research presents the results of the evaluation of teachers' understanding, use, and motivation in STEM-based teaching. This study is a part of the educational project "Strengthening Teaching Education Program" developed by the 'Caravan of Knowledge' corporate foundation and the 'Southeast Asian Ministers of Education Organisation Regional Centre for STEM Education'. The research was conducted with a diverse participants group of 50 teachers from different regions of Kazakhstan and science educators from Shokan Ualikhanov University with different teaching qualifications and experience level, primarily working with middle and high school students. The conducted survey explores several key areas: teachers' knowledge and experiences with STEM education, their motivation to adopt new practices, and challenges they face in the teaching process. The survey findings reveal the importance of continuous professional development, resource accessibility, and a collaborative educational community to support teachers in their efforts to implement STEM education effectively.

Keywords: STEM Education, professional qualification, professional experience, teaching practice, educational environment, teachers' motivation, technologies

1. Introduction

Teaching science always leads to the search for new teaching methods and techniques that motivate students to be an independent learner and creative thinker. Today, transfer of knowledge in teaching is not as important as developing skills that students need in their everyday life. That is why in the educational system of the Republic of Kazakhstan, there has been a need to search for new methods and techniques in the practice of teaching through STEM education.

The relevance of our research lies in the fact that STEM education contributes to the development of students' research skills and promotes 21st learning century skills according to the 4C model-creativity, communication, collaboration, critical thinking. For STEM education to be effective, it is important to connect it with real-life problems and present real-life situations that will contribute to the research. STEM projects develop the learning skills necessary for the student in everyday learning skills including critical thinking, communication, organisation and reflection. An analysis of the choice of technical specialties among graduates demonstrates that students successfully study in their chosen technical specialties upon graduation. An effective use of STEM learning approaches helps to improve students' research skills and help them to identify a research problem, design the experiment, analyse and evaluate findings. This approach contributes to the formation of a sustainable interest

among students in the study of technical sciences, guiding students toward future professions in STEM.

According to the report of Organisation for Economic Co-operation and Development (OECD**,** 2016) expanding education in science, technology, engineering and mathematics (STEM) remains foundational for many OECD countries and partner economies. Public budgets to boost STEM education have been increased in Belgium (Federal), Croatia, Latvia, South Africa and the United States. Other recent policy initiatives include attempts to make STEM subjects more interesting and attractive to young people (Ireland, New Zealand and Portugal), new training programmes and recruitment criteria for teachers (Croatia, Korea, Ireland, Norway and Sweden), and new teaching methods and IT-based pedagogical tools (Czech Republic, Ireland, Lithuania, Portugal and Spain).

Beyond theoretical knowledge, STEM education emphasises experiential learning through real-world applications. Two notable methodologies that support STEM learning are the Claim-Evidence-Reasoning (CER) method and SageModeler, both fostering students' ability to model, reason, and engage in scientific inquiry (Edutopia,2024). The CER method structures student responses by requiring a claim based on a question, supported by evidence, and justified through scientific reasoning. Widely used in classrooms, CER helps students develop critical thinking by requiring them to make evidence-based arguments, linking their observations to established scientific principles (Freeman, K. E. et al, 2008). SageModeler is a complementary tool that offers students hands-on opportunities to design and simulate dynamic systems. Through this tool, learners create visual models that reflect real-world systems such as ecosystems or economics, fostering deeper understanding by modifying variables and predicting outcomes. This process strengthens their ability to think like scientists and engineers, encouraging collaborative exploration and iterative problem solving.

In addition to these innovative methodologies, teacher motivation plays a crucial role in the success of STEM education. Professional development and engagement with these tools equip educators to implement them effectively, promoting student interest and motivation. Recent research highlights that motivated teachers are better able to inspire students, leading to improved learning outcomes in STEM fields across different educational settings, including Kazakhstan.

The rapid development of science, technology, engineering, and mathematics (STEM) education has become a global priority, with a focus on enhancing both students' and teachers' motivation toward these fields. Motivating educators and learners plays a crucial role in the effectiveness of STEM education, with factors such as career aspirations, family background, and teaching approaches influencing engagement levels (Gok, 2021).

Survey-based research is commonly employed to assess the motivational dynamics in STEM settings. This method provides insights into teachers' pedagogical practices and students' attitudes toward STEM subjects. Studies highlight that interactive teaching strategies and project-based learning can enhance intrinsic motivation among students (National Research Council, 1995).

Both teachers and students need continuous support to maintain high levels of motivation in STEM learning environments. Furthermore, international comparisons underscore the importance of developing tailored programmes to address contextual challenges in different countries, including Kazakhstan's efforts to align with global trends (Japashov et al., 2022). The effective integration of surveys and motivational strategies in STEM education is essential for fostering long-term engagement and professional development. This approach enables educators to refine their teaching methods and helps policymakers design targeted interventions, ultimately improving STEM outcomes.

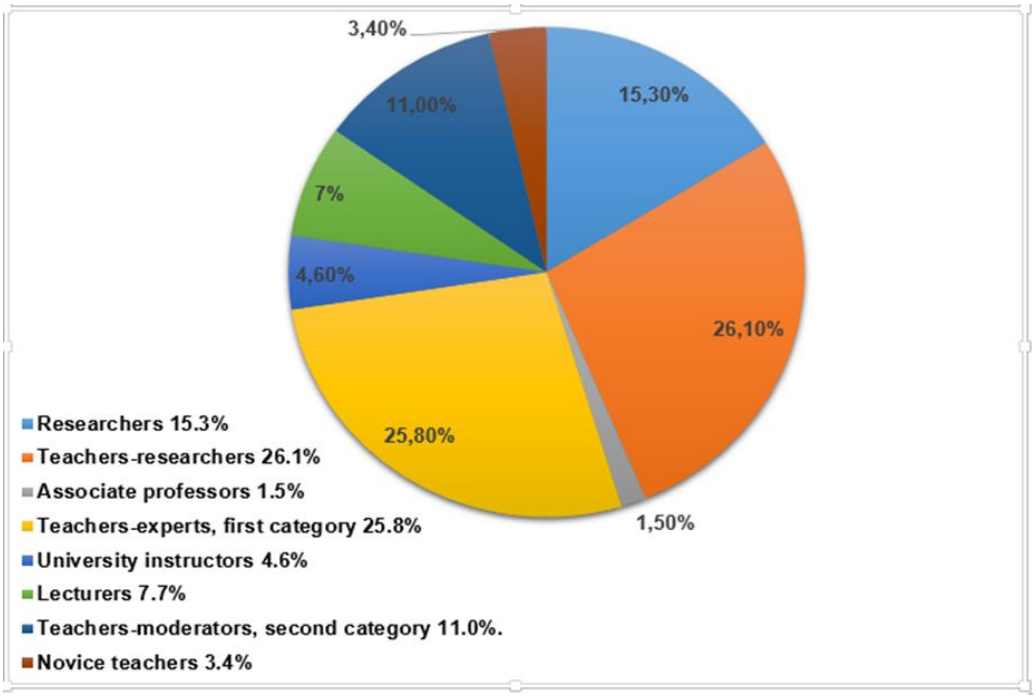
2. Insights from the Study

This survey was a part of the educational project 'Strengthening Teaching Education Program' developed by the 'Caravan of Knowledge' corporate foundation and the 'Southeast Asian Ministers of Education Organisation Regional Centre for STEM Education'. The aim of this research was to determine teachers' knowledge and experience of using STEM methods in the process of teaching, as well as their motivation in mastering new methods. The survey consisted of three blocks: general information about the teacher/educational organisation; implementation of STEM in the educational environment; teacher's motivation and readiness to learn.

General information about the teacher/educational organization, most of the participants of the survey work in schools (63.7%) and teach high school students; other participants (36.3%) work with middle school students. Analysis of the level of pedagogical professionalism showed that the participants had different levels of experience and qualification: among them, there were both experienced teachers and those at the early stages of their careers.

Most of the participants have research experience, which indicates that the programme is interesting to those who are already actively involved in research activity, and testifies to the importance of developing teaching and research methodology among teachers (researchers: 15.3%; teachers-researchers: 26.1%, associate professors: 1.5%). The second largest group consists of highly qualified experts (teachers-experts, first category: 25.8%), which most likely indicates that they are seeking to improve their skills within the framework of STEM education. A relatively significant part is made up of the participants interested in the training courses since they provide an opportunity to enhance their knowledge of using pedagogical methods and increase their qualification skills (university instructors: 4.6%; lecturers: 7.7%; teachers-moderators, second category: 11.0%). Novice teachers make only a small part: 3.4%; the representatives of this group have begun to master new teaching methods and implement them in their teaching activities quite recently.

Figure 1: Breakdown of Participants by Pedagogical Professionalism

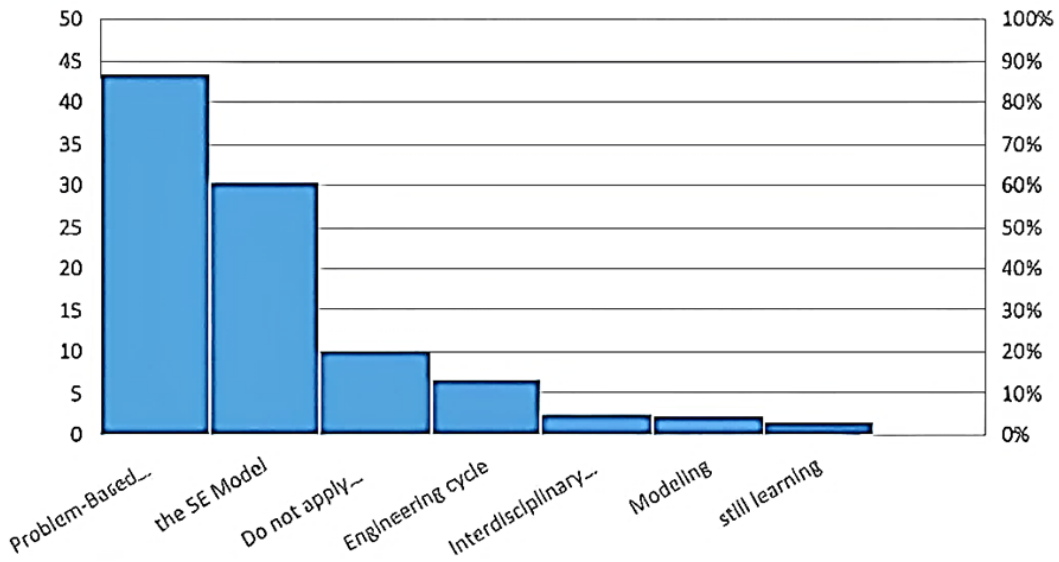


The participants regularly upgrade their professional qualifications, especially by attending courses organised by Orleu/Center of Pedagogical Excellence of AEO 'Nazarbayev Intellectual schools' (30.7%) and by taking online courses (webinars: 21.1%; online courses, MOOCs: 24.3%), which indicates the importance of continuous professional development in the sphere of education. It should be noted that teachers also attach importance to participation in conferences (23.9%). It is essential for teachers to exchange experience and be part of a professional community, since this allows them to keep pace with the modern teaching methods and technologies.

The second block Implementation of STEM in the educational environment, aims to assess teachers' knowledge and experience in using STEM. It provides an overview of their familiarity with STEM methods, their approaches to implementation in the educational process, and the challenges they may encounter. The analysis of the results showed that the participants, for the most part, tend to use these methods in their professional activity. PBL (problem-based learning) turned out to be the most popular method among the course participants (43.5%), which indicates that teachers consider problem-based learning an effective tool for engaging students in the learning process and developing their problem-solving skills. Also, a significant number of teachers (30.5%) apply the method known as 5E (Engage, Explore, Explain, Elaborate, Evaluate) that enables teachers to structure their teaching approach and helps students to understand the material much better. The less popular techniques include: methods of engineering cycle (6.8%), modeling (2.3%), Jigsaw (2.5%), using interdisciplinary connections (2.5%).

Some teachers do not apply STEM methods in their work at all, and a small percentage of teachers are still learning to use STEM methods, which is the evidence of their interest despite the lack of training. These findings may indicate that there are difficulties in implementing these methods due to such potential barriers as lack of resources, knowledge or time.

Figure 2: Usage of STEM Methods in Professional Activity



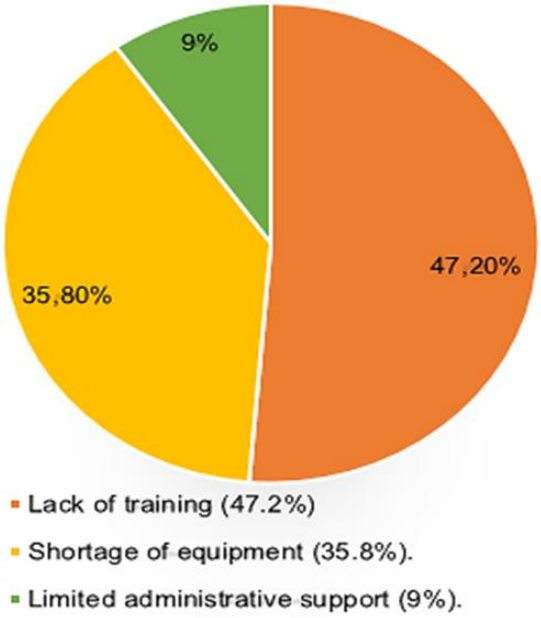
The results of the survey on the ways of integrating STEM technologies into the curriculum show that interactive technologies and online resources are used most frequently in order to improve the educational process (37.5%). To apply knowledge in practice and develop research skills, a significant proportion of course participants (30.3%) use projects and experiments as the main method of implementing STEM technologies. Almost a third of participants integrate STEM through interdisciplinary projects and contests. This data highlights the importance of interdisciplinary connections and an integrated approach to learning that can help students develop a variety of skills. A small number of teachers (0.9%)

use STEM during school subject weeks, which indicates that this method is less popular or less effective for integrating STEM into the educational process. However, there is also another small group of teachers (1.7%) who have not tried to integrate STEM into their programmes yet, and this fact may suggest that there is a need for further support and training in this area.

Most often, STEM methods are applied once or twice a week (33%) or a month (34.4%); only very few teachers use these methods at each lesson (1.4%). It is also important to note that despite the fact that most teachers implement STEM methods at least occasionally, a significant proportion of teachers (14.6%) do not implement STEM methods in their practice at all.

Answering the question about difficulties that teachers may face when implementing STEM methods in teaching, a large group of respondents (47.2%) pointed out the need for additional training and advanced courses in STEM that could help teachers use these methods more confidently and effectively. The lack of equipment is the second biggest challenge indicated by 35.8% of the respondents. According to 9.0% of the teachers, lack of support from administration is a difficulty the teachers can face as well. No difficulties in implementing STEM methods have ever been experienced by 5.8% of teachers. This fact can indicate that certain educational institutions have created favorable conditions for the integration of STEM into the educational process. Some participants of the survey (2.1%) chose the option “other”, but did not specify any difficulties. It appears, therefore, that the main barriers to the implementation of STEM methods in education are the lack of teachers’ knowledge and skills, as well as the lack of necessary resources.

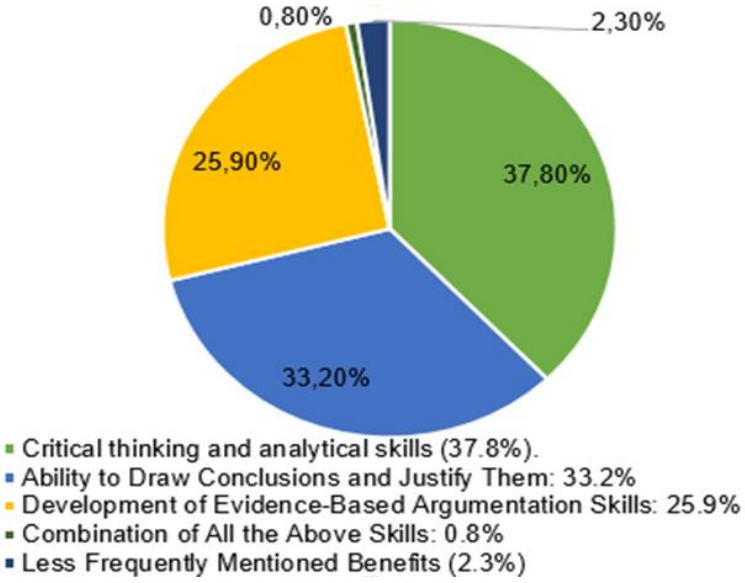
Figure 3: Challenges in STEM Implementation



The analysis of the question about the benefits that the participants see in using STEM methods for teaching students showed that the teachers see a lot of benefits in applying STEM methods in their professional activity. Therefore, it is quite obvious that application of STEM methods plays an important role in preparing students to solve various complex problems. The teachers marked the development of critical thinking and logical analysis as the most significant benefit (37.8%). The ability to draw conclusions and justify them was highlighted as the second most beneficial developed skill (33.2%). The development of evidence-based argumentation skills was indicated by 25.9% of the participants. 0.8% of the course

participants see significant benefits in developing a combination of all of the above skills. Hence, most teachers see the main benefits of STEM methods in developing logical analysis skills, critical thinking, and the ability to provide well-founded and evidence-based conclusions and arguments. Among less frequently indicated benefits the teachers named such skills as: 1) demonstration of individual abilities and creativity, 2) ability to work in a team, communication skills, 3) development of functional literacy and global thinking (2.3%). This can be attributed to the fact that these teachers focus on more specific applications of STEM methods.

Figure 4: Benefits of Using STEM Methods for Teaching



The block 'Teachers' motivation and readiness to learn' is aimed at determining the participants' level of intrinsic and extrinsic motivation to master new methods. The analysis of block 3 shows not only quantitative data, but also a qualitative reflection of the aspirations and challenges that teachers face in their quest for innovations in education. Knowledge of methods and tools. According to the survey results, a considerable number of participants are well aware of the Claim-Evidence-Reasoning method (CER): 68.6% of the respondents stated their awareness of it. This method helps to develop critical thinking and argumentation skills and is considered an important tool in the teaching practice. Other tools, however, are not equally well known to the participants. Only 48.6% of the respondents are familiar with Sage Modeler, which indicates the need to popularise this tool and train teachers to use it.

Motivation to study and apply technologies. According to the analysis of motivational factors, the opportunity to apply new methods in teaching practice is the leading incentive for 85.7% of the participants. This emphasises the desire of teachers not only to adapt to modern educational requirements, but also to actively implement innovations to improve the teaching process. The importance of improving the quality of education (65.7%) and preparing students for modern professions (62.9%) were also named the key motivational factors. Thus, we see that personal professional development is a significant driving force in motivation, indicating the desire of teachers to continuously improve their skills and knowledge.

3. Conclusion

The survey involved teachers with different professional experience and qualifications: from novice teachers to associate professors. Most of them are already actively involved in research activities, which is an indication of the interest in improving teaching methodology and research skills. Most of the survey participants work with high school students (63.7%), which emphasises the relevance of introducing STEM methods at this level of education. Teachers regularly upgrade their qualifications by attending courses, participating in webinars, online courses and conferences, thus striving to stay up to date with modern teaching methods and technologies, and to exchange experiences with colleagues.

Most teachers try to use STEM methods in their teaching practice. The most widely used methods are PBL (Problem-Based Learning) and 5E (Engage, Explore, Explain, Elaborate, Evaluate). Significantly less commonly used are engineering cycle methods, modeling and Jigsaw, which may indicate the need for further training in these areas. When integrating STEM technologies into curricula, teachers often resort to interactive technologies and online resources. Almost a third of the participants resort to projects, including interdisciplinary ones, experiments, and competitions to develop students' research skills, which highlights the importance of an integrated approach to teaching. The frequency of STEM methods implementation also varies: they are most often used once or twice a week/month, and very rarely at every lesson. It should be noted that a significant proportion of teachers do not use STEM methods at all, which highlights the need for further support in this area.

The respondents of the survey emphasise that STEM technologies play a significant role in developing students' critical thinking, analytical skills and ability to find evidence-based arguments. These technologies help to prepare students for the demands of the modern labor market and successful completion of integrated projects. Recognition of the importance of STEM technologies confirms their relevance and necessity in the educational process, as well as their contribution to the broader goals of education.

Despite certain positive aspects, the survey revealed several significant barriers. Among them, there is a lack of enough knowledge and skills, a shortage of equipment, and a lack of support from the administration. The participants expressed their willingness to overcome these difficulties through additional training courses, finding grants to purchase the necessary equipment, and sharing experience with colleagues. This demonstrates not only their awareness of the existing problems, but also a strong desire to find solutions.

A significant percentage of the participants (88.6%) noted that they keep up with current research and news in the field of STEM-based education. This testifies to the high level of interest and desire to be up to date with the latest trends and achievements in their professional field. The survey confirmed that the course participants see great value in the opportunities provided by STEM/STEAM technologies and are eager to implement new methods in their teaching practice. However, existing barriers such as lack of knowledge, equipment and administrative support require attention. Teachers demonstrate their willingness to overcome these difficulties through training, finding resources, and sharing experiences. These results highlight not only the importance of STEM/STEAM-based education, but also the need for a comprehensive approach to supporting teachers in their pursuit of innovations.

References

OECD (2016). *OECD Science, Technology and Innovation Outlook 2016 Country Profile*. OECD. http://dx.doi.org/10.1787/sti_in_outlook-2016-en

Edutopia. (2024). Using the CER method in math class. *Edutopia.* https://www.edutopia.org/article/using-cer-method-math-class

Freeman, K. E., Alston, S. T., & Winborne, D. G. (2008). Do learning communities enhance the quality of students' learning and motivation in STEM? *The Journal of Negro Education*, 77(3), 227–240.

Gok, T. (2021). The development of the STEM (science, technology, engineering, and mathematics) attitude and motivation survey towards secondary school students. *International Journal of Cognitive Research in Science, Engineering and Education (IJCRSEE)*, *9*(1), 105-119. https://doi.org/10.23947/2334-8496-2021-9-1-105-119

National Research Council. (1995). *Prudent practices in the laboratory: Handling and disposal of chemicals*. National Academies Press. https://doi.org/10.17226/4911

Japashov, N., Naushabekov, Z., Ongarbayev, S., Postiglione, A., & Balta, N. (2022). STEM career interest of Kazakhstani middle and high school students. *Education Sciences*, *12*(6), 397. https://doi.org/10.3390/educsci12060397

EVALUATING THE IMPACT OF A MATHEMATICS-THEMED SCIENCE SHOW ON ALGEBRAIC UNDERSTANDING AMONG YEAR 9 STUDENTS IN BRUNEI

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ABSTRACT

This study investigates the impact of Count on Me, a mathematics-themed science show, on improving the algebraic understanding of Year 9 students in Brunei. Developed by the Seria Energy Lab (SEL) in collaboration with Brunei's Ministry of Education, the show integrates interactive teaching strategies and informal science learning approaches to address the challenges students face in learning algebra while fostering essential 21st-century skills like critical thinking, creativity, collaboration, and communication. Using a quantitative pre- and post-test design, the study involved 211 students from government secondary schools in the Belait district, with assessments aligned to standardised objectives. The show leveraged on the CHAMP framework—curiosity, human, analogy, mechanics, and phenomena—combined with self-made visual aids and interactive techniques to engage students and simplify complex concepts. Results demonstrated a statistically significant improvement in students' algebraic performance, as seen in higher post-test scores, confirming the effectiveness of integrating entertainment with education to make learning more engaging and memorable. By bridging gaps in traditional teaching, the Count on Me science show highlights the potential of informal STEM education to create emotional connections, foster active participation, and enhance understanding of challenging topics like algebra. This research emphasises the importance of innovative educational approaches in improving STEM learning outcomes and inspiring greater student interest in mathematics.

Keywords: mathematics-themed science show, informal science learning, CHAMP framework

1. Introduction

Aligned with Brunei's National Education System for the 21st Century (SPN 21), mathematics is a core subject in secondary education, with algebra recognised as a core yet challenging subject for students (Ministry of Education, 2013; Wettergreen, 2022). Research has highlighted persistent difficulties in understanding algebra, with scholars emphasising the importance of interventions that improve algebraic reasoning, such as enhancing the understanding of variables, promoting generalisation skills, and fostering awareness of dynamic relationships between variables (Warren et al., 2016; Ndemo, 2018). Informal science learning environments, like science centres, have been identified as effective platforms to engage students and increase their interest, motivation, and understanding of science, mathematics, and other STEM related topics, through interactive experiences (Karim, 2020; Sinatra et al., 2015).

This study explores the effectiveness of a math-themed science show, 'Count on Me', developed by Seria Energy Lab (SEL) in collaboration with Brunei's Ministry of Education as part of the *Program Perkembangan Penuntut* (3P's). Designed to enhance Year 9 students'

algebraic understanding and foster 21st-century skills like critical thinking, collaboration, creativity, and communication, the show employs dynamic teaching strategies to make algebra more accessible (Mayer, 2003; Zhou and Brown, 2015) and easy to understand. By integrating mathematics into an engaging science narrative, the initiative aims to address gaps in traditional classroom teaching while leveraging the benefits of active learning approaches commonly used in informal science education (Lyons, 2006; Adelman, 2006).

Seria Energy Lab (SEL) is a science centre located in the Belait district, in a small town called Seria. With its vision to be a premier science centre in cultivating our youths of today for our leaders of tomorrow, SEL focuses mainly on three (3) key areas, such as the followings: assisting the nation, especially the youths with skills needed for the 21st century by ensuring that its activities also cover the enhancement of skills needed in order to shape successful leaders, interactive STEM education. At SEL, science is brought to life as it believes education should be made interactive and that learning is an active process. Lastly, sustainable energy. SEL aims to be the hub for the nation to understand better the importance of renewable energy through its high-end energy themed exhibitions.

This research addresses two key questions: (1) whether the math-themed science show enhances students' learning achievements in algebra and (2) whether it helps students apply basic arithmetic operations within algebraic contexts. The study builds on existing research showing the positive impact of science centres and outreach programmes in promoting active learning and engagement through science shows (Sadler, 2017; Falk et al., 2016; Walker, 2011). Interactive techniques, such as audience-performer dialogues and questioning, are known to improve understanding and maintain interest (Roslan et al., 2018; Abdurrahman, 2018; Walmsley, 2019). Inspired by these findings, the Count on Me show aims to foster algebraic reasoning while keeping students engaged during a critical period of their academic and career development (Doig, 2005; Attard, 2011; Hadibarata and Rubiy, 2019).

1.1 Theoretical Framework

This research explores how constructivism and social constructivism underpin the effectiveness of science shows in education. Grounded in theories by Vygotsky (1962) and Bruner (1915), it emphasises learning as an active process that thrives in social settings with guidance from a "more knowledgeable other" (MKO). Vygotsky's concept of scaffolding and Bruner's emphasis on interaction highlight the importance of educators or science communicators in facilitating understanding through questioning, motivation, and structured guidance. Watermeyer (2013) underscores that keeping audiences curious and engaged is crucial for active learning, which is central to science shows.

Science shows serve as examples of informal science learning, blending entertainment and education to engage audiences in hands-on, experiential learning. According to Wellcome Trust (Triyarat, 2017), informal science learning includes free-choice activities outside formal settings, such as science centres, museums, and media-based experiences. These activities complement formal education by offering engaging and accessible ways to explore scientific concepts. Research indicates that informal learning is effective due to its concise explanations, interactive nature, and personal relevance, which enhance comprehension and retention (Batrawi and Muhtaseb, 2012; Reiss et al., 2016).

Moreover, science shows—categorised as informal science learning—utilise performance elements like dramatic gestures, demonstrations, and interactive techniques to captivate audiences (Walker, 2012). Science communicators employ cognitive strategies such as asking, summarising, clarifying, and forecasting (Smith, 2002) to create a Zone of Proximal Development (ZPD), fostering deeper understanding and collaborative learning. By blending entertainment with education, science shows effectively reinforce formal learning and promote higher-level thinking skills, making them a powerful tool for engaging diverse audiences.

Science centres and museums often perform science shows (Price et al.,2015; Schechter et al., 2010; Walker, 2012; Walker et al., 2013) mainly for school students that visit (and this is considered for education purposes) (Sadler, 2006; Schmidt et al., 2012; Walker, 2012) also for entertainment (Bell, 2000; Sosabowski et al., 2009). Some authors focused more on describing the demos in the show inclusive of simple evaluation on the enjoyment or the educational values after attending the science shows (e.g., (Bell, 2000; Sosabowski et al., 2009), there is also research that shed light on the effect of science shows on engagement. Science shows developed by both Price et al., (2015) and Schechter et al., (2010) indicated an increase in knowledge and a positive outlook towards science from both adults and children. Past studies have indicated that the contributing factors to an effective delivery of science shows narrows down to strategic use of demonstrations, emotional connection, and audience interaction and it was confirmed by the study conducted (Austin and Sullivan, 2019).

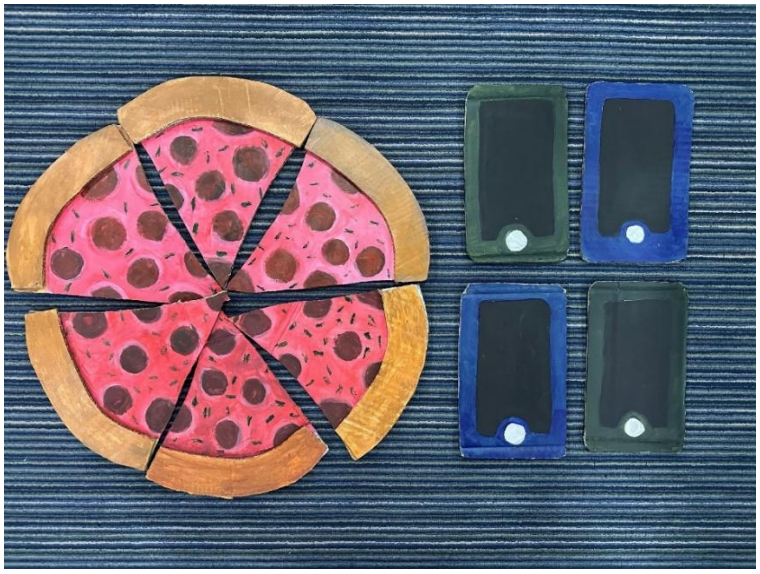
1.2 Development of Science Show

Sadler (2017) proposed various demonstration categories for delivering science shows, noting that different audience groups tend to respond differently to each category. These categories, collectively known as CHAMP, include curiosity, human, analogy, mechanics, and phenomena.

The curiosity category relies on science communicators or science show performers capturing attention through intriguing questions, surprising demonstrations, or dramatic elements. The human category involves using volunteers to promote audience interaction. By incorporating both asking questions from the audience and getting volunteers to answer and demonstrate how they come up with solutions for the questions being asked. This is where the science communicators posed multiple questions for each topic that were being delivered in Count on Me. The analogy category employs visual aids to illustrate concepts that are typically invisible, enhancing audience comprehension. Refer to Figure 1 and 2 for samples of visual aids used in science shows. This is the part where the science communicators used relevant visual aids in the show to ensure the audience able to relate the examples to their own experiences. In contrast, the mechanics and phenomena categories focus on real-life scientific applications and live demonstrations of scientific phenomena, often utilising specialised equipment that is not readily accessible to the audience. Using tangible examples such as 2x represents 2 pizzas and 3y represents 3 mobile phones, and when they are added together, the operation simply cannot be solved. This is due to different variables being used. Demonstrating real-life applications made the explanations easier, and the delivery of mathematical concepts clearer.

Figure 1: Visual aids used to recall basic operations in mathematics

Figure 2: Visual aids to represent variables in algebraic expression.



The Count on Me science show primarily utilised visual aids produced from self-made materials. Figure 1 and 2 are the samples of visual aids used in Count on Me science show. This deliberate approach to science communication was designed to adopt an emotional connection and active engagement between the science communicator and the student audience. These elements are crucial for the success of a science show, not only to help the audience retain information but also to maintain their attention throughout. Without these factors, there is a risk of losing audience interest, which can ultimately hinder their understanding of the show's context.

These visual aids were developed, keeping in mind the topics that will be delivered later during the show. Simple icons such as ‘pizzas’ and ‘mobile phones’ were being utilised in this context to make them relevant with the targeted audience who were relatively young demographically. Two of the said icons represent different variables such as ‘x’ and ‘y’ in algebraic expressions. The rationale behind this difference is to note that in some operations such as addition and subtraction, x and y are simply not added nor subtracted each other i.e. 2x + 2y remains as 2x + 2y.

Other teaching methods that were being employed in the show were the trivia game.

At SEL, science shows were developed following a framework as shown in Table 1 below. According to Karim (2020) this framework aims to ensure the science concept delivered in science shows would be well received by students experiencing the shows.

Table 1: Framework for the development of science content in science shows

Action	Description
Short and simple	The science explanations are made simple. The role of the science communicator is to communicate clearly and not communicate lots.
Step by step	The science concepts are delivered in a stepwise logical way. New information is added to what the science communicator has already explained or what people already know.
Adding complexity	Complexity is added following the audience’s age group. The younger the audience, the simpler the science is made.

Reiterating key ideas	Key ideas or science concepts in the shows are repeated regularly and at different angles in the demo.
Effective questioning	Reiterating key ideas above can be achieved through effective questioning, and this usually involves guiding questions.
Using analogies	Analogies can be used to make understanding complicated terms or concepts easier.
Body gestures	Body gestures can be utilised as visuals to explain the scientific concept that cannot be seen in demos (e.g. Particles getting squashed due to high pressure).

2. Methodology

This section describes the research design, description of participants, sampling and procedure for collecting information on the effectiveness of the Count on Me show for Year 9 students. This is then followed by a brief description of the assessment's reliability and validity.

2.1 Research Design

This study employs a quantitative research design to assess the impact of the Count on Me show on the algebra performance of Year 9 students in Brunei. A pre- and post-test experimental method was implemented, with standardised algebra assessments used to measure performance before and after the intervention. As Creswell (2002) outlines, pretests establish a baseline, while posttests evaluate changes following the intervention. The Count on Me show specifically targeted algebraic concepts, incorporating a framework for comprehensive data collection that included identifying participants, obtaining permissions, selecting appropriate instruments, and administering the tests.

2.2 Sampling of Participants in the Study

The study sampled 222 Year 9 students from all government secondary schools in the Belait district, facilitated through a collaborative project with Cluster 6 of the Ministry of Education (MOE). Informed consent was obtained via students' teachers. Due to absences during the intervention or tests, 11 students were excluded from the analysis, leaving a final sample of 211 participants (106 males and 105 females) from diverse socioeconomic backgrounds. Majority of the students are native Malay speakers with mixed abilities. However, in Brunei, core subjects such as Mathematics and Science are taught primarily in English. For this study, the Count on Me show was delivered in English.

2.3 Research Instrument

The pre- and post-tests contained 20 questions aligned with Bloom's Taxonomy and covered basic arithmetic and algebraic concepts such as factorisation and expansion. Arithmetic-focused questions assessed understanding of addition, subtraction, multiplication, and division, emphasising their application in real-world scenarios, as discussed by Raza (2022). The alignment of symbolic and non-symbolic numerical representations, highlighted by Chen and Li (2014), was key to understanding arithmetic principles and their role in algebra. These insights, along with validated test questions, were critical in evaluating the effectiveness of the intervention in improving students' algebraic skills. Moreover, the test questions were developed according to Cambridge GCE 'O' Level learning objectives and validated by science communicators.

The assessment was designed in such a way that the distribution typically reflects a mix of cognitive levels, progressing from foundational knowledge to higher-order thinking skills. Questions 1 were comprised of the basic operations such as addition, subtraction, multiplication, and division. These questions are categorised as 'Remembering and Understanding' according to Bloom's Taxonomy Level as they require the students to recall and apply the basic rules in mathematics. Questions 2 and 3 fall under the 'Understanding and Applying' whereby the students were required to apply basic arithmetic rules to solve square numbers and square roots.

Meanwhile Questions 4 were encompassed by factorisation questions. These questions involve 'Applying and Analysing' skills as students need to identify patterns and manipulate expressions. Similarly goes for Questions 5 which focused on expansion, covering minor 'Evaluation' in more detail and complex scenarios.

Following this, 30% of the assessment questions focus on lower-order skills which constitute foundational knowledge and comprehension. 70% make up the higher-order skills emphasising problem solving and critical thinking in algebra.

2.4 Reliability and Validity

Reliability in testing refers to a test's ability to consistently evaluate what it is designed to measure, ensuring stable results across different occasions (Mills, 2011). Meanwhile, validity represents how accurately a scientific observation measures or reflects what it claims to assess (Pelto and Pelto, 1978, p.33).

To ensure the validity and reliability of the instruments, researchers conducted a pilot study before the actual data collection. Nine Year 8 to Year 10 students participated in this preliminary test. Their feedback revealed that some parts of the test were too simple, while others were overly challenging. Moreover, the students completed the test in just 10 minutes, much faster than expected. Based on these findings, the researchers revised the test questions, which were subsequently reviewed by another researcher to ensure improvements and approval to carry out the Count on Me show.

Once approved, the science communicators were assigned to present the Count on Me show over a four-month period to students from various Belait secondary schools. Each session lasted approximately 45 minutes to 1 hour. The show was divided into two main parts: the show itself and, in the final 30 minutes, a trivia game. Students were grouped with mixed abilities and tasked with answering questions on different algebra sub-topics as a team. The team that answered all questions the fastest won the trivia game and received incentives for their effort.

3. Results and Discussion

This section presents the descriptive statistics of the participating students in the pre and post-test for the Count on Me show. The arithmetic- focused test questions were deployed, and results of students' scores were analysed. Findings from the data collection and analysis, addressing the research questions of the study are also elaborated in this section. Table 2 below presents the descriptive statistics of the participants that underwent the intervention and the tests. It contains the gender distribution of the participants, whereby out of 222 participants, 211 provided valid responses, while 11 responses were missing. Of the valid responses, 106 were from males, accounting for 47.7% of the total sample, and 105 were from females, representing 47.3%. The cumulative percentage indicates that 50.2% of the valid responses came from males, and the total of 100% includes both male and female participants.

Table 2: Descriptive Statistics of Participating Students

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	106	47.7	50.2	50.2
	Female	105	47.3	49.8	100
	Total	211	95	100	
Missing	System	11	5		
Total		222	100		

Meanwhile the data presented in Table 3 below are extracted from the pre- and post-tests conducted for the students that participated in the Count on Me show. Table 3 below constitutes the overall mean scores and standard deviation from the pre- and post-tests distributed before and after attending the Count on Me show respectively.

Table 3: Overall means score and standard deviation of students' pretest and post-test

	N	Mean	Standard Deviation
Students' score on the test before Count on Me show	211	21.19	9.0054
Students' score on the test after Count on Me show	211	23.16	7.8427

Table 3 indicates the overall mean scores for the post-test for all students from all participating schools are higher compared to pretests overall mean scores. To further investigate whether the difference in pretest and post-test overall mean scores is statistically significant, a Wilcoxon Signed Rank Test was performed using SPSS software version 29.

A normality test was first performed before conducting the data analysis. The test indicated that the data is not normally distributed hence, this further supports the usage of the Wilcoxon Signed-Rank test. Outcome of the test conducted showed the post-test ranks were statically higher than the pretest ranks. Whereby Z= -5.287 and the P value is 0.000 as shown in Table 4 below.

Table 4: Wilcoxon Signed Rank Test Result for pretest and post-test

	$Test\ Statistics^a$
	Score on students test after Count on Me show – score on students' test before Count on Me show
Z	-5.287^b
Asymp. Sig. (2-tailed)	0.000

The results from the pretest and post-test analysis revealed that after attending the Count on Me show, students' understanding of algebraic concepts significantly improved.

4. Conclusion

The findings from the study suggest that delivering math content by utilising a tool called science show is effective in enhancing students' understanding. This is also applicable to topics that can be as complex as algebraic and arithmetic concepts. However, this is provided that the required framework is met to ensure its effectiveness.

Science content, or in this study, math content in science shows is ensured to be made simple and exciting demonstrations are to be incorporated into shows. Science communicators or the science show performers must interact with the student audience to promote social interaction

during the show. As a more knowledgeable other (MKO), the science communicators can assist the student audience to internalise the information or content better.

This study indicates the importance of delivering math or science content in an interactive manner. The amalgamation of entertainment and education plays an important role to ensure teaching and learning are done in a dynamic approach. The communication of math or science content needs to be made exciting and engaging to enable its learners to create an emotional connection with the subject matter. Connection attracts attention and attention attracts learning (Karim, 2020).

References

Abdurrahman, M. (2018). Promoting active learning through interactive performances. *Journal of Education Research, 15*(1), 102–119.

Adelman, L. M**.** (2006). Informal science education: Engagement through exploration. *Journal of Informal Learning, 14*(2), 55–72.

Attard, C. (2011). The role of STEM education in promoting critical thinking and collaboration. *Educational Research Journal, 24*(3), 45–63.

Doig, B. (2005). Informal learning environments in STEM education. *Journal of Informal Science Learning, 8*(4), 67–75.

Falk, J. H., Storksdieck, M., & Dierking, L. D. (2016). The impact of science centers on public understanding of science. *Science Education, 99*(4), 601–620.

Hadibarata, T., & Rubiy, S. (2019). Enhancing learning outcomes through interactive teaching. *Journal of STEM Pedagogy, 17*(1), 33–48.

Karim, N. (2020). The role of informal science education in promoting STEM engagement. *Journal of Science Communication, 19*(3), 45–55.

Lyons, T. (2006). Different approaches to teaching STEM in informal learning settings. *Australian Journal of Science Education, 22*(3), 101–117.

Mayer, R. E. (2003). The promise of multimedia learning: Using the same instructional design methods across different media. *Learning and Instruction, 13*(2), 125–139.

Ministry of Education. (2013). *National education system for the 21st century (SPN 21). Brunei Darussalam: Ministry of Education.*

Ndemo, F. M. (2018). Enhancing algebraic understanding in secondary schools. *International Journal of STEM Education, 5*(2), 89–101.

Roslan, R., Sharif, M., & Yusof, N. (2018). Enhancing STEM engagement through questioning techniques in science shows. *Journal of STEM Education, 10*(2), 34–49.

Sadler, T. D. (2017). Science demonstrations: Captivating audiences through hands-on exploration. *International Journal of Science Education, 39*(6), 791–810.

Sinatra, G. M., Heddy, B. C., & Lombardi, D. (2015). The challenges of teaching and learning about science in informal environments. *Science Education, 99*(3), 456–473.

Walker, K. (2011). Audience engagement through interactive learning. *Educational Media Journal, 19*(4), 78–89.

Walmsley, P. (2019). Engaging audiences through science demonstrations. *Science Communication Review, 13*(3), 21–36.

Warren, E., Cooper, T., & Baturo, A. R. (2016). Developing algebraic reasoning in early mathematics. *Mathematics Education Research Journal, 28*(1), 1–22.

Watermeyer, R. (2013). Captivating curiosity in STEM communication. *Journal of Informal Learning Science Communication, 10*(4), 56–72.

Wettergreen, D. (2022). Challenges in teaching algebra: A global perspective. *Educational Journal of Mathematics, 28*(3), 45–59.

Zhou, M., & Brown, D. (2015). Educational learning theories: 21st-century perspectives. *Educational Theory and Practice, 12*(4), 67–79.

DESIGN, DEVELOPMENT, AND EVALUATION OF A-CARDS AS A SUPPLEMENTARY MATERIAL IN NAMING ACIDS AND PURE SUBSTANCES AND WRITING CHEMICAL FORMULAE

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ABSTRACT

Game-based learning (GBL) has attracted many researchers as it has proven to open opportunities for students to increase engagement and achieve learning more effectively. The idea behind GBL lies in the engaging nature of game elements, which can be transferred into the educational context. That said, this study aimed to develop and evaluate a card game that can be used as supplementary material in naming acids and pure substances and writing chemical formulae that integrate the GBL. This study used a design and development research design and a pre-experimental design to assess the card game's effectiveness in enhancing the academic achievement of the respondents. Moreover, the teacher-evaluators evaluated the card game using the following criteria: goals and objectives, card design, components and organisation, playability and playfulness, and usefulness. Based on the results, two criteria exceeded the overall garnered mean with a perfect rating of 5.0 (playability and playfulness, and usefulness), while the other criteria acquired a mean rating very close to the overall mean of 4.98. In terms of the student's academic achievement, the calculated p-value is 0.001. This implies a significant increase in the senior high school (SHS) STEM students' academic achievement after using the A-Cards. This result supports the claim of other pre-existing studies that educational card games are effective supplementary tools in increasing students' academic performance. Moreover, the students' game experience showed satisfaction and a positive overall game experience, wherein they were intrinsically motivated to learn and be engaged during the game. Lastly, the researchers recommend further studies that compare the effectiveness of the traditional method of teaching and utilisation of the educational card game.

Keywords: game-based learning, educational card game

1. Introduction

While chemistry provides tangible solutions to real-world problems, from medicine to materials science, its core concepts often reside in the abstract, requiring students to visualise and manipulate far beyond the reach of their senses. One particular concept that several studies found is that students encounter problems in naming and writing chemical formulae for inorganic compounds. A study by Mayeem (2018) found that SHS students perform poorly in writing chemical formulae and nomenclature of inorganic compounds. Another study conducted by Turacoglu et al. (2013) found that students posed a problem with the other necessary knowledge in nomenclature. The studies reveal that students encountered problems like (1) naming the monatomic anions and cations, like the usual naming of

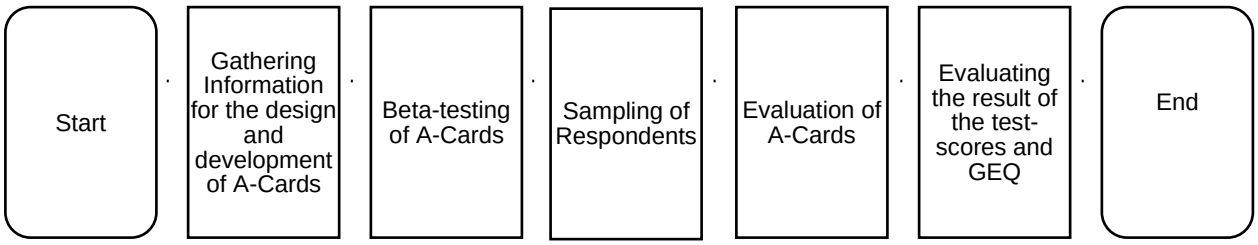
elements; (2) naming acid solutions like the ionic compound; (3) incorrect charges of anions; and (4) incorrect nomenclature of oxy-anions. Moreover, the study of Mayeem (2018) could explain this poor conception of chemical formulae and nomenclature of the SHS students: (1) chemical formulae and nomenclature are abstract concepts, and if no appropriate models are used in teaching, this becomes incomprehensible; (2) the previous instruction failed to help students make meaning of the concept and assimilate it into their own; and (3) students tended to use unrelated, correct ideas. In another study conducted by Baah and Krueger (2012), based on the results of the achievement test, the students had difficulties in naming a pure substance and naming it in the form of an acid. Accordingly, 40% of the students named it Hydrogen (II) Sulphate, and 6.5% had no answers. They interviewed the students who named it Hydrogen (II) Sulphate and found out that because of the two hydrogen atoms, they named it hydrogen with the Roman numeral sign of two. This indicates that students mixed up the rules of naming inorganic compounds. Instead of using the nomenclature of an acid or as a pure substance, they used the common nomenclature of an ionic compound, particularly the stock method. On the other side, 6.5% of students responded that there was a mistake in the formula and they decided not to answer. It indicates that 6.5% of students have no idea about the nomenclature of acids and nomenclature as a pure substance. This was further supported by Turacoglu et al. (2013), who found that students were naming the acid solutions like the rules in the ionic compound and using incorrect nomenclature of oxy-anions.

2. Methodology

2.1 Research Design

This study utilised a design and development research design and a one-group pretest and posttest design (a pre-experimental design) to test the effectiveness of the card game. The researchers developed A-Cards considering the following variables: goals and objectives, card design, components and organisation, playability and playfulness, and usefulness. In the primary phase, researchers gathered information for the design and development of A-Cards. Afterwards, the card game was developed, beta-tested, and evaluated by seven chemistry teachers based on the previously stated variables. After testing, researchers employed the study's sampling and gathered data from the respondents' scores for the researcher-made achievement test. Also, the researchers gathered data on the respondents' perceptions of the card game. Lastly, the researchers evaluated the score results of the researcher-made achievement test and the results of the adopted game experience questionnaire (GEQ). This process is shown in Figure 1.

Figure 1: Development of A-Cards



2.2 Evaluation of A-Cards

To evaluate the card game, the researchers used three research instruments. The researchers utilised (1) a 49-item Achievement Test Questionnaire used in both the pre-test and post-test, (2) an Adopted Card Game Evaluation Instrument for Science teachers to evaluate the game design and mechanics, and (3) the Adopted Game Experience Questionnaire (GEQ) for the students' game experience during and after the game. The Adopted Card Game Evaluation Instrument for Science Teachers is composed of five domains, which classify the questions to target different game features of the developed card game. These domains are the Goals and Objectives, Card Design, Components and Organisation, Playability and Playfulness, and Usefulness. The researchers used a Game Experience Questionnaire to assess the students' game experience. This instrument has three modules, namely In-game, Social Presence, and Post-game Module, with criteria composed of Immersion, Flow, Competence, Challenge, Negative Affect, Tension, and Positive Affect. Although the GEQ was originally utilised and established for computer games, research shows that it is also relevant and suitable across different game media, such as board games, dice games, and card games (Barbara, 2015).

3. Results and Discussion

3.1 Design and Development of A-Cards

Before coming up with the design, the researchers considered the variables: goals and objectives, card design, components and organisation, playability and playfulness, and usefulness. To support these considerations, the six essential elements of the game were taken into account in the design of A-Cards. These game elements are rules, competition, goals, outcome, decisions, and emotional attachment, which are from the study of Hinske et al. (2014). Also, the researchers designed the game in accordance with these six essential game elements, which are related to the considered five variables.

Figures 2A and 2B show two of the special cards from the A-cards set, which challenge the players' opponents to provide the chemical name or chemical formula to earn points. These special cards are designed to enhance the student-players' knowledge of naming and providing chemical formulae. Another card that addresses the goals and objectives of the card design is the "My Turn" card, shown in Figure 2C. Instead of challenging the opponent, players can choose to take on the challenge themselves to gain points by naming and providing chemical formulae.

Figure 2: Sample of Special Cards for Challenges

A *B* *C*

Figures 3A, 3B, and 3C are special cards that drive competition during the game. Aside from these, some cards intensify the competition and enhance the players' decision-making in managing and utilising their cards.

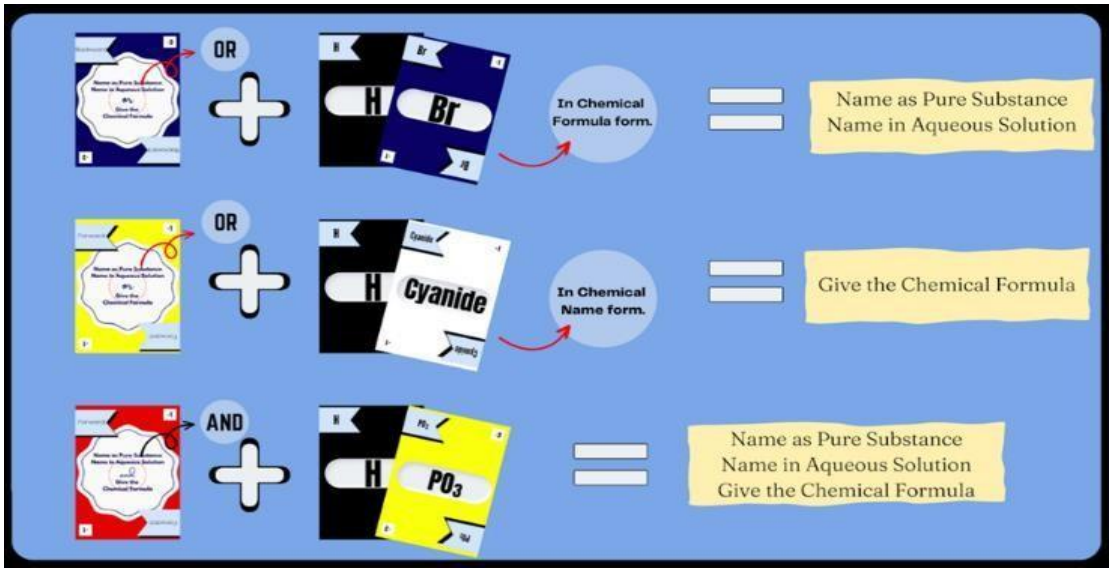
Figure 3: Sample of Special Cards for Playability

A *B* *C*

To guide the players to a more organised playing experience, rules and mechanics are established. Tan et al. (2016) highlighted that joyful and playful experience is a result of a high level of playability. Furthermore, it is stated that playability plays a significant role in increasing playfulness and excitement in gameplay. For A-Cards, playability is emphasised through organised rules that are rigorously examined. The following are rules and mechanics established for A-Cards:

1. The game should have a minimum of three [3] and a maximum of six [6] players.
2. Aside from the players, an umpire should be assigned to facilitate the addition and deduction of scores, as well as oversee the correctness of the players' answers. The following are the points: both 5 points for naming in aqueous solution and naming in pure substance and 3 points for giving the correct formula.
3. To determine the sequence of the players, each player should draw a card from the card pile and examine the corresponding charges indicated on the cards. The sequence should follow the order 1, -1, -2, and -3, respectively, with Hydrogen and Swap cards being 1. In cases where two or more players draw the same charge, these players must draw again.
4. The first player must always start with a combination of a Hydrogen (H) card and an anion card.
5. The next player will base their move on either the charge or the colour of the previous player's card laid on the table. If there is no card, the player should draw from the deck of unused cards as needed.
6. At the beginning of each game, every player will have one hundred [100] starting points. Deductions and additions will be made accordingly from this starting point.
7. When a player is challenged using the special cards, they have 40 seconds to name or provide the chemical formula.
8. Special cards for challenges, shown in Figures 3A and 3B, have different functions depending on what the card requires.
9. The difference of their functions is illustrated in Figure 4.

Figure 4: Illustration of the Functions of Special Cards for Challenges



10. Unless skipped, the player must play a card during every turn, including after drawing or using special cards with tasks. The flow of the game changes when a backward or forward card from the task cards is played.
11. The first player to discard all their cards will receive 100 points, while the second player will receive 50 points.
12. Tabulation of scores occurs when no more card combinations can be played by the players and there are no unused cards remaining in the deck. Then, the scores will determine the player's rank.

3.2 Science Teachers' Evaluation on A-Cards

Seven science teachers from different schools in the province of Misamis Oriental, namely Carmen National High School, Misamis Oriental General Comprehensive High School, and Tignapoloan National High School, participated in the study as evaluators of the game. The researchers used purposive sampling to select these evaluators. The criteria are as follows: (1) the teacher must have at least three years of experience teaching science, particularly General Chemistry (in either public or private schools), and (2) must be a senior high school (SHS) teacher. The sampling technique employed in this study is particularly effective when the researcher needs to explore a specific cultural field with knowledgeable experts.

Table 1: Science Teachers' Evaluation on A-Cards (N = 7)

Items	Frequency					Mean ± SD	Verbal Interpretation
Goals and Objectives							
	5	**4**	**3**	**2**	**1**	4.86 ± 0.40	Strongly Agree
1. The purpose and rationale for the game are fully explained.	6	1	0	0	0	5.00 ± 0.00	Strongly Agree
2. The goals and objectives of the game are clearly defined.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
3. The game was thought provoking.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
4. The game encouraged student interaction.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
5. The game promoted discussion of key topics.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree

6. The card game helps with my recall of concepts/terms.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
Average Mean						**4.98 ± 0.10**	**Strongly Agree**
Card Design							
7. Card size is appropriate.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
8. Having terms printed on all four sides of the card is a helpful feature for the players' handling of the cards.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
9. The picture printed on the card is representative of the topic.	6	1	0	0	0	4.86 ± 0.40	Strongly Agree
10. The material used in the preparation of the cards is durable.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
11. The deck of cards is compact and can be easily carried around	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
Average Mean						4.98 ± 0.10	Strongly Agree
Components and Organisation							
12. The directions were clear, concise, and easily understood.	6	1	0	0	0	4.86 ± 0.40	Strongly Agree
13. The game emphasised key points of the topic played.	6	1	0	0	0	4.86 ± 0.40	Strongly Agree
14. The terms used were appropriate to my level of knowledge.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
15. The number of cards was appropriate.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
16. The length of time required to play the game is reasonable.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
Average Mean						4.98 ± 0.20	Strongly Agree
Playability and Playfulness							
17. The game provides opportunity for healthy competition and cooperation.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
18. The rules of the game provide players with equal conditions for a fair play.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
19. The rules of the game provide a set of options for flexibility in making decisions when playing the game.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
20. Playing the game was fun.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
Average Mean						5.00 ± 0.00	Strongly Agree
Usefulness							
21. The game was effective in reviewing the material.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
22. The game encouraged the players to dig deeper into the subject matter.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
23. Playing the game is a productive use of time.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
24. Playing the game helps me establish better relationships with the members of the group.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
25. I would recommend the game to my peers.	7	0	0	0	0	5.00 ± 0.00	Strongly Agree
Average Mean						5.00 ± 0.00	Strongly Agree

The goals and objectives of the game were presented prior to the game intervention. Item 1 received the lowest mean rating (4.86, although still categorised as strongly agree) and was rated relatively lower compared to the other items under Goals and Objectives. However, the goals and objectives overall received high marks from the teacher-evaluators, with an average mean rating of 4.98 (strongly agree). Goals and objectives are a fundamental feature of

games; they distinguish games from casual activities. The high rating for this criterion indicates that the developed game (A-Cards) has established clear and strong goals and objectives, suggesting a positive evaluation of the game.

3.3 Effectiveness of the A-Cards

The researchers employed a random sampling technique using the fishbowl method. Seven rolled pieces of paper, each representing a section of the Grade 12 STEM classes at the University of Science and Technology of Southern Philippines (USTP-CDO), were placed in a bowl, and a paper was randomly selected to determine the respondents. The section randomly selected during the pilot testing was Zeal, comprising thirty-three (33) students. Meanwhile, thirty-six (36) students from section Advocacy were also randomly chosen for the pretest, followed by the treatment and then a post-test. The test consisted of forty-nine (49) multiple-choice questions. The table below shows the significant difference between the mean scores of the pretest and post-test, as determined using a paired t-test.

As shown in the table below, the calculated p-value is 0.001, with the remark being highly significant. This indicates a significant difference in the mean scores of the pretest and post-test results of the Grade 12 STEM students. This value reflects a substantial increase in the students' academic achievement after using the A-cards. Hence, the card game is effective as a supplementary material and can help enhance students' academic performance. This finding aligns with the results of studies conducted by Kavak (2012) and Rajashekar and Anjana (2016), which also demonstrated the effectiveness of educational card games as supplementary materials in reinforcing learning.

Table 2: Mean Score of the Pretest and Posttest

	Mean	SD	P-value	Remarks	Decision
Pretest	20.06	3.13	0.001	Highly Significant	Reject the Null Hypothesis
Posttest	29.39	9.73			

3.4 Students' Game Experience

The following are the results of the students' Game Experience Questionnaire, which contains three modules: namely, In-game Experience, Social Presence Experience, and Post-game Experience.

a. In-game Experience

The first module of GEQ assesses the players' in-game experience. As shown in Table 3, only Negative Affect is rated as "Not at all," with a score of 0.44 ± 0.70. This indicates that the students felt minimal boredom [item 3] and found the game less tiresome [item 7]. On the other hand, Sensory and Imagination Immersion received an "Extremely" response, corresponding to a score of 3.50 ± 0.60. According to Procci and Browers (2020), immersion is a measure of a person's subjective experience. A study highlighted that when players describe their sensation of immersion or the experience they perceive as immersion, their responses vary. Players frequently describe immersion as losing track of time, but they also associate it with challenging and intense situations (Farkas et al., 2020). The high score in immersion supports the importance of having low tension in the game. Tension scored 0.53 ± 0.80, which translates to "Slightly," suggesting that the students experienced slight "frustration" [item 6] and "irritation" [item 8] during the game. The remaining four components that received a "Fairly" response are Competence, Flow, Challenge, and Positive Affect.

The mean and SD of these components range from 2.72 to 3.50 and 0.80 to 1.00, respectively. These components denote positive experiences that the players had during the game. Experiences such as feeling successful [item 2], skillful [item 9], challenged [item 12], positive impressions [item 4], and contentment [item 11] scored higher than the negative experiences of the players. This result is significant in assessing the game's potential to promote engagement, motivation, and learning. Positive experiences make individuals intrinsically motivated to learn, which, in turn, enhances their learning outcomes (Paras and Bizzocchi, 2005).

Table 3: Results on the In-game Experience

Components	Mean ± SD	Equivalent Response
Competence	2.91 ± 1.00	Fairly
Sensory and Imagination Immersion	3.50 ± 0.60	Extremely
Flow	2.72 ± 1.00	Fairly
Tension	0.53 ± 0.80	Slightly
Challenge	3.10 ± 1.00	Fairly
Negative Affect	0.44 ± 0.70	Not at all
Positive Affect	3.35 ± 0.80	Fairly

b. Social Presence Experience

The second module of GEQ assesses the players' psychological and behavioural involvement, focusing on how the players affect each other during the game. Kiili et al. (2012) stated that the challenge level of a game is influenced by the behaviour of the player's opponent, particularly in competitive games. As shown in Table 4, Psychological Involvement - Negative Feelings and Behavioural Involvement scored a mean between 1.68 and 2.38 with an SD of 1.20, which translates to "Moderately" for both components. Psychological Involvement - Negative Feelings encompasses feelings of jealousy [item 7], revenge [item 16], malicious delight [item 17], and influencing others' moods [items 12 and 16] that the players experienced during the game. In short, a "Moderately" response to this component indicates a reasonable level of negative influence among the players during the game. As for Behavioural Involvement, this pertains to how the players' actions affect others' actions during the game. The "Moderately" response for this component signifies that the players' actions have a noticeable impact on the actions of their opponents or playmates. On the other hand, Psychological Involvement - Empathy scored higher than the other two components in this module. With a score of 3.08 ± 1.00, Psychological Involvement - Empathy received a "Fairly" response, meaning that the players "fairly" understood and connected with other players [item 4]. This also includes feeling happy when others are happy and making others happy when the player is happy [items 10 and 9]. A higher score in Empathy represents a positive outcome, suggesting that players are more likely to develop Empathy than Negative Feelings while playing the game.

Table 4: Results on the Social Presence Experience

Components	Mean ± SD	Equivalent Response
Psychological Involvement - Empathy	3.08 ± 1.00	Fairly
Psychological Involvement - Negative Feelings	1.68 ± 1.20	Moderately
Behavioral Involvement	2.38 ± 1.20	Moderately

c. Post-Game Experience

The final module of the GEQ assesses the players' experience after playing the game. Negative Experience scored relatively lower compared to the other components of this module, with a mean of 0.45 ± 0.70, which translates to "Not at all" in the equivalent responses. In contrast, Positive Experience scored the highest, with a mean of 2.96 ± 1.00, corresponding to the equivalent response "Fairly." The scores of these two opposing components significantly support their contrasting implications. Furthermore, the low score for the Tiredness component (0.56 ± 1.00, translating to "Slightly") supports the high score for Positive Experience. This result leaves a positive impression regarding the kind of experience A-Cards may provide its players. Lastly, "Returning to Reality" scored a relatively low 1.28 ± 1.10, which translates to "Slightly," indicating that although the game has immersive potential, the degree of immersion is low. A study conducted by Jennett et al. (2008) described immersion in various ways, including the idea that immersion involves losing awareness of the real world. This suggests that returning to reality is one experience players may encounter after being immersed in a game. Contrarily, the score for Returning to Reality was significantly lower compared to the Immersion component in the In-game Experience module, which scored highly. However, Bizzocchi (2007) elaborated on two distinct forms of immersion previously described by Coleridge (1984) and Csikszentmihalyi (1990). Coleridge's version involves immersion as a "suspension of disbelief" and a willingness to surrender to the pleasures of the story (Coleridge, 1984). Meanwhile, Csikszentmihalyi (1990) defined immersion as active participation in a dynamic process, referred to as the "flow" state. Bizzocchi (2007) further stated that "games do not necessarily involve story"; therefore, players can become immersed in an educational game even in the absence of a narrative or "story world".

Table 5: Results on the Post-Game Experience

Components	Mean ± SD	Equivalent Response
Positive Experience	2.96 ± 1.00	Fairly
Negative Experience	0.45 ± 0.70	Not at all
Tiredness	0.56 ± 1.00	Slightly
Returning to Reality	1.28 ± 1.10	Slightly

4. Conclusion

Based on the results, the teacher-evaluators gave a high satisfactory rating for the evaluation of the A-cards. They agreed that the card game is a very helpful supplementary tool in naming acids and pure substances and in writing chemical formulae. Additionally, the developed card

game is effective in improving students' academic performance. This suggests that A-Cards engage students by encouraging them to take an active role in applying their learning. It also supports the findings of other pre-existing studies that educational card games are an effective supplementary tool for enhancing students' academic performance. Regarding the game experience with A-Cards, the student-players expressed satisfaction during and after the game, as well as with their playing experience alongside their co-players. Therefore, the use of A-Cards promotes engagement, motivation, learning, and, at the same time, positive player experiences. However, there are significant limitations to this study, particularly the lack of a control group using traditional teaching methods instead of the card game, as well as investigations into students' prior knowledge or external factors that could potentially affect the post-test scores.

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References

Baah, R., & Anthony-Krueger, C. (2012). An Investigation into Senior High School Students' Difficulties and Understanding in Naming Inorganic Compounds by IUPAC Nomenclature.

Barbara, J. (2015). Measuring user experience in multiplayer board games. *Games and Culture, 12*(7-8), 623-649.

Bizzocchi, J. (2007). Games and narrative: An analytical framework. *Loading-The Journal of the Canadian Games Studies Association*, *1*(1), 5-10.

Coleridge, S. T. (1984). Biographia literaria, or, Biographical sketches of my literary life and opinions (Vol. 7). *Princeton University Press*.

Csikszentmihalyi, M. (1990). Flow. The Psychology of Optimal Experience. *New York Harper Perennial.*

Farkas, T., Wiseman, S., Cairns, P., & Fiebrink, R. (2020). A grounded analysis of player-described board game immersion. *Proceedings of the Annual Symposium on Computer-Human Interaction in Play.* https://doi.org/10.1145/3410404.3414224

Hinske, S., Lampe, M., Magerkurth, C., & Röcker, C. (2007). Classifying pervasive games: on pervasive computing and mixed reality. *Concepts and technologies for pervasive games-a reader for pervasive gaming research*, *1*(20), 1-20.

Jennett, C., Cox, A. L., Cairns, P., Dhoparee, S., Epps, A., Tijs, T., & Walton, A. (2008). Measuring and defining the experience of immersion in games. *International journal of human-computer studies,* 66(9), 641-661.

Kavak, N. (2012). ChemOkey: A game to reinforce nomenclature. *Journal of chemical education, 89*(8), 1047-1049.

Kiili, K., De Freitas, S., Arnab, S., & Lainema, T. (2012). The design principles for flow experience in educational games. *Procedia Computer Science*, 15, 78-91.

Mayeem, B. P. Naa, A. M., & Adjei, A. (2018). Enhancing senior high school students understanding of chemical formulae and nomenclature of inorganic compounds by the use of Improvised Conceptual Models. *Journal of Education and Practice. 9*(6), 22-45.

Paras, B. S., & Bizzocchi, J. (2005, June). Game, Motivation, and Effective Learning: An Integrated Model for Educational Game Design. *In Proceeding of DiGRA 2005 Conference.*

Procci, K., & Bowers, C. (2011). An examination of flow and immersion in games. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 55*(1), 2183–2187. https://doi.org/10.1177/1071181311551455

Rajashekar, R. K., & Anjana B. (2016). Effectiveness of educational card game as a Supplementary educational tool in academic performance. *Indian Journal of Clinical Anatomy and Physiology 3*(1): 4-7.

Tan, J. L., Goh, D. H. L., Ang, R. P., & Huan, V. S. (2016). Learning efficacy and user acceptance of a game-based social skills learning environment. *International journal of child-computer interaction, 9*, 1-19.

Turaçoğlu, İ., Alpat, Ş., & Ellez, A. M. (2013). Effects of Jigsaw on Teaching Chemical Nomenclature. *Education & Science/Egitim ve Bilim, 38*(167).

THE IMPACT OF DESIGN THINKING AND INNOVATIVE WORK BEHAVIOURS ON FILIPINO GEN Z NOVICE SCIENCE EDUCATORS' SAFE LABORATORY TEACHING PRAXIS

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ABSTRACT

The emergence of Generation Z as educators signals the need to understand their distinctive mindsets and progressive actions. As a segment of this cohort establishes its niche in science education, there remains a paucity of research examining the intersection of their Design Thinking (DT) and Innovative Work Behaviours (IWB). Amplifying the urgency of such an inquiry is the limited understanding of how this age group perceives and implements laboratory safety, an integral aspect of their role as science educators. This study purported to explore the impact of DT and IWB on newly derived factors of Safe Laboratory Teaching Praxis (SLTP). A quantitative approach, incorporating bivariate (correlation) and multivariate (Exploratory Factor Analysis [EFA] and multiple regression) statistics, was employed to examine these dynamics. One hundred fifty-six (156) Filipino Gen Z novice science teachers from strategic regions in the Philippines completed the Creative Synthesis Inventory, IWB Scale, and Laboratory Safety Questionnaire. The EFA of SLTP revealed five (5) factors. Albeit DT and IWB sub-dimensions were found to be positively correlated, not all sub-dimensions significantly influenced SLTP factors in multiple regression analysis. Among the various sub-dimensions, *Visualisation* and *Discovery* in DT, along with *Opportunity Exploration* and *Idea Sustainability* in IWB, were found to positively influence certain SLTP factors across the regression models. These findings offer preliminary yet profound insights into the cognitive and psychomotor dimensions of the emerging cohort of science educators. They underscore the necessity of tailored professional development strategies that are crucial for advancing the facilitation of safe laboratory learning environments within contemporary educational institutions.

Keywords: Design Thinking, Innovative Work Behaviours, Safe Laboratory Teaching, Gen Z, Science Educators

1. Introduction

Generation Z (henceforth "***Gen Z***"), a demographic born between 1997 and 2012 (Dimock, 2019), is gradually entering the workforce across various industries. Shaped by the advent of social media and technology, they bring unconventional ideations and behaviours that may significantly influence the dynamics of contemporary educational organisations. Like their millennial predecessors, they are expected to exhibit distinct teaching '*Ethos*' (Beliefs) and organisational '*Personae*' (Identity) (Obmerga and de Guzman, 2024). Amanah and associates (2023) contend that their digital nativity and resistance to traditional educational systems could redefine longstanding roles of educators, potentially altering school structures and practices.

Science education, often seen as both fluctuating and stable, exists in a tension between maintaining rigorous standards and fostering innovation (Wollmann and Lange-Schubert,

2022). Science educators face the dichotomous challenge of integrating new practices while adhering to established standards, particularly in laboratory settings. Laboratories are pivotal to science instruction, providing students with hands-on experiences that bridge theoretical concepts. However, while dynamic laboratory approaches are widely encouraged, they must be balanced with the imperative of safety to mitigate risks and injuries (Geraldez et al., 2023).

Whether inward-tending or outward-looking, Gen Z's unique attributes hold profound implications for laboratory teaching practices. Characterised by their embrace of out-of-the-box thinking, this cohort's alignment with Design Thinking (henceforth "***DT***") warrants exploration. Rooted in engineering, DT emphasises creative and iterative processes (Badding, 2017) that align with Gen Z's nonlinear orientations, potentially serving as a mental framework for navigating complex educational challenges. However, their impulsive tendencies could impede adherence to DT's cyclic and incremental principles, potentially compromising the transmission of critical skills in science education. This confluence of generational traits and pedagogical demands underscores the need to critically examine DT's applicability within their teaching praxis. Complementing this cognitive lens, Innovative Work Behaviours (henceforth "***IWB***") add a behavioural dimension to revitalising laboratory teaching. Recognised for fostering curiosity, critical thinking, and authentic learning experiences, IWB enables professionals, including educators, to challenge stagnation and pioneer novel practices (Lambriex-Schmitz et al., 2020). Yet, the tension between Gen Z's trailblazing tendencies and the strict safety protocols integral to laboratory teaching remains an open question.

DT and IWB were selected as independent variables to examine the cognitive and behavioural dimensions of Filipino Gen Z novice science educators, whose creativity and adaptability underscore their budding professional identity. This investigation addresses a critical academic gap in understanding how their innovative dispositions shape laboratory teaching practices. Despite growing research on Gen Z's potential as professional workers and novice educators, significant gaps persist in understanding how their creative mindsets and progressive behaviours influence their Safe Laboratory Teaching Praxis (henceforth "***SLTP***"). Exploring this intersection addresses a significant gap: *how DT and IWB collectively influence Filipino Gen Z novice science educators' SLTP*. Such inquiry is pivotal for developing countries like the Philippines, where empowering Gen Z educators could enhance Science, Technology, Engineering, and Mathematics (STEM) competitiveness and bolster global education metrics.

Cognisant of the foregoing assertions, this quantitative research purported to address the literature blank spot by exploring the interplay between DT, IWB, and SLTP among Filipino Gen Z novice science teachers. Hence, the study sought to answer the following research questions:

1. What is the respondents' performance profile in the specific sub-dimensions of the independent variables: (a) DT (Visualise, Discover, Prototype, and Evaluate) and (b) IWB (Opportunity Exploration, Idea Generation, Idea Promotion, Idea Realisation, and Idea Sustainability)?
2. What are the underlying sub-dimensions of SLTP that make sense among the respondents?
3. Is there a correlation that exists between the sub-dimensions of the independent variables: DT and IWB?
4. Which among the sub-dimensions of (a) DT and (b) IWB positively impact the respondents' newly emerged SLTP sub-dimensions?

2. Literature Review, Hypotheses Development, and Theoretical Framework

2.1 The Cognitive and Psychomotor Domains of the Novice Science Educators in the Laboratory

The traditional purview of organisational behaviour posits that a person's cognitive (*knowledge*), affective (*attitude*), and psychomotor (*skills*) dimensions shape their professional practices (Ichsan et al., 2023). Within science education, effective teaching necessitates critical thinking and adept navigation of laboratory and fieldwork settings. While some scholars emphasise the role of emotions in scientific processes, others contend that knowledge and skills alone suffice for risk mitigation and hazard control in laboratory teaching (Akyol and Taş, 2024). As Gen Z enters science education, their adherence to safe laboratory standards, including hazard awareness and procedural skill contextualisation (Nwune et al., 2023), remains uncertain.

Null Hypothesis (H_0) 1: There is no significant correlation between the DT and IWB of Filipino Gen Z novice science educators.

Alternative Hypothesis (H_a) 1: There is a significant correlation between the DT and IWB of Gen Z novice science educators.

2.2 The Design Thinking and Safe Laboratory Teaching Praxis

Design Thinking, an emergent model for anticipatory practice, serves as a foundation for enhancing professional implementation across disciplines (Badding, 2017). Beyond being a framework for a wide array of actionable conditions, its core premise in the literature is its capacity to foster the consideration and (re)discovery of prudent ideas to enrich actual practices (Razzouk and Shute, 2012). Recognised for its adaptability and potential to generate mindful and practical solutions, this approach has extended into educational fields such as mathematics, more recently, the sciences. As regulatory bodies continually update laboratory standards to address evolving compliance needs, science educators must recalibrate their practices to align with stringent protocols, enhancing safety, authentic learning, and scientific enquiry (Sison, 2021).

Null Hypothesis (H_0) 2: DT sub-dimensions do not significantly impact the SLTP of Filipino Gen Z novice science educators.

Alternative Hypothesis (H_a) 2: One to two DT sub-dimensions significantly impact the SLTP of Filipino Gen Z novice science educators.

2.3 The Innovative Work Behaviours and Safe Laboratory Teaching Praxis

Lambriex-Schmitz and collaborators (2020) highlighted that workplace innovation hinges on the amalgamation of bold practices and inquisitive ideations demonstrated by professionals. Science educators must keep pace with scientific and disciplinal trends due to the continuous influx of discoveries in their field. However, despite their innovative drive, certain practices—such as strict adherence to laboratory safety protocols and high teaching standards—remain non-negotiable (National Research Council, 2010). While emerging research explores teachers' innovative behaviours, these studies predominantly focus on general education and reflect perspectives from earlier generations of science educators.

Null Hypothesis (H_0) 3: IWB sub-dimensions do not significantly impact the SLTP of Filipino Gen Z novice science educators.

Alternative Hypothesis (H_a) 3: One to two IWB sub-dimensions significantly impact the SLTP of Filipino Gen Z novice science educators.

2.4 Safe Laboratory Learning Facilitation among Science Educators

Laboratory instruction lies at the heart of science education, bridging the gap between theory and practice to foster technical understanding (Fu et al., 2023). Although literature supports advancements in laboratory practices in higher education and industry training (Schröder et al., 2016), research on safety within basic education science laboratories remains limited (Mohzana et al., 2023). Existing frameworks, such as those by the National Research Council (2010), often draw on general safety protocols, neglecting the specific needs of educational contexts. Safety communication tools and checklists, while prevalent, tend to be generic, overlooking the nuanced requirements of younger science educators (Akpullukcu and Cavas, 2017). Additionally, laboratory safety resources are frequently inaccessible or inconsistent across studies, often reflecting the perspectives of older educators (Sadler et al., 2011).

2.5 Theoretical Framework

This inquiry was grounded on the Theory of Reasoned Action (TRA) as espoused by Ajzen and Fishbein (1980), a framework frequently employed in rich and resonant educational studies (Obmerga, 2020). Among novice Gen Z science educators, adherence to laboratory safety norms is uncharted, with cultural values like *Hiya* (Shame) and *Delicadeza* (Propriety) potentially balancing neoliberal traits (Landa-Jocano, 2006). Anchoring on the underpinnings of TRA, the framework guided the careful examination of the impact of the respondents' DT and IWB into SLTP, exploring if their unconventional yet rationalised actions and other socio-professional norms governed their perspectives on laboratory safety.

3. Methods

3.1 Design

This study employed a quantitative research approach to investigate the impact of DT and IWB on SLTP among Filipino Gen Z novice science educators. A conglomeration of correlational-predictive research designs, relying on descriptive and inferential statistics—both bivariate and multivariate in nature—was utilised. Descriptive statistics outlined the respondents' demographic information and provided insights into their performance with the components of each instrument. Inferentially, Exploratory Factor Analysis (EFA) identified underlying sub-dimensions of SLTP that aligned with respondents' perspectives, while correlational analysis assessed the relationship between their cognitive (DT) and psychomotor (IWB) attributes. To further examine the individual impacts of the sub-dimensions on SLTP, the Multiple Regression Analysis was utilised.

3.2 Respondents and Locale

A total of one hundred fifty-six (156) respondents participated in this inquiry. Since the study involved multiple regression, an *A priori* power analysis (Soper, 2024) was conducted before data collection to determine the required sample size, enriching the study's methodological rigor. The configurations were set with an effect size of f = 0.15 (Cohen's f^2), signifying a medium effect, a standardised statistical power of 0.8, and an alpha level of 0.05. The sampling also considered the independent variable (IWB) with the most predictors (5), yielding a minimum sample size estimate of 91–93. The recruited sample (N = 156) exceeded this threshold, enhancing the study's reliability and validity. This sample size aligned with Hair and colleagues' (2010) recommendation of at least a hundred samples for regression models with 3-5 predictors, ensuring stable parameter estimates. A sample size larger than the minimum required further enhanced the precision of the regression coefficients and reduced standard errors.

Respondents were recruited using a purposive sampling technique, with the following inclusion criteria: (a) natural-born Filipino citizen, (b) part of the Gen Z (1997–2012), (c) a holder of a Bachelor of Elementary Education or Bachelor of Secondary Education major in Science, (d) currently teaching science-related subjects (pure laboratory or lecture with laboratory sessions), (e) licensed professional teacher or otherwise, and (f) willing to participate in the study. The participants were from the National Capital Region (NCR) and Region IV-A: CALABARZON, both strategic areas intersecting educational, cultural, political, and economic domains in the Philippines. As the participants hailed from locales representing diverse perspectives and dynamic intersections of experiences and backgrounds, their quantified responses provided a multifaceted lens, enriching the depth and enhancing the generalisability of the study's findings.

3.3 Instrumentation

The inquiry employed a three-part instrument. Standardised questionnaires with excellent psychometric properties were used. The DT was measured with the 19-item Creative Synthesis Inventory (CSI; α = 0.87) with four (4) sub-dimensions by Badding (2017), using a 6-point Likert scale ranging from 6 (*Always*) to 1 (*Never*). The CSI was primarily selected due to its simple yet relatable pool of questions concerning creativity at the cognitive level. Moreover, the IWB was measured with the 44-item Innovative Work Behaviours tool (IWB; α = 0.94) with five (5) sub-dimensions by Lambriex-Schmitz and collaborators (2020), using a 5-point scale ranging from 5 (*Always*) to 1 (*Never*). The IWB was strategically chosen due to its widespread use in (non)educational inquiries relating to innovation. Further, the SLTP was measured with the 36-item Laboratory Safety Questionnaire (LSQ; α = 0.98) by Akpullukcu and Cavas (2017), a 4-point scale ranging from 4 (*Strongly Agree*) to 1 (*Strongly Disagree*). The LSQ is explicitly designed for integrated science laboratory safety but lacks predefined sub-dimensions. This stipulation positioned the tool as a strategic instrument for surfacing new dimensions of SLTP, as respondents perceived through the inquiry's EFA segment.

3.4 Data Gathering Procedure

After identifying respondents who met the inclusion criteria, the author formally contacted them, outlining the study's aims and specific objectives. Once participants signified their intent to join, they received a Quick Response (QR) code directing them to a Google Form containing the four-part instrument. The form presented an embedded Informed Consent section, which they had to acknowledge before proceeding to the survey. Detailed assurances of compliance with the Data Privacy Act of the Philippines were also provided. Respondents were provided with sufficient time to complete the survey, promoting thoughtful responses and systematic data retrieval.

3.5 Data Analysis

The study employed IBM Statistical Package for the Social Sciences (SPSS) version 25 to construct a comprehensive profile of the respondents regarding their demographic information and instrument performance. Inferentially, SPSS was utilised to examine correlations and multicollinearity concerns among the independent variables and used to facilitate an EFA to identify novel latent dimensions within the LSQ instrument as perceived by the respondents, capitalising on EFA's data reduction capabilities and its value for refining theoretical precepts (Reio and Shuck, 2014). Subsequently, Multiple Regression Analysis was applied to evaluate the unique impacts of DT and IWB sub-dimensions on the newly surfaced SLTP factors. This allowed isolating only those sub-dimensions demonstrating significant positive impacts, thereby pinpointing the sub-dimensions contributing constructively to SLTP.

3.6 Ethical Considerations

The author adopted nonproprietary instruments under Creative Commons licenses, enabling fair use for educational research. Albeit such is the case, as an added measure, he also sought permissions from the instrument developers. Respondents received comprehensive briefings on the study's overarching aims, specific objectives, phases, minimal risks, data handling protocols, and strict adherence to privacy and confidentiality. They were assured of the right to withdraw at any point. Informed consent forms were secured before distributing the four-part instrument.

4. Results and Discussion

4.1 Description of the Study Respondents

Eighty-seven (87) out of the 156 total respondents fall within the 23 to 26 age range (55.77%), with a gender distribution of 75 males (48.08%) and 81 females (51.92%). A substantial number of these educators (83; 53.21%) hail from Region IV-A: CALABARZON, Philippines, a region renowned for its semi-urban settings and progressive educational districts. Regarding academic credentials, 151 respondents (96.79%) hold a bachelor's degree in education, and 114 (73.08%) possess a professional teaching license. One hundred twenty (120) respondents (76.92%) are affiliated with private schools and have varied in-service teaching experience, with a notable segment in their first year of teaching (87; 55.77%). Their instructional responsibilities span diverse science subjects, including Chemistry (48; 30.77%), Biological Science (55; 35.26%), and Physics (60; 38.46%), fields that traditionally require continuous laboratory engagement. Post-graduate laboratory teaching training remains relatively limited, with only 16 respondents (16.67%) having received additional laboratory capacity-building stint beyond college. However, the majority (146; 93.59%) expressed interest in advancing their laboratory safety education.

4.2 Exposition of the Statistical Analyses

RQ1: *What is the respondents' performance profile in the specific sub-dimensions of the independent variables: (a) DT and (b) IWB?*

Table 1: The Respondents' Performance Profile in the Independent Variables' Sub-Dimensions

The Independent Variables and its Sub-Dimensions	N	Min	Max	Mean	Std Dev
Design Thinking (DT)					
Visualise (VIS)	156	2.00	6.00	4.51	0.74
*Discover (*DIS)	156	2.20	6.00	4.88	0.76
Prototype (PROT)	156	1.00	6.00	4.39	0.89
Evaluate (EVAL)	156	2.00	6.00	4.67	0.84
Innovative Work Behaviours (IWB)					
Opportunity Exploration (OE)	156	2.25	5.00	4.10	0.61
Idea Generation (IG)	156	2.00	5.00	3.99	0.59
Idea Promotion (IP)	156	1.14	5.00	3.88	0.66
Idea Realisation (IR)	156	1.89	5.00	4.00	0.61
Idea Sustainability (IS)	156	1.76	5.00	3.86	0.65

The selected descriptive statistical analyses of the standardised instruments revealed that respondents demonstrate a strong engagement with the sub-dimensions of DT, especially in the areas of DIS (M = 4.88, SD = 0.76) and EVAL (M = 4.67, SD = 0.84). These findings

suggest that Gen Z science educators are adept at identifying opportunities for innovation and critically evaluating their ideas. Akyol and Taş (2024) expounded that, as recent graduates of pre-service teacher programmes, novice science educators were trained to be mindful of the procedural efficacy of their actions. Additionally, VIS (M = 4.51, SD = 0.74) and PROT (M = 4.39, SD = 0.89) also showed positive engagement, suggesting proficiency in conceptualising and testing ideas. This aligns with the contentions of Mohzana and collaborators (2023), who argue that science educators invest considerable effort into optimising their practices, even within the constraints of laboratory innovation. Meanwhile, the sub-dimensions of IWB reflect slightly lower engagement levels, with OE exhibiting the highest mean (M = 4.10, SD = 0.61) and IS the lowest (M = 3.86, SD = 0.65). These results accentuate strengths and potential growth areas in educators' innovative work tendencies.

RQ2: *What are the underlying sub-dimensions of SLTP that make sense among the respondents?*

The Exploratory Factor Analysis (EFA) provided renewed perspectives on laboratory safety that resonates with the sensibilities of the new wave of science educators. Initially, factor analysis was conducted using the principal component method with varimax rotation on thirty-six (36) generic laboratory safety-related statements to identify the underlying dimensions of SLTP among the respondents. Prior to factor analysis, the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity were employed to assess data suitability. The KMO result indicated 93% adequacy, and Bartlett's Test of Sphericity yielded a value of 4619.92 with a significance level below 0.001, confirming that the data were suitable for factor analysis. The reliability coefficient (Cronbach's α) was calculated for each factor dimension to evaluate the internal consistency of items within each scale. Consistent with established statistical decision rules, factors with reliability coefficients of 0.60 or higher were considered acceptable. All factors in the analysis exhibited strong reliability, with α values ranging from 0.84 to 0.94. A thorough review of item retention was performed, with all factor loadings and communalities below 0.40 removed according to decision rules. This process resulted in the retention of all survey items, capturing five (5) dimensions. Each factor achieved an Eigenvalue above 1, and the five (5) dimensions were labeled sequentially according to their decreasing explained variance.

Table 2: The EFA of Safe Laboratory Teaching Praxis

Safe Laboratory Teaching Praxis (SLTP) Factors and Items	Factor Loading	Eigenvalue	Variance (%)	Reliability Coefficient
Factor 1: *Safeguarding Students' Safety and Health* (SFGR)		4.38	18.57	0.94
I have knowledge of how to intervene if the need arises in case of ingestion of any chemicals	0.83			
I have knowledge of how to intervene if the need arises with inhalation of chemicals	0.80			
I have knowledge of what should be done if any chemicals splash into the eyes	0.74			
I have knowledge of how to intervene in the accident that occurs as a result of electric current	0.73			
I work with an inventory that has the identifications of all chemicals in the laboratory	0.68			
I have knowledge of how to respond in case of a burn that occurs from contact with hot objects	0.66			
I have knowledge of how to store chemicals that need to have special conditions	0.65			
I have knowledge of how to store and keep solid chemicals	0.57			
I have knowledge of what should be done in case of bleeding	0.49			

Factor 2: *Sustaining Laboratory Standard Adherence* (SUS)		4.08	15.93	0.91
I have never left the laboratory before checking all electrical devices	0.77			
I get students to wash their hands and faces with water after the activities	0.76			
I have never left the laboratory before checking the water system	0.74			
I have never left the laboratory before checking the gas installations	0.64			
I have information about the health status of my students	0.63			
I have always taken care that all shelves have protection sets on the front sides	0.61			
I have labeled the remaining materials from experiments and stored it in an appropriate manner after the activities	0.59			
I have always taken care that the shelves are firmly attached to the wall	0.56			
I have always worn an apron during activities in the laboratory	0.50			
I have knowledge of how to design the desks for the students in the laboratory	0.46			
Factor 3: *Systematising the Laboratory Workspace* (SYS)		2.67	13.97	0.90
I have knowledge of the precautions to be taken in case of spills and splashes of chemicals	0.69			
I have always ensured that the laboratory is clean and tidy	0.68			
I have knowledge of the precautions to be taken in case of a fire in the laboratory	0.67			
I have knowledge of which emergency kits must be in a laboratory for use in case of an emergency situation	0.65			
I always take care to put laboratory materials in the right places after using them	0.56			
I have knowledge of how to store and keep the liquid chemicals	0.53			
I have knowledge of what the standards of an ideal laboratory for schools should be	0.49			
Factor 4: *Strengthening the Laboratory Safety Culture* (STRE)		1.88	10.74	0.85
I have knowledge of how to use a fire extinguisher in case of a fire	0.65			
I have knowledge of how to use a fire blanket in case of a fire	0.59			
I have knowledge of the phone numbers to call in an emergency situation	0.55			
I have knowledge of how to use first aid kits in the laboratory	0.54			
I have knowledge of how to use a bucket of sand in case of a fire	0.52			
I have knowledge of the students' needs during an emergency and the uses of an emergency exit plan	0.48			
Factor 5: *Suppressing Sources of Hazardous Conditions* (SUPP)		1.60	8.24	0.84
I have knowledge of how to use electrical and lighting in the laboratory	0.69			
I have knowledge of how to use the water system in the laboratory	0.65			
I have knowledge of how to use gas installations	0.62			

I have knowledge of how to use the ventilation system inside the laboratory	0.53
Total Explained Variance	67.48

Notes: Kaiser-Meyer-Olkin Measure of Sampling Adequacy = 0.93 (93%); Bartlett's Test of Sphericity = 4619.92

Albeit numerous laboratory guidelines exist in the literature, most studies tend to focus on specific, isolated variables of laboratory safety in the industry setting, which limits their applicability within the broader context of science education (National Research Council, 2010). Given that the dimensions that make sense to Gen Z novice science educators have been identified, the dependent variable, STLP, will henceforth be represented as a multifaceted construct comprising five (5) sub-dimensions, rather than as a unitary variable, as lifted in the original work of Akpullukcu and Cavas (2017). The surfaced dimensions from the EFA provide laboratory educators with safety-related facets that are particularly meaningful to the youngest demographic of science teachers, enhancing the practical applicability of safety practices in contemporary educational settings.

The Factor 1, *Safeguarding Students' Safety and Health* ("***SFGR***"), captures the science educator's active role in protecting students from harm by preparing for and responding to potential risks. It emphasises knowledge and readiness to handle emergencies and accidents, such as chemical splashes, burns, and bleeding incidents. It encompasses skills for immediate interventions to protect oneself and the students. Moreover, Factor 2, *Sustaining Laboratory Standard Adherence* ("***SUS***"), conveys the constant attentiveness required to uphold laboratory safety, aligning with the science educator's responsibility to prevent untoward incidents through careful observation. It reflects the diligent oversight of laboratory conditions, including checking systems, organising materials, and ensuring that students consistently follow safety protocols. Additionally, Factor 3, *Systematising the Laboratory Workspace* ("***SYS***"), reflects the importance of a well-planned physical space, ensuring safety through effective laboratory organisation. It involves organising and setting up the laboratory space, including maintaining cleanliness, preparing for emergencies, and arranging a layout that supports a safe learning environment. Further, Factor 4, *Strengthening the Laboratory Safety Culture* ("***STRE***"), underscores the instructional aspect of safety preparation, enabling students to respond correctly during emergencies. It accentuates the science educator's role in preparing for emergencies by teaching students how to use safety equipment, locate emergency exits, and understand response protocols. Lastly, Factor 5, *Suppressing Sources of Hazardous Conditions* ("***SUPP***"), typifies the active control and use of critical laboratory systems, ensuring safe and practical functionality in the laboratory. It focuses on the proactive handling and management of essential laboratory systems, such as electrical, water, gas, and ventilation.

RQ3: *Is there a correlation that exists between the sub-dimensions of the independent variables: DT and IWB?*

The Correlation Analysis of the sub-dimensions of the independent variables, treated as aggregated scores under the assumption of equidistant response options, revealed significant positive correlations among all pairs of sub-dimensions, with p-values indicating moderate to high statistical significance. The finding confirms that the DT among the respondents is significantly correlated with their IWB. In light of such findings, the Null Hypothesis (H_0) 1 is rejected in favor of the Alternative Hypothesis (H_a) 1. VIS showed significant positive correlations with both PROT ($r = 0.64$, $p<.01$) and EVAL ($r = 0.62$, $p<.01$), indicating a strong link between envisioning solutions and hands-on creation and critical assessment of ideas. Moreover, DIS correlated positively with PROT ($r = 0.70$, $p<.001$) and EVAL ($r = 0.73$, $p<.001$), suggesting that a focus on discovery aligns with active engagement in developing and testing concepts. Such premises, borne from statistical results, affirm that, even without rigorous training with the school safety culture, prudent science educators tend to factor in safety-

related dimensions even at the conceptualisation stage of their endeavours (Faulconer et al., 2020). In the Filipino cultural context, individuals frequently employ *Pag-usisa* (Inquiry) and *Pagkilatis* (Scrutiny) to achieve a thorough comprehension of situations (Landa-Jocano, 2006). The PROT in DT, essential in materialising ideas, notably correlated with IR in IWB ($r = 0.69$, $p<.001$), underscoring prototyping's role in bringing ideas to fruition. This notion is grounded in the work of Fu and fellows (2023), who assert that science practitioners are intrinsically motivated to translate their ideas into practice out of utilitarianism. In Filipino culture, decisions and actions are frequently guided by *Kabuluhan* (Significance), emphasising a collective sense of social responsibility to effect meaningful change (Landa-Jocano, 2006).

Table 3: The Correlation Matrix of the Independent Variables' Sub-Dimensions

	VIS	DIS	PROT	EVAL	OE	IG	IP	IR	IS
VIS (DT)	1								
DIS (DT)	0.58**	1							
PROT (DT)	0.64**	0.70***	1						
EVAL (DT)	0.62**	0.73***	0.78***	1					
OE (IWB)	0.46*	0.60***	0.52**	0.59***	1				
IG (IWB)	0.49*	0.56**	0.46*	0.50*	0.61***	1			
IP (IWB)	0.53**	0.54**	0.61***	0.63***	0.58***	0.75***	1		
IR (IWB)	0.54**	0.62***	0.69***	0.66***	0.65***	0.67***	0.78***	1	
IS (IWB)	0.50*	0.51*	0.62***	0.60***	0.57***	0.64***	0.80***	0.85***	1

*Notes: * p < .05, ** p < .01, *** p < .001; Variance Inflation Factor (VIF) of ≤ 4*

In the IWB sub-dimensions, strong correlations suggested a structured progression among these behaviours and with DT elements. OE correlates with IP ($r = 0.58$, $p<.001$) and IR ($r = 0.65$, $p<.001$), indicating that exploring new ideas naturally leads to promoting and implementing them. Such a proposition traces its nexus in the work of Nwune and fellows (2023), suggesting that science educators prioritise effectively implementing concepts aligned with their professional interests and values. Although *Mahiyain* (Reserved) behaviour is typical among Filipinos (Landa-Jocano, 2006), the respondents were willing to transcend these norms to pursue their goals. Additionally, IP demonstrated a high correlation with IS ($r = 0.80$, $p<.001$), indicating that advocating for ideas is crucial for sustaining innovation. To date, there is a notable scarcity of research investigating the sustainability practices of the youngest generation of science educators. This pioneering study is among the first to reveal that Gen Z educators are consciously attentive to the long-term viability of their professional activities. Cross-dimensionally, EVAL from DT correlated with IP ($r = 0.63$, $p<.001$) and IR in IWB ($r = 0.66$, $p<.001$), suggesting that thorough evaluation plays a vital role in progressing innovative work. Despite being in the budding phases of their careers, the respondents anchored with the assertions of Sahin and Sasmaz-Oren (2022), who argue that the success of scientific ventures relate not only toward the attitudes of science educators but also on their commitment to refine their practices continually. The Filipino practice of *Pagsusuri* (Assessment) is closely linked to self-reflection and acts as a conduit for achieving *Kahusayan* (Mastery) (Landa-Jocano, 2006).

The matrix indicated moderate to strong correlations among some sub-dimensions within DT and IWB. However, multicollinearity was not deemed problematic. The Variance Inflation Factor (VIF) was computed for each sub-dimension to assess this concern further. The obtained VIF values, ranging from 1 to 4 across all variable combinations, were below the critical threshold of 10, suggesting that multicollinearity did not pose a significant issue (Field, 2013). Additionally, although certain sub-dimensions exhibited moderate correlations, these correlations did not reflect excessive redundancy that could substantially compromise the model's reliability or the estimation of unique contributions to the dependent variable. As a result, the author proceeded with the Multiple Regression Analysis without adjustments for multicollinearity, ensuring the integrity and robustness of the results.

RQ4: *Which among the sub-dimensions of (a) DT and (b) IWB positively impact the respondents' newly emerged SLTP sub-dimensions?*

Table 4: The Multiple Regression Matrix of the Independent and Dependent Variables

Model	Explanatory Variables	β Coefficient	R^2	F	t-value	p-value
DT sub-dimensions (IV) as Predictors → Specific SLTP sub-dimension (DV)						
Model 1	*VIS, DIS, *PROT, *EVAL → SFGR	1.87	0.35	5.57	2.36	0.019
Model 2	*VIS, DIS, *PROT, *EVAL → SUS	0.31	0.10	17.36	4.16	0.000
Model 3	*VIS, DIS, *PROT, *EVAL → SYS	0.40	0.16	29.56	5.43	0.000
Model 4	*VIS, DIS, *PROT, *EVAL → STRE	0.32	0.10	18.39	4.28	0.000
Model 5	VIS, *DIS, *PROT, *EVAL → SUPP	0.22	0.51	8.33	2.88	0.004
IWB sub-dimensions (IV) as Predictors → Specific SLTP sub-dimension (DV)						
Model 6	OE, *IG, *IP, *IR, *IS → SGFR	0.24	0.06	10.06	3.17	0.002
Model 7	OE, *IG, *IP, *IR, IS → SUS	0.23 (OE); 0.21 (IS)	0.16	14.63	2.60 (OE); 2.37 (IS)	0.010 (OE); 0.019 (IS)
Model 8	OE, *IG, *IP, *IR, *IS → SYS	0.45	0.20	40.49	3.66	0.000
Model 9	OE, *IG, *IP, *IR, *IS → STRE	0.40	0.16	29.50	5.43	0.000
Model 10	OE, *IG, *IP, *IR, *IS → SUPP	0.39	0.15	28.52	5.34	0.000

*Notes: *Excluded Variables; The Stepwise method was performed in SPSS v25 due to the nature of Research Question 4 and to strategically identify the DT and IWB sub-dimensions that positively impact(s) on the SLTP sub-dimensions. The excluded sub-dimensions were omitted from the final models due to statistical insignificance and model fit optimization.*

The Multiple Regression Analysis examined relationships between Likert-scale variables, which were treated as interval data in accordance with established educational research practices. The results revealed β coefficients ranging from 0.21 to 1.87 and R^2 values between 0.06 and 0.51. While the explanatory power is modest, these findings are consistent with typical educational research outcomes, where various influencing factors shape complex human behaviours. Given the focus of the inquiry on uncovering the impacts of the hidden terrain of the mindset and behaviours of the cohort in SLTP, even moderate effects offered valuable insights. This underscores the importance of a nuanced understanding of the multifaceted nature of the cohort.

In DT, the findings supported the Alternative Hypothesis (H_a) 2, revealing that the DIS sub-dimension consistently exerts a significant impact across several SLTP dimensions. Specifically, DIS positively impacts SFGR in Model 1 ($\beta = 1.87$, $R^2 = 0.35$, $p = 0.019$), SUS in Model 2 ($\beta = 0.31$, $R^2 = 0.10$, $p < 0.001$), SYS in Model 3 ($\beta = 0.40$, $R^2 = 0.16$, $p < 0.001$), and STRE in Model 4 ($\beta = 0.32$, $R^2 = 0.10$, $p < 0.001$). The discovery process, as a blanket approach to expanding scientific knowledge, is often heightened when individuals are introduced to unfamiliar environments. Filipinos often engage in *Pagtuklas* (Discovery) in a subtle manner, gauging potential courses of action before fully committing to their pursuits (Landa-Jocano, 2006). Moreover, VIS alone was found to significantly impact SUPP in Model 5 ($\beta = 0.22$, $R^2 = 0.51$, $p = 0.004$), underscoring its critical role in hazard identification and mitigation. This suggests that although the respondents are novice teachers, they display a proactive tendency. Such a trait resonates with the practices of progressive science educators who prioritise accident prevention and effective suppression strategies. Filipinos often demonstrate *Malasakit* (Compassion) by embodying a profound sense of responsibility and concern for the welfare of others. This value is expressed through actions that exceed what is required to prevent harm or address potential risks (Landa-Jocano, 2006). Across models, other DT sub-dimensions, specifically PROT and EVAL, were consistently excluded, indicating their lack of significant impact on SLTP. This exclusion may reflect the respondents' limited firsthand experience creating and assessing safety-focused procedural elements within SLTP.

In IWB, the analysis also supported Alternative Hypothesis (H_a) 3, indicating that OE significantly impacts various SLTP dimensions. In Model 6, OE affects SFGR ($\beta = 0.24$, $R^2 =$

0.06, p = 0.002), while in Model 7, both OE (β = 0.23, p = 0.010) and IS (β = 0.21, p = 0.019) jointly contribute to SUS, with an $R^2 = 0.16$. Additionally, OE alone significantly impacts SYS in Model 8 (β = 0.45, $R^2 = 0.20$, p < 0.001), STRE in Model 9 (β = 0.40, $R^2 = 0.16$, p < 0.001), and SUPP in Model 10 (β = 0.39, $R^2 = 0.15$, p < 0.001). Given that many recently hired Gen Z science educators are still acclimating to diverse roles and responsibilities within academic institutions, they tend to learn the rudiments of their roles by adopting the best practices of other teachers through continuous engagement and interaction. The Filipino value of *Bayanihan* (Communal Spirit), reflecting unity and cooperation (Landa-Jocano, 2006), aligns with cohorts' tendency to adopt the best practices from other teachers while trying to fit themselves in their new realities. Furthermore, the exclusion of other IWB sub-dimensions, such as IG, IP, and IR, indicates that the focus on ideation and conceptualisation may not align closely with the procedural and safety-oriented outcomes emphasised in SLTP at this stage in their careers.

Essentially, the consistent exclusion of certain sub-dimensions underscores that not all aspects of DT and IWB variables impact SLTP, yet it instils the importance of focusing on actionable dimensions that directly impact safety practices. These findings lay the empirical cornerstones for professional learning programmes to enhance the focused competencies among science educators in laboratory settings. The VIS and DIS in DT, along with OE and IS in IWB, provide complementary foundations for the professional development of new science teachers in SLTP. These sub-dimensions cultivate critical skills such as creative problem-solving, adaptability, and continuous improvement—essential qualities for navigating the complexities of laboratory environments. The VIS enables teachers to anticipate safety risks and design proactive solutions, while DIS helps them identify innovative ways to address challenges. Similarly, OE empowers teachers to uncover gaps in safety practices and explore practical improvements, while IS ensures these solutions remain viable and continuously improved. Altogether, these competencies can foster a dynamic and student-centred approach to laboratory safety.

5. Conclusion

Early-career experiences of teachers, across cultures and disciplines, reveal common challenges that transcend generational divides. The findings highlight that SLTP extends beyond resource management and procedural compliance, embodying responsibility and situational awareness among novice science educators. Reframing safety as a core component of scientific inquiry, rather than a mere regulatory obligation, enables early-career educators to cultivate learning environments that inspire experimentation, curiosity, and learning through calculated risk. This paradigm fosters a science culture rooted in exploration, where safety seamlessly integrates into the teaching process.

5.1 Theoretical Contributions

This research contributes five (5) key theoretical advancements. *First*, while existing studies explore Gen Z perspectives on 21st century science learning, they predominantly analyse pre-service educators (Ichsan et al., 2023). This pioneering inquiry focuses on the older subset of Gen Z, specifically as they transition to in-service science teaching roles. *Second*, although empirical studies address laboratory safety, they largely pertain to tertiary medical education (Geraldez et al., 2023) or scientific reasoning among pre-service teachers (Sahin and Sasmaz-Oren, 2022). This study provides fresh insights into SLTP, contextualised for Gen Z science educators at the basic education level. *Third*, apart from Fu and colleagues (2023) examining safety in a Chinese university setting, no recent research connects laboratory safety with nonlinear competencies like DT and IWB, particularly in developing countries within East and Southeast Asia. This Philippine-based study is the first to explore their combined

impact on SLTP, addressing a critical gap. *Fourth*, EFA results redefine SLTP sub-dimensions relevant to Gen Z educators, demonstrating the cohort's openness to data-driven findings over pre-existing frameworks. *Fifth*, this inquiry introduces regression models that identify skill gaps and strengths within SLTP, offering actionable frameworks for educators, policymakers, and researchers to enhance safety practices through DT and IWB across diverse contexts.

5.2 Practical Implications

This research offers four (4) practical implications. *First*, the findings offer a guide for Gen Z science educators entering the in-service practice to harness their DT and IWB attributes in enhancing SLTP. *Second*, with limited instruments addressing school laboratory safety, this study builds on Akpullukcu and Cavas' (2017) LSQ. While the original LSQ suits general use, the newly evolved components cater specifically to younger educators, enriching the tool while honouring its original design. *Third*, multiple regression findings reveal strengths and areas for improvement in DT and IWB among novice educators, informing teacher training and professional development to strengthen SLTP. *Fourth*, as DT and IWB transcend general sciences, these concepts hold potential for application across STEM fields, enriching educational discourse and practice.

5.3 Limitations and Future Research Directions

A primary methodological limitation lies in the use of purposive sampling, which, despite its strategic selection, constrains the generalisability of findings. While the sample was informed by power analysis, it may not entirely capture the diverse demographic landscape of Filipino Gen Z novice science educators. Future studies could benefit from broader sampling techniques to enhance representativeness and transferability. Moreover, the sample size, while sufficient for this analysis, may limit the robustness of multivariate approaches. Future researchers are encouraged to adopt advanced techniques, such as Covariance-based Structural Equation Modelling, with larger samples to address the study's 14 latent and 99 observed variables more comprehensively. Additionally, the cross-sectional design also precludes causal inferences regarding the impact of DT and IWB on SLTP, highlighting the value of longitudinal designs, such as institutional ethnographies, to track these dynamics over time in naturalistic settings. Further, the self-reported nature of the instruments introduces potential response biases. Complementary qualitative methods, such as cross-case analyses, could provide deeper insights into novice educators' lived experiences with SLTP. Lastly, while DT and IWB proved insightful for science education, their focus on SLTP may limit applicability across broader STEM fields. Future studies might explore these dimensions alongside affective domain predictors to holistically examine their relevance in other STEM contexts.

References

Ajzen, I. and Fishbein, M. (1980). Understanding attitudes and predicting social behavior. *Englewood Cliffs*.

Akpullukcu, S. and Cavas, B. (2017). The development of laboratory safety questionnaires for middle school science teachers. *Science Education International*, *28*(3), 224–231. https://doi.org/10.33828/sei.v28.i3.6

Akyol, G. and Taş, Y. (2024). Preservice teachers' science process skills and science teaching efficacy beliefs in an inquiry-oriented laboratory context. *The Electronic Journal for Research in Science & Mathematics Education*, *28*(1). 93–109. https://ejrsme.icrsme.com/article/view/22235

Amanah, S., Sadono, D., Fatchiya, A., Sulistiawati, A., Aulia, T., and Seminar, A. U. (2023). Strengthening the competencies of Gen-Z students as future change agents: Learning

from extension science and communication of innovation course (KPM121C). *International Journal of Information and Education Technology*, 13(10), 1646–1655. https://www.ijiet.org/vol13/IJIET-V13N10-1973.pdf

Badding, S. (2017). *The creative synthesis inventory: Constructing quantitative measures capturing attributes of design thinking* [Doctoral dissertation]. *Colorado State University*. https://hdl.handle.net/10217/184013

Dimock, M. (2019). Defining generations: Where millennials end and Generation Z begins. *Pew Research Center*, 17(1), 1–7. http://www.pewresearch.org/fact-tank/2019/01/17/where-millennials-end-and-generation-z-begins/

Faulconer, E., Dixon, Z., Griffith, J. C. and Frank, H. (2020). Surveying the safety culture of academic laboratories. *Journal of College Science Teaching*, *50*(2), 18-26. https://doi.org/10.1080/0047231X.2020.12290681

Field, A. (2013). Discovering Statistics Using IBM SPSS statistics. *SAGE Publications*.

Fu, D., Wang, P., and Zhu, K. (2023). Research on effective methods of laboratory safety education for college students. *EDP Sciences SHS Web of Conferences*, 174, 1–4. https://doi.org/10.1051/shsconf/202317401017

Geraldez, K. F., Aguilar, C., Toledo, I. W. and Deocades, E. I. (2023). Knowledge, attitude, and practices towards laboratory safety measures among Notre Dame of Marbel University medical technology students. *Psychology and Education: A Multidisciplinary Journal, 8*(8), 982–996. https://scimatic.org/storage/journals/11/pdfs/1250.pdf

Hair, J. F., Black, W. C., Babin, B. J., and Anderson, R. E. (2010). Multivariate data analysis (7th ed.). *Pearson Prentice Hall*.

Ichsan, I., Suharyat, Y., Santosa, T. A. and Satria, E. (2023). The effectiveness of STEM-based learning in teaching 21st century skills in Generation Z students in science learning: A meta-analysis. *Jurnal Penelitian Pendidikan IPA*, *9*(1), 150-166. https://doi.org/10.29303/jppipa.v9i1.2517

Lambriex-Schmitz, P., Van der Klink, M. R., Beausaert, S., Bijker, M. and Segers, M. (2020). Towards successful innovations in education: Development and validation of a multi-dimensional innovative work behaviour instrument. *Vocations and Learning, 13*, 313-340. https://doi.org/10.1007/s12186-020-09242-4

Jocano, F. L. (2006). Filipino Value System: A Cultural Definition*. PUNLAD Research House*.

Mohzana, M., Murcahyanto, H., Fahrurrozi, M., and Supriadi, Y. N. (2023). Optimization of management of laboratory facilities in the process of learning science at high school. *Jurnal Penelitian Pendidikan IPA*, *9*(10), 8226-8234. https://doi.org/10.29303/jppipa.v9i10.5249

National Research Council. (2010). *Promoting chemical laboratory safety and security in developing countries*. *National Academies Press*.

Nwune, E. C., Oguezue, N. K., Samuel, N. N. C. and Okwuduba, E. N. (2023). Exploring the perspectives of Generation Z in-service science teachers about the potential use of learning technologies for laboratory instruction in the Nigerian context. *International Journal of Innovative Research in Education*, *5*(2), 28-35. https://doi.org/10.30572/ijire.5.2.2023.028

Obmerga, M. E. (2020). The impact of design thinking and grit on Filipino millennial academic supervisors' transformational leadership attributes: A structural equation model. *Asian Journal on Perspectives in Education*, *1*(1), 24–51. https://ajpe.feu.edu.ph/index.php/ajpe/article/view/7639

Obmerga, M. E. and de Guzman, A. B. (2024). Birds of a feather flock together: Understanding Filipino millennial academic managers' mindset. *Educational Management Administration & Leadership*, *52*(5), 1206-1230. https://doi.org/10.1177/17411432221114696

Razzouk, R. and Shute, V. (2012). What is design thinking and why is it important?. *Review of Educational Research*, *82*(3), 330-348. https://doi.org/10.3102/0034654312457429

Reio, T. G. and Shuck, B. (2014). Exploratory factor analysis. *Advances in Developing Human Resources*, *17*(1), 12-25. https://doi.org/10.1177/1523422314559804

Sadler, T. D., Puig, A. and Trutschel, B. K. (2011). Laboratory instructional practices inventory: A tool for assessing the transformation of undergraduate laboratory instruction. *Journal of College Science Teaching*, *41*(1), 25. https://www.nsta.org/journal-college-science-teaching/journal-college-science-teaching-septemberoctober-2011/laboratory

Sahin, F. and Sasmaz Oren, F. (2022). Laboratory as an instrument in improving the scientific reasoning skills of pre-service science teachers with different cognitive styles. *Science Insights Education Frontiers*, *13*(2), 1875-1897. https://files.eric.ed.gov/fulltext/EJ1364928.pdf

Schröder, I., Huang, D. Y. Q., Ellis, O., Gibson, J. H. and Wayne, N. L. (2016). Laboratory safety attitudes and practices: A comparison of academic, government, and industry researchers. *Journal of Chemical Health and Safety*, *23*(1), 12-23. https://doi.org/10.1016/j.jchas.2015.03.001

Sison, M. (2021). Compliance on laboratory safety guidelines and policies in chemistry. *Southeast Asian Journal of Science and Technology*, *6*(1), 122-138. https://www.sajst.org/online/index.php/sajst/article/view/276

Soper, D. S. (2024). A-Priori Sample Size Calculator for Multiple Regression [Software]. https://www.danielsoper.com/statcalc/calculator.aspx?id=1

Wollmann, K. and Lange-Schubert, K. (2022). The development of prospective primary school science teachers' TPaCK fostered by innovative science-teacher education. *Education Sciences*, *12*(6), 381. https://doi.org/10.3390/educsci12060381

STUDENT

SECTION

NATURE'S PALETTE: IMPROVISED ECO-FRIENDLY pH PAPER INDICATORS

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ABSTRACT

The growing demand for sustainable and cost-effective materials in science education has spurred research into natural alternatives to synthetic laboratory tools. A paper that changes colour when pH changes is called a pH paper indicator. This study uses locally sourced plant extracts, specifically Butterfly Pea (*Clitoria Ternatea*), Gumamela (*Hibiscus rosa-sinensis*), and Bougainvillea (Bougainvillea sp.) (Bougainvillea sp.) flowers, as eco-friendly pH paper indicators. This study aims to provide a practical and environmentally conscious solution for the scarcity of laboratory materials, particularly in chemistry experiments in educational settings. The research focuses on improvising viable alternatives to synthetic pH indicators, which are often costly and less accessible. Pigments were extracted from the selected flowers and infused onto bond paper to produce pH strips. These strips were then tested against ten (10) household chemicals, ranging from acidic to basic (pH 1 to 10), to evaluate their efficacy. The results indicate that natural indicators can effectively detect pH levels, demonstrating their potential as sustainable and practical alternatives to synthetic pH paper. The findings reveal that plant-based pH indicators can be sustainable and practical alternatives to synthetic options. This research enhances science education by offering accessible, cost-effective, and innovative tools for hands-on learning for students and educators.

Keywords: Butterfly Pea Flower (BPF), Gumamela, Bougainvillea, Anthocyanin, Eco-friendly, pH indicator

1. Introduction

1.1 Background of the Study

pH indicator, also known as an Acid-Base indicator, is a material used to determine whether a solution is acidic, neutral, or basic. pH indicators are paper strips treated with a chemical known as Flavin, which is soluble in water and changes colour in the presence of various solutions (Pro, 2023). The paper changes to a red hue when exposed to an acidic solution. In basic solutions, the paper shifts to a greenish-blue colour. In a neutral solution, the paper adopts a light green shade. On the other hand, Anthocyanins are prominent natural pigments responsible for red, orange, pink, and blue colours found in various fruits, vegetables, and flowers like red cabbage, purple carrot, grape, pomegranate seed, butterfly pea, and red rose (Zhao et al., 2022). Chemically, anthocyanins belong to a subgroup of polyphenols characterised by a flavylium cation structure, with over 600 types identified in nature. In general, anthocyanins exhibit red hues under acidic conditions, purple in neutral pH, and blue

or green in increasingly alkaline conditions. The specific shade can vary based on the plant source. This variation is due to differences in anthocyanin structure and the presence of other pigments or compounds (Khoo et al., 2017). Using fruits, vegetables, or flowers rich in anthocyanins as ingredients for pH indicators is advantageous. Numerous indicators used in laboratories today are synthetic, including pH paper, litmus paper, thymol blue, methyl red, methyl orange, methyl yellow, and others in laboratories and used to determine the pH of any substances (Hanson, 2018). However, synthetic pH indicators commonly used have drawbacks, such as being relatively expensive and not readily available in all regions (Roy & Rhim, 2020). In line with this, Science laboratory equipment in the Philippines is inadequate for students' utilisation of hands-on activities (Caga-Anan et al., 2021). Tupas and Matsuura (2020) added that the science laboratory's lack of equipment and materials challenges science teachers. In addition, the insufficiency of laboratory tools negatively impacts instructional strategies and lesson planning, which makes conducting experiments and involving students in hands-on activities challenging (Navarro, 2024). As a result, students face challenges in developing practical skills and applying scientific concepts.

To address these issues, this research proposes preparing natural pH paper strips using extracts from Butterfly Pea (*Clitoria ternatea*), Gumamela (*Hibiscus rosa-sinensis*), and Bougainvillea *(Bougainvillea sp.) sp.*) flower extracts due to their accessibility, non-toxicity, eco-friendly properties, affordability, simple preparation method (utilising basic paper), and durability.

The Butterfly Pea flower, also known as blue ternate or *Clitoria ternatea*, has a wealth of bioactive compounds traditionally used in medicine (Weerasinghe et al., 2022). It is a perennial vine native to tropical areas in Asia. It blooms year-round, producing delicate, deep-blue flowers. Additionally, Butterfly pea is a source of anthocyanins, which provide a stable blue colour and are polyacylated (Abidin et al., 2019). Gumamela, also known as *Hibiscus rosa-sinensis*, is a safe plant with potential human health benefits (Ware, 2024; DOST, 2022). Its flowers contain polyphenols, flavonoids, and anthocyanins (Stuart, 2023). Similarly, Bougainvilleas are not harmful to humans or pets but should not be consumed (Spengler, 2022). Bougainvillea *(Bougainvillea sp.)* flowers have been found to have high levels of anthocyanin content (Abdelrahman, 2024b). Both Bougainvilleas and Gumamela are popular ornamental plants in the Philippines, blooming year-round, especially during the summer (Nabor, 2016).

This study draws inspiration from previous research, which can be a tool in creating our pH indicator paper using natural ingredients as a resource for laboratory experiments. The objective is to contribute to sustainable and cost-effective laboratory practices by introducing environmentally friendly pH indicators into educational settings.

1.2 Statement of the Problem

This study aims to explore the possibility of using Butterfly Pea *(Clitoria ternatea)*, Gumamela (*Hibiscus rosa-sinensis*), and Bougainvillea (Bougainvillea sp.) (*Bougainvillea (Bougainvillea sp.)* extracts in improvising cost-effective and eco-friendly pH indicators which can be used as material for science laboratories.

This research seeks to address the following key questions:

1. What natural materials may be used to improvise a pH paper indicator?
2. How may the extract of the material be fused to create an improvised pH paper?
3. What are the colour reactions or changes of the sample improvised pH paper indicator in different sample substances: Lemon, Vinegar, Coffee, Milk, Tap- Water, Dishwashing liquid, Shampoo, Baking soda, and Bleach?

2. Methods

2.1 Plant Selection

The researchers selected three (3) plants to prepare pH paper strips for easy availability. Butterfly Pea Flower (*Clitoria ternatea*), commonly known as Blue ternate, is a vibrant blue flower with intense purplish-blue petals; Gumamela, also known as Hibiscus, is a striking red flower with large, vibrant petals that can range from deep crimson to bright scarlet; and Bougainvillea *(Bougainvillea sp.)* is a vibrant red flower that is the bract surrounding the small, inconspicuous white or purple flowers at the centre. All three flowers are rich in anthocyanins, which are pigments responsible for their distinctive colours and make them ideal for use in creating pH indicator paper.

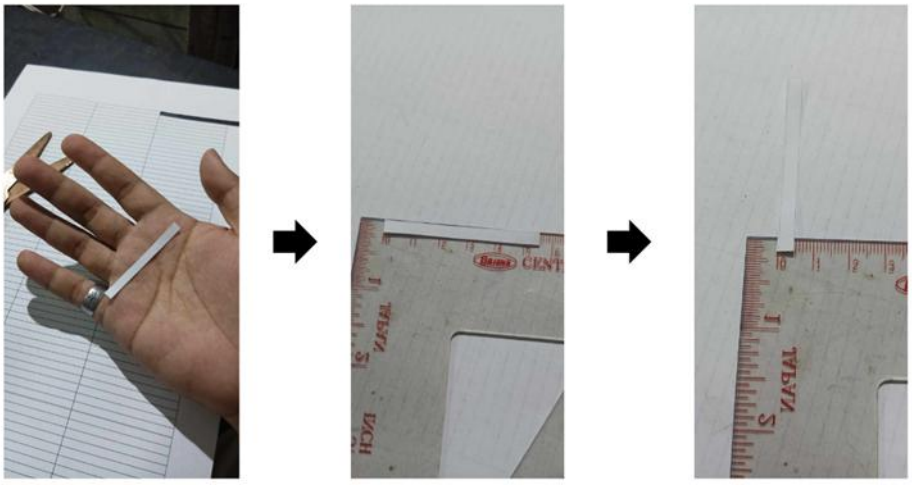
Figure 1: Plant Selection

Gumamela Bougainvillaea Butterfly pea

2.2 Preparation of pH-paper Indicator Strips

- Get a piece of clean bond paper.
- Cut it into 5.5 cm x 0.7 cm (length x width).

Figure 2: Preparation of pH paper strips



2.3 Extraction Process

To be able to create a pH indicator from Butterfly Pea, Gumamela, and extracts, the procedure for the extraction is the following;

- Preparation of ingredients.
  - Place 100 g of Butterfly peas, Gumamela flowers, and Bougainvillea flowers in a mortar and pestle and crush it until the juices come out. Make sure to remove all the green parts of the flower.
  - Place each in a beaker and cover with 250 mL of water to submerge the Butterfly Pea, Gumamela, and Bougainvillea.

- Boiling the Mixture.
  - Bring the water to a boil and simmer until the colour of the flower becomes pale and the water becomes dark.

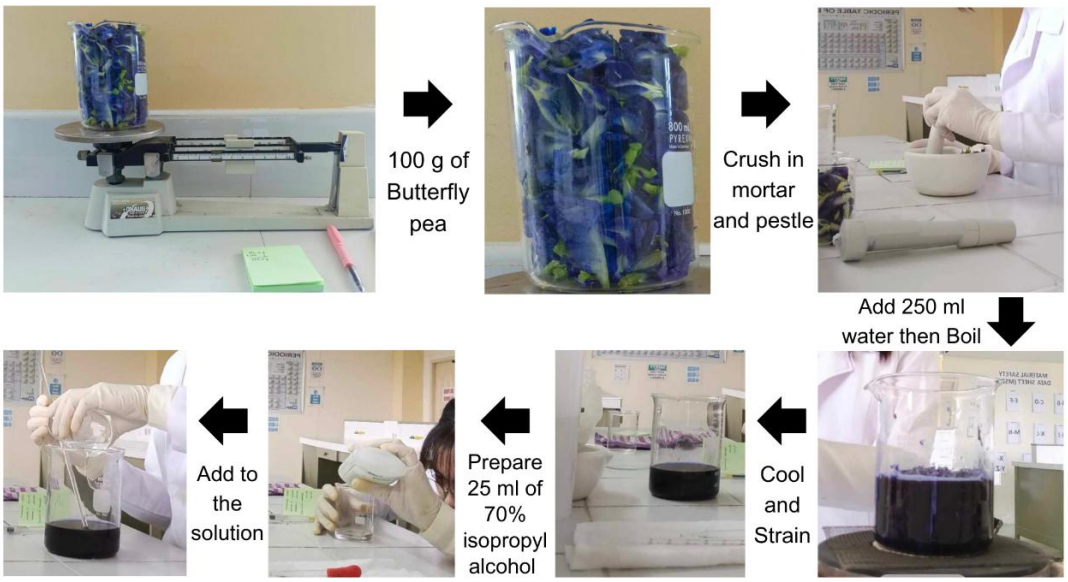
- Allow it to cool.
  - Turn off the stove and let the solution cool until it reaches room temperature.

- Straining the Solution.
  - Use a filter to strain the solution, separating the liquid from the solids.

- Add 25 mL of 70% isopropyl alcohol to the indicator solution.

- Transfer and Store.
  - Transfer the strained solution into a container.
  - Store in a dry and dark place.

Figure 3: Butterfly Pea Flower Extraction Process



2.4 Infusion of solutions into paper strips

- Place the cut strips into a beaker and immerse them in the extracted solution to ensure even colouration.

- Repeat this process three times, with each immersion lasting 30 minutes, and allow one hour to elapse between each immersion.

- Air-dry for 24 hours.

Figure 4: Butterfly Pea extract infusion into paper strips

2.5 Testing the reactions of the improvised material in the selected samples

The testing part includes testing different substances using the eco-friendly pH paper indicator, including lemon, vinegar, coffee, milk, tap water, baking soda, dishwashing liquid, shampoo, and bleach.

2.6 Laboratory Safety Measures

- Wear gloves, laboratory coats, and other protective gear to avoid direct skin contact with plant extracts and other chemicals.
- Ensure all plant materials are clean and debris-free before extraction to avoid contamination.
- Utilise mortar and pestle for carefully crushing plant materials to prevent equipment injury or damage.
- Monitor the boiling process to avoid burns or overheating.
- Handle 70% isopropyl alcohol carefully, and ensure it is stored away from open flames.
- Store the prepared solutions in a dry, dark place to prevent exposure to light and moisture, which could degrade the materials.
- Ensure clean and sanitised handling of bond paper strips to prevent contamination during infusion with indicator solutions.
- Label all prepared solutions and tested substances to avoid confusion and accidental misuse during experiments.
- Properly dispose of plant residues and other waste materials to ensure an environmentally friendly and safe workspace.

3. Results and Discussion

According to the Global Innovation Index (2023), the Philippines is ranked 56th out of 132 in innovation. Science laboratory equipment in the Philippines is inadequate for students to utilise hands-on activities. Moreover, our country ranked third-lowest in science (PISA, 2022).

For this purpose, the researchers came up with the idea of utilising local materials to address these drawbacks by selecting Butterfly Pea (*Clitoria ternate*), Gumamela (*Hibiscus rosa-sinensis*), and Bougainvillea *(Bougainvillea sp.)* flower extracts as natural pH paper strips, which somehow have the same results to the synthetic pH paper strips.

In this study, the researchers used ten (10) common household chemicals, such as lemon or lime, vinegar, coffee, water, milk, soap, dishwashing liquid, baking soda, and bleach, with a pH ranging from 2 to 10.

3.1 Selection of Flowers for Natural pH paper

The researchers used Bougainvillea (Bougainvillea sp.), Gumamela (*Hibiscus rosa-sinensis*), and Butterfly Pea (*Clitoria ternatea*) flowers for natural pH paper due to their year-round availability and well-documented pH-indicating properties.

Firstly, these flowers are popular ornamental plants in the Philippines and bloom throughout the year, making them readily available for continuous use (Nabor, 2016). Additionally, they are known to be non-toxic, and while Bougainvillea should not be ingested, it poses no harm to humans or pets when handled (Spengler, 2022).

More importantly, these flowers are rich in bioactive compounds that react to pH changes. Bougainvillea and Gumamela contain anthocyanins, which exhibit colour changes in response to acidity or alkalinity (Abdelrahman, 2024b). Butterfly Pea is a particularly valuable source of polyacrylate anthocyanins, contributing to its stable blue colour and making it an effective pH indicator (Abidin et al., 2019). Additionally, according to Paje (2021), Butterfly Pea and Gumamela display different colour changes when exposed to varying pH levels, making them ideal natural indicators for pH testing.

Using these locally available flowers allows us to produce natural pH paper that is both eco-friendly and effective. Their natural properties as pH indicators, combined with their year-round availability, ensure a sustainable and dependable source.

3.2 Extractions and Infusion

The researchers initiated the experiment by crushing the flower petals, utilising a mortar and pestle to extract the juice.

The researchers adapted Madriaga's (2021) extraction method in her paper “Homemade pH Indicators.” The procedure begins by simmering the crushed petals in distilled water until they lose their vibrant colour, allowing the extract to be effectively infused in the water. Subsequently, the paper strips were immersed in the extracted solution thrice, with each immersion lasting for 30 minutes and an interval of one hour between immersions. This was followed by 24 hours of air drying.

The researchers adhered to the following ratios: 100 grams of flower petals to 250 mL of water, along with 25 mL of isopropyl alcohol. This ratio ensured that the petals were fully submerged in the distilled water and that the water did not evaporate quickly when boiling.

The inclusion of alcohol in the mixture was implemented to prevent the development of mould and bacteria.

3.3 Testing of Paper Strips

Figure 5: Butterfly Pea/Blue ternate paper strip colour results in solutions

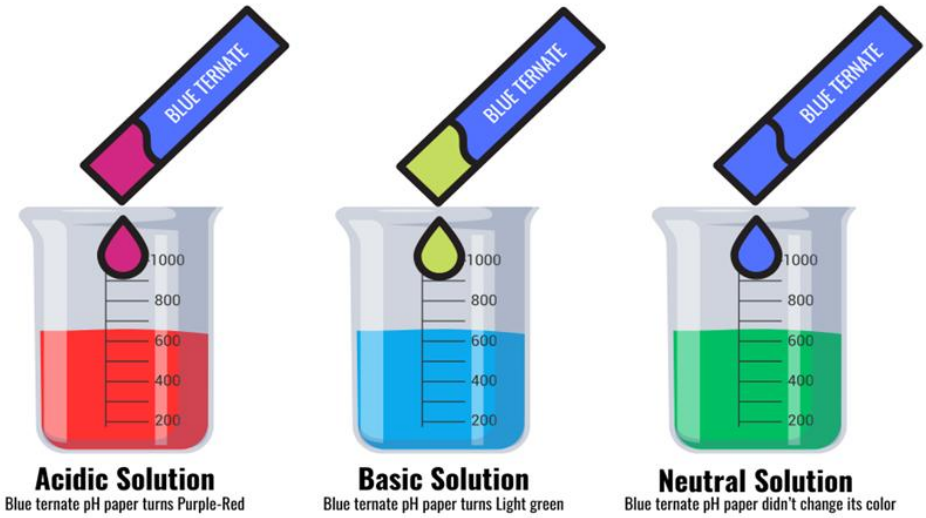


Figure 5 presents the colour responses of natural paper strips infused with Butterfly Pea. The strips turn purple-red in acidic solutions, light green to yellow in basic solutions, and show no colour change in neutral solutions.

The colour changes observed in our natural pH indicators are consistent with Zhao's findings (2022). Zhao reported that anthocyanin pigments from flower extracts turn red under acidic conditions and shift from green to yellow in basic conditions. Escher's study (2020a) supports these observations, noting that a red colour appears at a pH below 3.2, transitions from purple to blue between pH 5.2 and 8.2, and changes from light blue to dark green between pH 8.2 and 10.2. Additionally, *Clitoria ternatea*, a plant known for its red and blue flowers and anthocyanin content, had a concentration of 227.42 mg/kg, ranking third in the study (Stuart, 2023).

Figure 6: Bougainvillea paper strip colour results in solutions

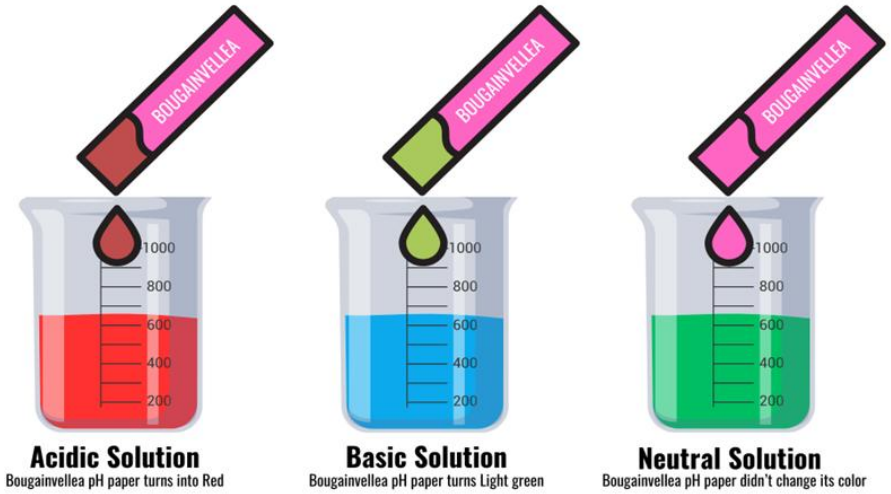


Figure 6 illustrates the colour responses of Bougainvillea-infused natural paper strips. In acidic solutions, the strips turned red; in basic solutions, they appeared light green; and in neutral solutions, no significant colour change was observed.

These results generally align with the findings of Roy and Rhim (2021), who also confirmed that pH levels affect the colour of anthocyanins. Roy and Rhim's study found that in acidic conditions, anthocyanins in Bougainvillea *(Bougainvillea sp.)* display red or purple hues, and in basic conditions, they shift to green or yellow. While Roy and Rhim's study noted that blue colour was found at a neutral pH. The absence of a colour change in this study may be slightly different. Despite this difference, the overall trend in colour shifts in acidic and basic environments aligns with Roy and Rhim's conclusions.

In Abdelrahman's (2024) study on anthocyanin-rich extracts, Bougainvillea was found to have a total phenolic content (TPC) of 180 mg.

Figure 7: Gumamela paper strip colour results in solutions

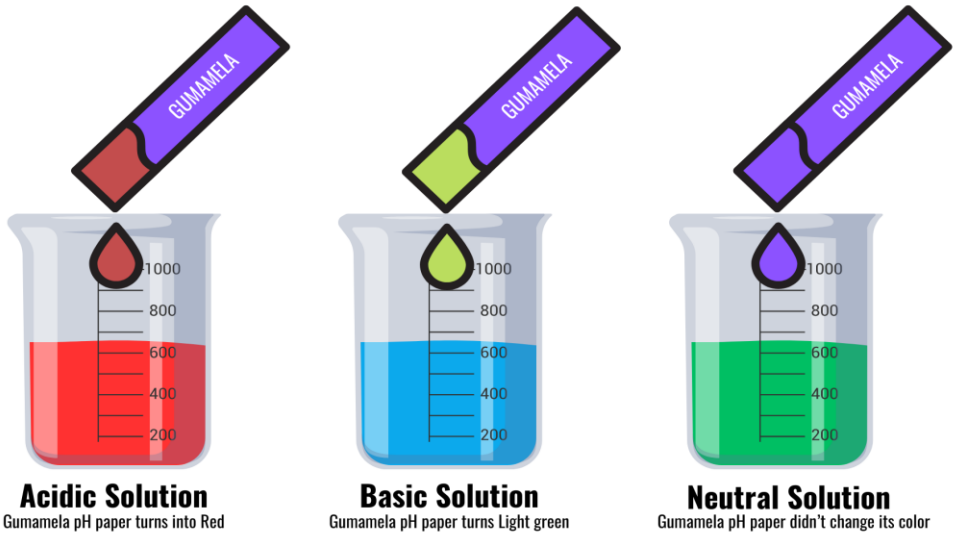


Figure 7 presents the colour responses of natural strips exposed to pH changes caused by household chemicals. The paper strips infused with Gumamela extract showed various colours in different solutions. They turned red in acidic solutions, light green in basic solutions, and showed no colour change in neutral solutions.

In line with this, a study conducted by Paje in 2021 further supports our findings. According to their results, the Gumamela indicator turned red in acidic solutions, light pink in neutral solutions, and dark green in basic solutions. While there were some minor differences, our study is consistent with these findings.

3.4 Comparative testing of different household items

The researchers used a pH meter to measure the pH of each household item, ranging from pH 2 (acidic) to pH 10 (basic), to distinguish the substances' acidic or basic nature and observe their reactions with different natural pH indicators.

Figure 8: pH paper testing colour results (actual picture)

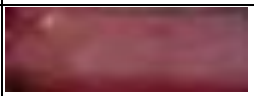
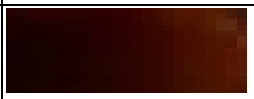
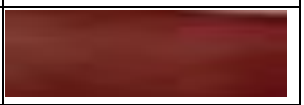
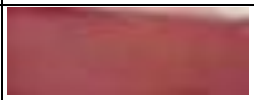
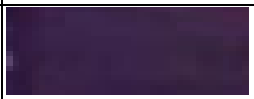
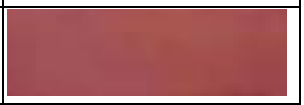
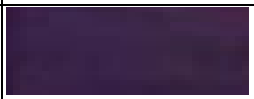
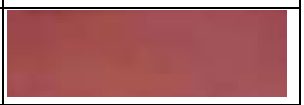
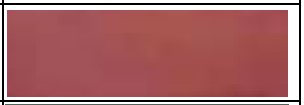
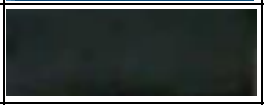
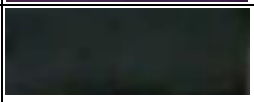
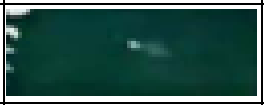
pH Paper Testing Colour Results				
pH Level	**Substances**	**Blue Ternate**	**Gumamela**	**Bougainvillea**
	Original Colour			
2	**Lemon**			
2	**Vinegar**			
4.7	**Coffee**			
6.9	**Milk**			
7	**Tap Water**			
7.5	**Dish-washing Liquid**			
9	**Shampoo**			
9.5	**Baking Soda**			
10	**Bleach**			

Figure 9: pH paper testing colour results

Bougainvillea, Blue Ternate, and Gumamela pH Paper Testing				
	Substances	**Color Results**		
pH Level	**Original Color**	**Blue ternate**	**Gumamela**	**Bougainvillea**
2	**Lemon**			
2	**Vinegar**			
4.7	**Coffee**			
6.9	**Milk**			
7	**Tap Water**			
7.5	**Dishwashing Liquid**			
9	**Shampoo**			
9.5	**Baking Soda**			
10	**Bleach**			

Based on the data presented in the table above, it is evident that the Butterfly Pea, Bougainvillea, and Gumamela paper strips display a red to purplish-red hue when exposed to Lemon (pH of 2), Vinegar (pH of 2), and Coffee (pH of 4.7). This indicates that these substances fall within the acidic range. The acidic nature of Lemon can be attributed to the presence of citric acid. According to Ali (2020), around 5% of Lemon juice is citric acid (Vitamin C), which gives Lemon a sour taste. Citric acid is classified as a weak organic acid found naturally in many fruits, especially citrus fruits. Vinegar, which contains acetic acid as a byproduct of fermentation, has a characteristic odour and is about 4-6% acetic acid in water (Karki, 2023). On the other hand, coffee consists of various acids such as chlorogenic, quinic, citric, acetic, lactic, malic, phosphoric, linoleic, and palmitic acid (Jeon et al., 2017).

These observations align with the known behaviour of anthocyanins, which undergo chemical transformations in response to changes in environmental pH. According to Zheng et al. (2022), anthocyanins are stable and exhibit a reddish colour under acidic conditions due to their flavylium form. This is consistent with the red-to-purplish-red hue observed in the paper strips when exposed to acidic substances like Lemon, vinegar, and coffee. Galingana and Organo (2016) noted that the transformation of anthocyanins from flavylium to chalcone occurs in basic conditions, leading to a shift in colour.

In contrast, the paper strips exhibit a pale green colour when subjected to shampoo (pH of 9), turn green in the presence of baking soda (pH of 9.5), and display a yellow hue when exposed to bleach (pH of 10). These observations suggest that these substances are in the basic range. Baking soda, or sodium bicarbonate ($NaHCO_3$), is a salt that comprises the strong base sodium hydroxide and the weak carbonic acid, making it a basic salt with a slightly bitter taste. Similarly, bleach can be classified as a base since it dissociates into sodium and hypochlorite ions in water, generating a weak base solution. In basic conditions, anthocyanins undergo deprotonation, transforming into chalcones, which explains the shift from red to green or yellow, as seen in the paper strips exposed to basic substances (Zheng et al., 2022; Galingana and Organo, 2016).

In addition to the substances previously discussed, the researchers investigated the pH levels of milk, dishwashing liquid, and tap water. The pH of milk was recorded at 6.9, while tap water demonstrated a pH of 7, and the dishwashing liquid exhibited a pH of 7.5. Notably, none of the pH indicator strips displayed any colour change when exposed to these substances. Although milk is often considered neutral because its pH is close to 7, it is not strictly neutral because it contains lactic acid. Over time, the lactic acid present in milk can lower the pH, resulting in increased acidity and a sour taste.

4. Conclusion

Synthetic indicator paper strips are expensive and not easily accessible. Therefore, paper indicators that are affordable and readily available are needed. In this study, we prepared three paper indicator strips using Gumamela (*Hibiscus rosa-sinensis*), Bougainvillea *(Bougainvillea sp.),* and Butterfly Pea Flower (*Clitoria ternatea*).

Research on anthocyanin extraction and its application in pH testing demonstrates the effectiveness of natural plant materials, such as Butterfly Pea Flowers, as reliable pH indicators. The findings confirm that Butterfly Pea Flowers are rich in anthocyanins, which can be efficiently extracted through crushing and boiling. These anthocyanins exhibit distinct colour changes across different pH levels, making them ideal for pH indicator applications.

Crashing before boiling was the most effective method for extracting flavonoids from Gumamela, Bougainvillea, and Butterfly Pea, which is crucial for maximising the yield of

anthocyanins. This approach improves extraction efficiency by utilising heat to dissolve anthocyanins more effectively. According to Mattioli (2020), anthocyanins are water-soluble pigments commonly found in fruits and flowers, and they become soluble in water when exposed to heat.

During the study, it was observed that some of the prepared pH paper samples underwent oxidation, resulting in discolouration when not stored in an airtight container. This issue prompted a repetition of the preparation process to ensure consistency and reliability. Research has shown that anthocyanins are susceptible to oxidation, which can lead to changes in colour and a decrease in their effectiveness as pH indicators. Higher temperatures speed up this oxidation process, causing products to turn brown when exposed to oxygen. According to Enaru (2021), oxygen accelerates the breakdown of anthocyanins by either directly oxidising them or by oxidising enzymes.

The development of pH test papers using anthocyanins extracted from natural plant materials offers a promising alternative to traditional synthetic indicators, reducing the reliance on synthetic dyes. This approach provides a cost-effective solution and promotes using sustainable and eco-friendly materials in environmental monitoring.

The results showed that Gumamela and Bougainvillea indicator paper turned red in acidic solutions and shifted to shades of green to yellow in basic conditions. Similarly, Butterfly Pea indicator paper displays purple-red hues in acidic solutions and transitions to green or yellow in basic ones. However, the natural pH strips developed in this study are less sensitive to detecting minor pH changes, especially in substances with pH levels near neutral. This limitation arises from the broader pH range for which the strips are designed, making it difficult to detect subtle colour variations in mildly acidic or neutral solutions.

This study demonstrates that natural indicator paper strips are an affordable and effective alternative to synthetic ones, providing similar functionality in pH testing. The findings regarding oxidation stress the importance of proper storage, with airtight containers being crucial to preserving the indicators' effectiveness and reliability.

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References

Journals

Abdelrahman, K. N., Ghany, A. G. A. A., Saber, R. A., Osman, A., Sitohy, B., & Sitohy, M. (2024b). Anthocyanins from pomegranate peel (Punica granatum), chilli pepper fruit (Capsicum annuum), and bougainvillaea flowers (Bougainvillea spectabilis) with multiple bio functions: Antibacterial, antioxidant, and anticancer. *Heliyon*, *10*(11), e32222.

Abidin, Z. H. Z., Manah, N. S. A., Hadi, A. N., Saugi, N. S., Fuad, F. A., Mazni, N. A., ... & Arof, A. K. (2019). The colour stability of natural blue dye extracted from Clitoria ternatea L. in poly (acrylamide-co-acrylic acid) coating film. *Pigment & Resin Technology*, *48*(4), 265-271.

Ali, S. (2020). Lemon juice antioxidant activity against oxidative stress. *Baghdad Science Journal*, *17*(1 (Suppl.)), 0207-0207.

Enaru, B., Drețcanu, G., Pop, T. D., Stănilă, A., & Diaconeasa, Z. (2021). Anthocyanins: factors affecting their stability and degradation. *Antioxidants*, *10*(12), 1967.

Escher, G. B., Wen, M., Zhang, L., Rosso, N. D., & Granato, D. (2020). Phenolic composition by UHPLC-Q-TOF-MS/MS and stability of anthocyanins from Clitoria ternatea L. (butterfly pea) blue petals. *Food Chemistry*, *331*, 127341.

Galingana, M. O., & Organo, V. G. (2016). *A simple colorimetric procedure differentiating anions using flower pigments from Anthurium andreanum*. *Oriental Journal of Chemistry*, 32(3), 1347-1352.

Khoo, H. E., Azlan, A., Tang, S. T., & Lim, S. M. (2017). Anthocyanidins and anthocyanins: coloured pigments as food, pharmaceutical ingredients, and the potential health benefits. *Food & Nutrition Research*, *61*(1), 1361779.

Mattioli, R., Francioso, A., Mosca, L., & Silva, P. (2020). Anthocyanins: A Comprehensive review of their chemical properties and health effects on cardiovascular and neurodegenerative diseases. *Molecules*, *25*(17), 3809.

Navarro, F. G., Paglinawan, J. L., & Paje, J. M. (2024). Teachers' perception and intervention strategies on the scarcity of laboratory tools*. International Journal of All Research Writings*, 5(11), 196-206.

Paje, N., & Ramirez, S. (2021). Acid-Base Indicator Properties of Gumamela Petal Varieties. *Agrikultura CRI Journal 1 (1)*, *1*(2782–8816).

Roy, S., & Rhim, J. (2020). Anthocyanin food colorant and its application in pH-responsive colour change indicator films. *Critical Reviews in Food Science and Nutrition*, *61*(14), 2297–2325.

Tupas, F. P., & Matsuura, T. (2020). *Science teaching and learning in Japan And the Philippines: a comparative study.* Universal Journal of Educational Research, 8(4), 1237-1245.

Zhao, L., Liu, Y., Zhao, L., & Wang, Y. (2022). Anthocyanin-based pH-Sensitive smart packaging films for monitoring food freshness. *Journal of Agriculture and Food Research*, *9*, 100340.

Zheng, L., Liu, L., Yu, J., & Shao, P. (2022). *Novel trends and applications of Natural pH responsive indicator film in food packaging for improved quality monitoring. Food Control*, 134, 108769.

Online sources

Caga-Anan, K. P., MA, MAEd, M. J. a. P., & Dbm, H. P. R. (2021, August 1). Insufficiency of science laboratory equipment/apparatus: the struggles of science teachers in the implementation of laboratory works and activities. *University of Mindanao Institutional Repository.* https://repository.umindanao.edu.ph/handle/20.500.14045/1147

Department of Science and Technology. (2022). Gumamela contains Ingredients potential to prevent cancer, study. Department of Science and Technology*, Philippine Council for Health Research and Development.* https://www.pchrd.dost.gov.ph/news_and_updates/Gumamela-contains-ingredients-potential-in-preventing-cancer-study

Hanson, A. L. (2018, 2021/10/16/). Acid-base indicators. *Access Science.* https://www.accessscience.com/content/acid-base-indicators/004600

Madriaga, A. (2021). Homemade pH Indicators. *ResearchGate*. https://doi.org/10.13140/RG.2.2.25768.49924

Nabor, V. A. P. B. P. (2016, June 16). Sun-loving Gumamelas. *Mama Nene's Garden.* https://mamanenesgarden.wordpress.com/2011/06/16/sun-loving-gumamelas/

PISA: Programme for International Student Assessment. (n.d.). *OECD.* https://www.oecd.org/en/about/programmes/pisa.html

Pro, L. (2023, November 27). How does PH paper work and what does it detect? *Lab Pro.* https://labproinc.com/blogs/laboratory-equipment/how-does-ph-paper-work-and-what-does-it-detect

Spengler, T. (2022, April 19). Is Bougainvillea Toxic? *Hunker.* https://www.hunker.com/13404728/is-bougainvillea-toxic/

Ware, Megan, RDN, L.D. (2024, April 8). Hibiscus tea benefits and nutrition. *Medical News Today*. https://www.medicalnewstoday.com/articles/318120

STREET FOOD OUTSIDE CAMPUS: IMPLICATION TO HEALTH, FOOD SAFETY, AND FOOD SANITATION

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ABSTRACT

This study investigated the microbiological quality of street food sauces outside Gordon College, Olongapo City, to assess its potential health risks, and analysing the microbial content and consumers' perception of the different food safety practices, the research aimed to provide its implications to the health, food safety, and food sanitation. This study used descriptive research design with microbial analysis to select street food sauces and it uses a convenience sampling method for the 66 College of Education, Arts, and Sciences students. The findings of this research found that the microbial content of the street food sauces is safe for consumption, and supported by consumers' perception that they perceived the street food and its sauces are properly handled (M = 2.899), preparedly handled (M = 3.197), and stored properly (M = 2.996). However, despite low levels of coliforms and *E. coli*, the absence of these bacteria does not guarantee safety, highlighting the importance of continued adherence to and improvement of food safety and sanitation practices to reduce the risk of foodborne illnesses.

Keywords: street food, sauces, health, food safety, food sanitation

1. Introduction

1.1 Background of the Study

Foods and beverages prepared and sold by sellers in public areas and swiftly consumed by customers are referred to as street food (Sezgin and Sanlier, 2016). Due to economic and cultural factors, street food sellers are dispersed worldwide and offer a diverse range of food, making up a huge portion of the diets of urban people in many different countries (Campos, et. al, 2015). About 2.5 billion people eat street food worldwide. However, because there are no mechanisms to assess and guarantee food safety standards, street foods could be harmful to public health even though they are inexpensive and readily available (FAO, 2022).

Street food has become a defining feature of local food culture, especially to the poor and developing countries. Globalisation influenced the growth of street food vending by increasing its demand, diversifying ingredients, and innovating new flavours and a variety of street foods caused by cultural exchange. A wide variety of street foods can be found throughout the vast Asian continent, and they are becoming increasingly well-liked in both big cities and small towns' local culinary scenes. 15–50% of Asian urban households' food budgets go toward street food (Food and Agriculture Organization, n.d.).

In a study conducted in Jashore, Bangladesh by Hossain and Dey (2019) ,a higher number of microorganisms, namely *Salmonella spp.* and *Escherichia coli* were detected in all the street food sauce samples that underwent microbial testing. It was also revealed that among all the 30 interviewed street vendors, no one insists on receiving training on proper food preparation standards. In another related study, which accounts for the food safety practices of Kolkata, street food sellers surrounding India's medical colleges, it is determined that the food vendors' hygiene measures were not clear, increasing the likelihood that the food given may be contaminated by microorganisms. According to the data, about 81% of street vendors did not wear hand gloves, aprons, or head hats when preparing and selling food, nor did they have clean nails (Ghosh, 2023).

The third Sustainable Development Goal (SDG), "Good Health and Well-Being," seeks to promote well-being and guarantee that individuals of all ages lead healthy lives (UNDESA, 2024). The study enhances this goal by examining the microbial composition of sauces from street food and their potential health effects. Understanding the microbiological risks associated with street food can support efforts to improve public health and reduce the incidence of foodborne illnesses.

However, despite existing laws in the Philippines about food safety, problems about this in the country remain a challenge. According to a local study, *E. coli* was found in street food sauces supplied near the University of Eastern Philippines. This recommends that street food sellers be better informed about food sanitation and hygiene procedures to guarantee safer and higher-quality food delivery (Dagalea et al., 2021), regardless of the minimal count of microorganisms. The possible risk of food-borne illnesses linked to eating street food close to schools is highlighted by this study.

As street food evolves in other countries, the growth of street food in the Philippines also continues. In many cities and towns in developing nations, street vendors are crucial to providing the food needs of urban people. It offers an enormous range of reasonably priced and conveniently accessible foods to millions of consumers every day (Jambre and Lagorra, 2022). It is becoming more widely acknowledged that street food vendors have a significant socioeconomic impact on employment prospects, offering special income, especially to women, and supplying meals at reasonable prices to urban lower-income populations (Mohammedsani and Mohammed, 2020). Street food provides several types of food, from skewered pork, *isaw* (a pig or a chicken's large intestine), *kwek-kwek* (quail egg coated with orange-coloured batter), *kikiam*, fish balls and squid balls, and handmade sauces. Street food has become a part of the daily lifestyle of Filipinos especially when grabbing a quick snack to relieve their hunger in between breaks in class or work.

Because street food is so readily available, customers who rely on it are more concerned with its convenience than its safety, quality, or hygiene. It has been determined that these food stands are not the most hygienic. Jambre and Lagorra (2022) reveal that many of the vendors were unaware of proper cleanliness practices when handling, processing, or preparing food, because their facilities lack basic infrastructure like refrigeration and water connections, and the hygienic quality may be compromised, endangering the public's health.

Like most cities, Olongapo City comprises different schools and institutions, primarily targeted by street food vendors due to the large number of potential customers. Students are likely to spend their money or allowance on buying street foods since these are usually their cravings, especially during breaks or after school. As most students only want to satisfy their cravings or hunger, they neither think about the quality nor even care about the possible diseases that these street foods may bring to them.

Hence, the purpose of this study is to examine the microbiological quality of the sauces sold by various street food vendors in the vicinity of Gordon College, one of the institutions located

at Olongapo City. By analysing the microbial content of the selected sauce samples and considering the unhygienic practices of food vendors, the researchers envision gaining valuable insights into the potential risk of street food consumption to consumer health in the area. The result of this study can then be used as an implication to health, food safety, and food sanitation for the consumers of street food outside the campus.

1.2 Statement of the Problem

This study aims to analyse the microbiological aspects of street food sauces outside campus about the consumer's perception of the food safety practices of street food vendors as an implication to health, food safety, and food sanitation.

Specifically, it sought to answer the following questions:

1. What are the microbial counts in street food sauces sold outside campus based on the total coliform count and *Escherichia coli*?
2. How do street food vendors adhere to food safety practices, specifically in handling, storage, and preparation methods of street food sauces, in the perception and awareness of the customers?
3. What are the implications of the microbial counts in street food sauces and consumers' perception to the:
    a. health;
    b. food safety; and
    c. food sanitation?

2. Methodology

2.1 Research Design

This study used descriptive research design with microbial analysis for selected street food sauces. Singh (2023) defined this research design as it aims to illustrate the features of a phenomenon or topic being studied. In addition to making observations and then comparing and analysing them, descriptive research design often provides answers to significant challenges and develops knowledge ideas. It constantly aims to give details about the occurrence, including how, when, where, and what the problem or phenomenon is. (Heath, 2023). This research design will be utilised as it describes the microbial analysis of street food sauces that will utilise the laboratory procedures that will be conducted as DOST-Regional Standard Testing Laboratory III and assessing the food safety practices – handling, preparation, and storage – perceived by the customers to the street food vendors outside campus through a survey questionnaire.

2.2 Respondents of the Study

Sixty-six (66) students from the Gordon College- College of Education, Arts, and Sciences took part in the study as respondents during the Second Semester of the Academic Year 2023-2024.

2.3 Research Instrument

A survey questionnaire was administered to assess the perceptions of consumers on street foods as well as food safety practices that they regularly observe on street food vendors using Google Forms and disseminated through various online platforms. The questionnaire was adapted from one that has been used in previous studies conducted by Wiatrowski, Czarnieka-Skubina, and Trafialek (2021) which consists of questions that evaluate numerous elements, including food utensils, food handling and storage, personal cleanliness, and the condition of the environment in and around the workspace.

To gather precise and direct data from the respondents, the researchers employed a 4-point Likert scale, wherein respondents were able to choose from 1–4 scales: 1 = strongly disagree, 2 = disagree, 3 = agree, and 4 = strongly agree.

2.4 Statistical Treatment of Data

The gathered data will be processed using Microsoft Excel. The following statistical methods were employed to answer the specific questions raised by the study: Mean and descriptive rating scales. Mean and descriptive ratings will be used to describe the customer's perception and awareness of food safety practices, specifically in handling, storage, and preparation methods of street food sauces of the adherence of street food vendors. The descriptive rating scale of the handling, preparation, and storing methods for street food and its sauces is stated below.

Table 1: Descriptive Rating Scale for Handling Methods of Street Food and its Sauces

Rating Scale	Range	Descriptive Interpretation	Verbal Interpretation
4	3.25 – 4.00	Strongly Agree	The street food and its sauces are properly and carefully handled.
3	2.50 – 3.24	Agree	The street food and its sauces are handled properly.
2	1.75 – 2.49	Disagree	The street food and its sauces are not properly handled.
1	1.00 – 1.74	Strongly Disagree	The street food and its sauces are not properly and carefully handled.

Table 2: Descriptive Rating Scale for Preparation Methods of Street Food and its Sauces

Rating Scale	Range	Descriptive Interpretation	Verbal Interpretation
4	3.25 – 4.00	Strongly Agree	The street food and its sauces are properly and carefully prepared.
3	2.50 – 3.24	Agree	The street food and its sauces are properly prepared.
2	1.75 – 2.49	Disagree	The street food and its sauces are not properly prepared.
1	1.00 – 1.74	Strongly Disagree	The street food and its sauces are properly and carefully prepared.

Table 3: Descriptive Rating Scale for Storing Methods of Street Food and its Sauces

Rating Scale	Range	Descriptive Interpretation	Verbal Interpretation
4	3.25 – 4.00	Strongly Agree	The street food and its sauces are properly and carefully stored.
3	2.50 – 3.24	Agree	The street food and its sauces are properly stored.
2	1.75 – 2.49	Disagree	The street food and its sauces are not properly stored.
1	1.00 – 1.74	Strongly Disagree	The street food and its sauces are not properly and carefully stored.

2.5 Ethical Considerations

To acquire samples of street food sauces for testing in the Regional Standard Testing Laboratory – Region III for total coliform count and *E. coli*, the researchers sent a letter of request to the street food vendor, with the guarantee that the findings would be handled in the most confidentiality. The researchers requested approval from the dean of the College of Education, Arts, and Sciences for the survey questionnaire, which will be answered by the 66 college respondents. By Republic Act No. 10173, often known as the "Data Privacy Act of 2012," the researchers will inform the participants that all information gathered will be handled with the utmost confidentiality and will be used for research purposes only.

3. Results and Discussion

3.1 Microbial Counts in Street Food Sauces by means of Total Coliform Count and E. coli

The street food sauces obtained from the street food stall outside campus, Sweet, Spicy, and Vinegar Sauces, the Sweet Sauce revealed an estimated Coliform Count has an amount less than 10 CFU/g, and its estimated *E. coli* count has an amount of 2.5 x 10^2 CFU/g. For the Spicy Sauce, it revealed that the estimated Coliform Count has an amount less than 10 CFU/g, and the estimated *E. coli* count has an amount of less than 10 CFU/g. For the Vinegar Sauce, it revealed that the estimated Coliform Count has an amount less than 10 CFU/g, and the estimated *E. coli* count has an amount of less than 10 CFU/g. According to Food and Drugs Administration (FDA) Circular No. 2013-010 dated February 27, 2013, entitled Revised Guidelines for the Assessment of Microbiological Quantity of Processed Food, a sauce that is ready to eat is said to be safe and considered safe for consumption, it must obtain a maximum of 10^2, for coliform count and *E. coli*. Whereas all the street food sauces – the sweet, spicy, and vinegar sauces, were safe for consumption. Relative to the results of the study of Tolentino, et al. (2024) where most of the sauce samples got a total coliform count of <10 CFU/g and the *E. coli* count in the initial and subsequent testing phase (below the limit of detection) which indicates the minimal amount of bacterial contamination. The microbial counts in street food sauces sold outside campus are <10 CFU/g in three sauces for Total Coliform Count, 2.5 x 10^2 CFU/g for Sweet Sauce and <10 CFU/g for Spicy and Vinegar Sauce for *E. coli* count. Therefore, it is considered safe.

3.2 Food Safety Practices as Consumers' Perception

Table 4 shows that the findings surrounding consumers' perceptions of street food handling reveal a general agreement on the safety practices employed by vendors. With a mean score of 2.899, respondents believe that street food and its sauces are handled properly. Key safety practices such as washing hands before serving food were emphasised, and respondents particularly agreed on the importance of using utensils—like tongs and spoons—during food preparation. These insights align with Castillo's (2019) study, which highlights that vendors are more motivated to maintain hygiene and appearance, positively impacting customer attraction and health. Furthermore, the emphasis on proper handling of food and sauces resonates with guidelines from the FAO and WHO (2009), underscoring that effective hygiene management is critical for preventing foodborne illnesses and protecting public health.

Table 4: Handling of Street Food and its Sauces Based on Consumers Perception

Indicators	Mean	Descriptive Interpretation	Verbal Interpretation
1. The staff/s wash their hands before/after touching unwrapped raw foods.	2.682	Agree	The street food and its sauces are handled properly.
2. The staff/s wash their hands before/after touching prepared foods.	2.682	Agree	The street food and its sauces are handled properly.
3. The staff/s use soaps/detergents to wash their hands or use disinfectant spray (e.g., alcohol) when soap/detergents are not available.	2.667	Agree	The street food and its sauces are handled properly.
4. They use utensils/equipment such as tongs, forks, spoons, or spatulas in processing their food.	3.424	Strongly Agree	The street food and its sauces are properly and carefully handled.
5. The staff handling the food processing use tissue/cloth when sneezing or coughing.	2.833	Agree	The street food and its sauces are handled properly.
6. The staff touch unnecessary things while handling food (money, hair, face, etc.).	3.106	Agree	The street food and its sauces are handled properly.
AVERAGE	**2.899**	**Agree**	**The street food and its sauces are handled properly.**

Table 5 shows that consumers have a favourable view of street food preparation, reflected in a mean score of 3.197. Respondents strongly agree on having waste disposal bins near vendors' work areas, highlighting the importance of cleanliness in ensuring food safety. Supporting this, Tolentino et al. (2024) found that consumers prioritise cleanliness in assessing vendors, with clean preparation areas and proper hygiene being crucial for preventing foodborne illnesses. These findings align with the FAO and WHO (2009) guidelines, which stress that all parties in the food chain share the responsibility for food safety, a critical factor in protecting public health.

Table 5: Preparation of Street Food and its Sauces Based on Consumers Perception

Indicators	Mean	Descriptive Interpretation	Verbal Interpretation
1. The staff/s wash their hands regularly before/after working on an order.	2.803	Agree	The street food and its sauces are properly prepared.
2. The working area of the staff/s looks hygienic.	2.879	Agree	The street food and its sauces are properly prepared.
3. The cart is in good condition (clean, undamaged, easy to wash and disinfect).	2.955	Agree	The street food and its sauces are properly prepared.
4. The staff/s clean their workspace regularly (e.g., after processing food, when a customer spilled some sauce on the joint venture or cap, etc.).	3.076	Agree	The street food and its sauces are properly prepared.
5. The staff/s wear appropriate working equipment, such as, apron, masks, gloves, and caps/hair nets.	2.606	Agree	The street food and its sauces are properly prepared.
6. The staff/s wash their utensils/equipment before/after using it.	2.955	Agree	The street food and its sauces are properly prepared.
7. The utensils/equipment used in making the product are clean and safe to use (e.g., no rust).	3.136	Agree	The street food and its sauces are properly prepared.
8. There are waste disposal bins/trash cans available near the working area.	3.379	Strongly Agree	The street food and its sauces are properly and carefully prepared.
AVERAGE	**3.197**	**Agree**	**The street food and its sauces are properly prepared.**

Table 6 shows that consumers have a positive view of street food storage, with an average score of 2.996. The sauces scored highest at 3.076, suggesting they are considered safe for consumption. However, risks associated with improper temperature control can lead to spoilage and harmful microorganisms, like *E. coli*, as noted by Alimi (2016). Tolentino et al. (2024) emphasise the need for diligent food handling and storage. A lower score of 2.727 reflects concerns over pest exposure, highlighting the importance of cleanliness. The FAO and WHO (2009) warn that pests can increase foodborne illness risks, underscoring the need for effective pest management.

Table 6: Storage of Street Food and its Sauces Based on Consumers Perception

Indicators	Mean	Descriptive Interpretation	Verbal Interpretation
1. The raw and cooked foods are kept separately.	3.197	Agree	The street food and its sauces are properly stored.
2. The sauces (Vinegar, Sweet, and Spicy) are stored in large containers and dispensed with different serving ladles.	3.242	Agree	The street food and its sauces are properly stored.
3. The food looks fresh; still warm when served, neither dry nor soggy, no sour smell/taste and absence of mold growth.	3.000	Agree	The street food and its sauces are properly stored.
4. The sauces are in good condition and have no spoilage such as sour taste/smell, cloudiness (for vinegar sauce), bubbly, and thickness or lumpiness (for sweet and spicy sauce).	3.076	Agree	The street food and its sauces are properly stored.
5. The displayed food and sauces are placed in an area that does not get direct sunlight.	2.894	Agree	The street food and its sauces are properly stored.
6. The lid of the sauce containers is kept closed when not used.	2.833	Agree	The street food and its sauces are properly stored.
7. The food is not exposed to pests (flies, ants) in the production and display area.	2.727	Agree	The street food and its sauces are properly stored.
AVERAGE	**2.996**	**Agree**	**The street food and its sauces are properly stored.**

By reducing contamination and upholding hygiene, the handling, preparation, and storage of street food and its sauces all contribute to health, food safety, and food sanitation. Foodborne illness risks are decreased by following proper procedures, such as using proper utensils, keeping work areas clean, and storing food in a safe environment.

3.3 Microbial Analysis Results and Consumers' Perception on Handling, Preparation, and Storage Results' Implications

3.3.1 Health

The microbiological analysis of street food sauces conducted by DOST-RSTL confirmed their safety for consumption, supported by consumers' positive perceptions regarding the handling, preparation, and storage practices of street food sellers. However, Barcelon et al. (2012) pointed out that low or absent levels of Total Coliform and E. coli do not guarantee safety, as exceeding acceptable coliform limits can indicate potential bacterial contamination. Additionally, while coliforms are commonly used as hygiene indicators, they do not detect other harmful microbes (Amar, 2018; Szita et al., 2003). Quiliope and Teves (2016)

emphasised the importance of educating students buying street food near schools about the associated risks and advocated for strict food safety regulations for vendors to protect public health. This indicates that despite the seeming safety of street food sauces based on initial tests, the potential for bacterial contamination and the presence of harmful microbes necessitates enhanced food safety measures and consumer education to prevent foodborne illnesses.

3.3.2 Food Safety

Street food sellers must follow strict food safety regulations regarding the handling, preparation, and storage of their dishes and sauces. This study shows that consumers believe street food is well-managed, indicating confidence in vendors' safety practices. Supporting this, Werkneh et al. (2023) found that most vendors in cities stick to good practices, with 61.1% using trash cans and 83.9% covering food. Similarly, Benitez and Olmogues (2021) noted that vendors ensure hygiene by trimming nails, wearing hairnets and masks, washing hands, and using clean, unexpired ingredients in a tidy environment. Overall, these findings highlight that adherence to food safety regulations significantly reduces the risk of microbial contamination, ensuring safer street food consumption for consumers.

3.3.3 Food Sanitation

Tables 4 and 5 reveal that customer perceptions align with the proper handling and preparation practices of street food vendors, supporting findings by Buted and Ylagan (2014) that indicated customers recognise vendors' adherence to food sanitation procedures. These practices are crucial for reducing the risk of foodborne illnesses, as highlighted by the WHO's emphasis on sanitation and handwashing. To bolster these efforts, Jambre and Lagorra (2022) recommend the full implementation of sanitation laws and regular monitoring by local health authorities to ensure compliance. Similarly, Sezgin and Sanlier (2022) advocate for educational programmes for street food vendors, enhanced food preparation environments, and better waste management. Collectively, these insights underscore the importance of enforcing sanitation laws, educating vendors on best practices, and maintaining consistent monitoring as essential steps to improve food sanitation and reduce foodborne illness risks.

4. Conclusion

Based on the findings of the study, the microbiological analysis of sweet, spicy, and vinegar street food sauces indicates they are generally safe for consumer use, as per FDA standards. Although consumers view street food vendors as following effective food safety practices, there is a need for improved pest control to mitigate potential contamination risks. Ongoing education about food safety and hygiene, alongside regular monitoring, is essential to ensure safe street food consumption and uphold public health standards.

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References

Alimi, B. (2016). Risk factors in street food practices in developing countries: A review. *Food Science and Human Wellness*, *5*(3), 141-148. https://doi.org/10.1016/j.fshw.2016.05.001

Barcelon, E. G., Collado, D. M. R., Eustaquio, S. A., Luna, M. N. H., Santos, K. J. C., Sombrano, M. C. S., & Villaceran, D. P. (2012). Consumer perception and microbiological analysis on safety of street food dipping sauces. *Asian Journal of Agriculture and Food Sciences*, 3(1), 97–102. https://www.ajouronline.com/index.php/AJAFS/article/view/2355/1265

Benitez, V., & Olmogues, A. (2021). Food Safety practices among street food vendors in Dipolog City. *International Journal of Advanced Multidisciplinary Studies*, 1, 12–23. https://www.ijams-bbp.net/wp-content/uploads/2021/11/IJAMS-OCTOBER-12-23.pdf

Buted, D. R., & Ylagan, A. P. (2014). Street food preparation practices. *Asia Pacific Journal of Education, Arts and Sciences*, *1*(2), 53-60.

Campos, J., Gil, J., Mourao, J., Peixe, L., & Antunes, P. (2015, August 03). Ready-to-eat street-vended food as a potential vehicle of bacterial pathogens and antimicrobial resistance: An exploratory study in Porto region, Portugal. *International Journal of Food Microbiology*, *206*, 1-6. https://doi.org/10.1016/j.ijfoodmicro.2015.04.016

Castillo, C.B. (2019). Compliance to food safety standards of ambulant vendors in two cities of Nueva Ecija, Philippines. *Asia-Pacific Journal of Innovation in Hospitality & Tourism*, *8*(2). https://fslmjournals.taylors.edu.my/wp-content/uploads/APJIHT/APJIHT-2019-8-2/APJIHT-2019-P8-8-2.pdf

Dagalea, F. M. S., et al. (2021). Are street foods safe: Detection of Escherichia coli in street foods sauces. *South Asian Journal of Research in Microbiology, 9*(3), 41-45.

Ghosh, A. (2023). An account of hygienic practices and street food safety around the Medical Colleges of Kolkata, India. *Journal of Pure & Applied Microbiology*, *17*(4). https://doi.org/10.22207/JPAM.17.4.48

Hossain, M., & Dey, B. K. (2019). Microbial contamination of handmade sauce used by street food vendors in Jashore, Bangladesh. *Journal of Food Quality and Hazards Control, 6*(3), 115-120. https://www.researchgate.net/publication/335619597_Microbial_Contamination_of_Handmade_Sauce_Used_by_Street_Food_Vendors_in_Jashore_Bangladesh

Jambre, K. G. E., & Lagorra, M. J. P. (2022). Bacteriological analysis of street foods in Dipolog City. *International Journal of Advanced Multidisciplinary Studies, 2*(1), 33-41. https://ijams-bbp.net/wp-content/uploads/2022/04/IJAMS-JANUARY-33-41.pdf

Mohammedsani, Z. & Mohammed, A. (2020). Street food consumption and associated health risk. *International Journal of Research Studies in Agricultural Sciences (IJRSAS), 6*(7), pp. 8-18, http://dx.doi.org/10.20431/2454-6224.0607002

Quiliope, J. and Teves, K. (2016). Hygiene and sanitation practices of street food vendors in Mabinay: District II Elementary Schools, Negros Oriental, Philippines. https://www.ocerint.org/intcess16_epublication/papers/273.pdf

Tolentino, C. F., Alindugan, D. G., Castillo, P. B. D., De Sagun, L. M. M., Macalindong, J. N., Rivera, C. R., & Mangarin, J. A. (2024). Be aware mga suki: Practices of food safety and appropriate hygiene among sidewalk vendors in Balayan, Batangas. *Guild of Educators in Tesol International Research Journal, 2*(1), 102–132. https://doi.org/10.5281/zenodo.10893007

United Nations Department of Economic and Social Affairs. (2024). The 17 Goals. https://sdgs.un.org/goals

Werkneh, A., Tewelde, M., Gebrehiwet, T., Islam, M., & Belew, M. (2023). Food safety knowledge, attitude and practices of street food vendors and associated factors in Mekelle City, Northern Ethiopia. *Heliyon, 9*(4). https://www.cell.com/heliyon/pdf/S2405-8440(23)02333-2.pdf

Wiatrowski, M., Czarniecka-Skubina, E., & Trafiałek, J. (2021). Consumer eating behavior and opinions about the food safety of street food in Poland. *Nutrients, 13*(2), 594.

World Health Organization and Food and Agriculture Organization of the United Nations. (2022). Food safety is everyone's business in street food vending. *World Health Organization.* https://iris.who.int/handle/10665/354468

World Health Organization. (n.d). Sustainable Development Goals. *World Health Organization.* https://www.who.int/europe/about-us/our-work/sustainable-development-goals

INTEGRATION OF BIODIVERSITY CONSERVATION IN THE COURSE SCIENCE, TECHNOLOGY, AND SOCIETY TOWARDS KNOWLEDGE, ATTITUDE, AND PRACTICE AMONG PUBLIC COLLEGE STUDENTS

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ABSTRACT

This study examines the integration of biodiversity conservation in the Science, Technology, and Society (STS) curriculum and its impact on students' knowledge, attitudes, and practices regarding biodiversity conservation using the ANOVA test. This study also measures the significant relationship between integrating biodiversity conservation and students' knowledge, attitudes, and practices. The study uses a quantitative-correlational research design to target public Higher Education Institutions (HEIs) students in Davao del Norte, Philippines. Results show a high level of curriculum integration for biodiversity conservation, with a mean score of 22.16 and a very high knowledge level (mean score of 4.32), indicating effective educational strategies within the STS curriculum. Students demonstrate a significantly positive attitude toward biodiversity conservation, with an average score of 4.20, shaped by their knowledge and curriculum exposure. Furthermore, students actively practice conservation, as shown by a mean score of 4.23, suggesting they are committed to applying their knowledge and attitudes in practical settings. The study also finds significant variations in integration effectiveness across schools, with a p-value of 0.001, suggesting that resource availability, teacher training, and institutional focus influence outcomes. A significant relationship is established between curriculum integration and both knowledge and attitudes toward conservation (p-value = 0.001), although no direct link is found with practice (p-value = 0.052), indicating that external elements may impact students' conservation behaviours. Additionally, the study incorporates teaching-learning activities that focus on biodiversity threats, enabling students to analyse the effects of habitat loss, pollution, climate change, and overexploitation, thus fostering a comprehensive understanding of biodiversity challenges.

Keywords: Biodiversity conservation, STS curriculum, syllabus

1. Introduction

Biodiversity loss is a pressing environmental crisis, threatening the natural world and human well-being. The Philippines, unfortunately, is a hotspot for biodiversity loss, ranking among the top ten countries with the most threatened species. Habitat loss, overexploitation, pollution, climate change, and invasive species all contribute to this alarming trend. This situation underscores the urgency of taking action, not just for conservation but for the very future of our planet (CI, 2013; DENR, 2015).

Studies have shown a lack of understanding and appreciation for biodiversity and opposition to its protection (Elder et al., 2015). Ebua et al. (2011) suggest that a crucial factor in

addressing this challenge is understanding public knowledge, attitude, and practice (KAP) toward conservation efforts.

Consequently, Sustainable Development Goals (SDGs) offer a framework for tackling interconnected issues to achieve sustainable development, which implies addressing current demands while ensuring that future generations can meet their own. Among these goals, SDG 13 specifically targets climate change, a significant driver of biodiversity loss and associated problems like habitat degradation and species migration (Sustainable Development Goal, 2015).

Furthermore, the Convention on Biological Diversity promotes the importance of communication, education, and awareness campaigns. These programmes seek to promote a deeper understanding of biodiversity's value and empower individuals to take action. The Philippines recognises this by mandating the integration of environmental education at all levels of schooling, from daycare to higher education (Official Gazette, 2020).

Fortunately, one of the courses mandated by the Commission on Higher Education through Memorandum Order No. 20 Series of 2013 is Science, Technology, and Society, which focuses on current issues like climate change and environmental awareness that emphasises knowledge, experiences, values, and responsible practices towards the environment (Toomey et al., 2017).

Given the significant role of higher education in shaping future leaders, policymakers, and professionals, studying the effectiveness of integrating biodiversity conservation within STS courses is highly relevant. This research has the potential to provide valuable insights into how educational policies and curricula can be designed or modified to promote biodiversity conservation through assessing their knowledge, attitude, and practice. This can ultimately influence the approaches taken by educational institutions and government agencies in their conservation education initiatives. It also fosters a generation of environmentally conscious citizens better equipped to address ecological challenges. By embedding biodiversity conservation into STS courses, universities and other colleges can help advance sustainable practices and policies at a broader societal level.

While existing research explores biodiversity awareness education and KAP assessment in various groups, a gap exists in studies explicitly evaluating the efficacy of integrating biodiversity conservation within STS approaches in tertiary education for transforming KAP towards biodiversity conservation (Coracero, 2021; Halim et al., 2021; Delector, 2023). This highlights the need for further exploration to bridge this knowledge and methodological gap.

2. Methods

2.1 Research Design

This study employed a quantitative descriptive-correlational research design to investigate the integration of biodiversity conservation in the Science, Technology, and Society (STS) course and its impact on public college students' knowledge, attitudes, and practices. The study focused on public higher education institutions using stratified random sampling to select 600 student respondents from various programmes. The respondents voluntarily participated, and confidentiality was maintained throughout the process. The research was conducted in four institutions in Davao del Norte. These locations were chosen to capture the diverse educational experiences of the students across their programmes.

2.2 Research Instrument

The survey instrument included demographic questions as the first part of the questionnaire. Part two is a 30-item Multiple Choice Questionnaire that assesses the level of integration in biodiversity conservation. The items underwent item analysis and had a Cronbach Alpha value of .88, indicating good internal consistency. This part of the questionnaire began with a stem followed by four options. Correct answers were scored 1 point, while wrong answers were marked 0. The mean score was calculated to determine the classification level of biodiversity conservation integration, categorising it into five levels: very high, high, moderate, low, or very low. The scoring of the level of integration in biodiversity conservation was based on parameters adapted from those used by Coracero et al. (2022).

Furthermore, the study also utilised an adapted questionnaire from Delector (2023) to assess their knowledge and Afroz and Ilham (2020) for the attitude and practice, which were modified in the context of biodiversity. The Likert Scale, a method of quantitative value, was used to make it amenable to statistical analysis, wherein a numerical value was assigned to each potential choice, and a mean figure for all the responses was computed at the end of the evaluation or survey. The final average score represented the overall level of perceptions as manifested (Term, 2004). This questionnaire also showed good internal consistency during pilot testing and was validated by three field experts.

2.3 Data Gathering Procedure

The researcher took several steps and measures in the data-gathering procedure, such as seeking permission to conduct the study and ensuring ethical considerations, including respect for participants, beneficence, and justice. The study adhered to principles from the Belmont Report, ensuring informed consent, confidentiality, and equitable participant selection. Data analysis utilised statistical tools like mean and ANOVA to determine the relationships between knowledge, attitudes, and practices. The results aimed to inform educational strategies and enhance biodiversity conservation education.

3. Results and Discussion

Table 1: Students' Integration on Biodiversity Conservation

School	Mean Score	SD	Descriptive Equivalent
School A	24.287	2.6275	High
School B	21.560	4.8942	High
School C	21.767	5.1324	High
School D	21.007	4.5162	High
Overall	**22.16**	**4.57**	**High**

School A has the highest mean score at 24.287 in the integration of biodiversity conservation, with a standard deviation of 2.6275, a high classification level for biodiversity integration in the course STS. Meanwhile, School D has the lowest mean score at 21.007, with a standard deviation of 4.5162. This indicates that, on average, students at School D have the least integration into biodiversity conservation among the four schools but are still on the high-level classification of biodiversity conservation. Schools with higher mean scores and lower standard deviations, like School A, have more effective programmes or educational initiatives in place to promote biodiversity conservation, such as partnering with Interfacing Development Interventions for Sustainability (IDIS) to advance sustainable development initiatives, fostering environmental stewardship and community engagement, which are crucial aspects of biodiversity conservation. The total mean score for the integration of biodiversity conservation

was high for the four public higher institutions in Davao del Norte after they completed the STS course by educating students about biodiversity conservation. According to Reber et al. (2022) and Coracero et al. (2022), the STS course can help them become more informed citizens and advocates for sustainable practices as this curriculum is an interdisciplinary field that examines the interconnectedness of scientific knowledge, technological advancements, and societal values, exploring how these domains influence and shape one another (Hackett et al., 2008; Jasanoff, 2004). It also emphasises the dynamic relationships among science, which drives innovation; technology, which addresses human needs; and society, which shapes and is transformed by scientific and technological developments (Bijker et al., 2012). Consequently, STS evaluates the development, accessibility, and societal acceptance of these technologies, ensuring the equitable application of conservation efforts (Turner et al., 2003).

Moreover, studies examining the long-term effects of integrating Science, Technology, and Society (STS) curricula on students' conservation behaviors indicate that such integration can have a positive impact on students' environmental awareness and behaviours. For instance, a study by Fytopoulou et al. (2023) compared the environmental attitudes of students in forestry and literature programmes at a Greek university and found that students in environmental disciplines exhibited higher levels of environmental awareness, demonstrating the influence of specialised curricula on pro-environmental attitudes. This aligns with the findings of a study that demonstrated higher outcomes in science-related programmes, particularly in agriculture, at School A. Thus, this underscores the importance of curriculum content and experiential learning in shaping students' environmental attitudes and behaviours, suggesting that integrating STS principles into education can lead to more sustainable conservation practices.

Table 2: Level of Students' Knowledge Towards Biodiversity Conservation

	Item	Mean	SD	Descriptive Equivalent
1.	Biodiversity plays an important role in maintaining ecosystem functions.	4.67	0.57	Very High
2.	Biodiversity is everywhere.	4.64	0.60	Very High
3.	Biodiversity covers the variability among living organisms found in different habitats.	4.63	0.56	Very High
4.	Biodiversity can be measured through the species composition, specifically in the number of species and individuals.	4.42	0.66	Very High
5.	Reforestation activities can help maintain biodiversity.	4.38	0.97	Very High
6.	Changes in biological interaction, like predation and parasitism, can affect biodiversity.	4.25	0.79	Very High
7.	Losing a species can affect humans.	4.25	0.87	Very High
8.	All species present in the world have not yet been discovered.	4.19	0.89	High
9.	Invasive species negatively affect the diversity of an ecosystem	3.95	0.96	High
10.	Evolution cannot replace missing or extinct species.	3.86	0.98	High
	Overall	**4.32**	**0.45**	**Very High**

Table 2 assesses students' knowledge levels regarding biodiversity conservation across various aspects. The overall mean score is 4.32 with a standard deviation of 0.45, which falls under the "Very High" descriptive equivalent. This indicates that, generally, students possess a very high understanding of biodiversity conservation. This coincides with the high integration of biodiversity conservation into the STS curriculum. The strong correlation between curriculum content and student comprehension underscores the importance of curricular

design in promoting environmental awareness and education. Consequently, these findings highlight the success of current educational strategies in fostering a deep understanding of biodiversity conservation among students. According to Monroe et al. (2019), the very high knowledge levels reflect the quality and comprehensiveness of the instructional materials used in the school. Studies have shown that well-structured educational programmes can significantly improve students' environmental literacy.

Table 2.1: Level of Students' Attitude Towards Biodiversity Conservation

Item	Mean	SD	Descriptive Equivalent
1. We will lose some endemic species that are major contributors to biodiversity worldwide if we do not protect them through biodiversity education.	4.44	0.68	Very Positive
2. Integrating biodiversity conservation in the course Science, Technology, and Society is an assurance of the continued economic prosperity of our country.	4.43	0.63	Very Positive
3. Any of us can significantly contribute to solving the problem of biodiversity issues by studying STS.	4.40	0.71	Very Positive
4. The demand for economic growth, which concerns some environmental restrictions related to biodiversity-related issues, is very important and should be integrated into the STS course.	4.36	0.68	Very Positive
Almost all human activities result in the loss of biodiversity.	4.32	0.81	Very Positive
5. Exploiting natural resources for human needs through developing tools must be stopped to prevent the loss of habitat and wildlife populations.	4.26	0.77	Very Positive
6. I feel alarmed about the extinction of local species of flora and fauna.	4.25	0.70	Very Positive
7. The natural world is sacred and should be left in peace.	4.23	0.79	Very Positive
8. STS can do to help stop the degradation of the world's biodiversity.	4.15	0.74	Positive
9. Science and technology can solve biodiversity issues and problems.	4.14	0.76	Positive
10. The problems of biodiversity issues should not be left to experts and the instructors teaching STS.	3.91	1.00	Positive
11. I am willing to sacrifice my possessions or money to deal with biodiversity issues and concerns.	3.87	0.83	Positive
12. People who took up STS worry too much about the problem of biodiversity issues.	3.86	0.89	Positive
Overall	**4.20**	**0.46**	**Very Positive**

Students' attitudes towards biodiversity conservation, demonstrating a "Very Positive" overall mean with a score of 4.20, are highlighted in table 2.1. Studies have shown that exposure to interdisciplinary courses like STS can significantly enhance students' environmental awareness and positively influence their attitudes toward conservation and biodiversity protection (Holbrook and Rannikmae, 2007). Exposure to such interdisciplinary courses has significantly enhanced students' environmental awareness and fostered positive attitudes toward conservation and biodiversity protection. These results imply the effectiveness of integrating interdisciplinary approaches into the Science, Technology, and Society curriculum to cultivate a proactive and positive stance on environmental issues among students.

Table 2.2: Level of Students' Practice Towards Biodiversity Conservation

	Item Description	Mean	SD	Descriptive Equivalent
1.	Switch off electrical appliances in my home that I don't need when I am not around.	4.59	0.70	Always
2.	Turn off the air-conditioner and lights in the classroom after the class finishes and it gets empty at my university.	4.48	0.82	Always
3.	Conserve the use of water supply at my place.	4.47	0.73	Always
4.	Willing to utilise renewable energy.	4.43	0.73	Always
5.	Dispose of recyclable material (e.g. [as] plastic bottles, newspaper, glass) separately at home.	4.36	0.82	Always
6.	Avoid using the animal skinned [animal skin] product.	4.22	1.03	Always
7.	Interested in paying more for environmentally friendly products	4.21	0.89	Always
8.	Prefer public transport rather than private one.	4.13	0.94	Often
9.	Avoid using plastic straws at restaurants/cafes.	4.09	0.95	Often
10.	Talk about environmental sustainability with my friends and family.	4.04	1.01	Often
11.	Bring my own reusable bag for grocery shopping.	4.03	1.00	Often
12.	Participate in events (ex, seminars, talks, workshop[s]) that relate to environmental sustainability.	3.96	1.07	Often
13.	Have taken other courses related to environmental awareness.	3.92	1.08	Often
	Overall	**4.23**	**0.55**	**Always**

Also, table 2.2 examines students' practices towards biodiversity conservation, indicating a strong commitment to conserving biodiversity with an overall mean score of 4.23, rated as "Always. Educational strategies in STS that incorporate hands-on activities, real-world problem-solving, and community involvement have effectively enhanced pro-environmental behaviors among students (Monroe, 2003). This underscores the importance of experiential and community-based learning in fostering students' strong commitment to biodiversity conservation. Continuing and expanding these integrative educational practices could further reinforce students' commitment to biodiversity conservation and lead to broader environmental stewardship.

Table 3: Significant Difference in Their Level of Integration on Biodiversity Conservation When Grouped According to School

School	Mean	SD	f-value	p-value	Decision
School A	24.287	2.6275	16.412	0.001	Reject H_{01}
School B	21.560	4.8942			
School C	21.767	5.1324			
School D	21.007	4.5162			

The results of the ANOVA test in table 3, which indicate an f-value of 16.412 and a p-value of 0.001, reveal a statistically significant difference in integrating biodiversity conservation practices among schools. Such findings suggest a more standardised approach to integrating biodiversity conservation practices to ensure consistent and effective environmental education across all schools. Jickling and Wals (2008) mentioned that schools that adopt curricula specifically designed to include environmental education can ensure that biodiversity conservation is systematically covered. Additionally, district or national-level policies that mandate environmental education can drive schools to implement comprehensive programmes.

Table 4: *Significant Relationship Between the Integration of Biodiversity Conservation and Students' Knowledge, Attitude, and Practice*

Independent Variable	Dependent Variable	r-value	p-value	Decision
Integration of Biodiversity Conservation	Knowledge	0.244*	0.001	Reject H_{02}
	Attitude	0.135*	0.001	
	Practice	0.079	0.052	

**p<0.05*

The relationship of integrating biodiversity conservation in table 4 shows a moderate positive correlation with students' knowledge, as indicated by an R-value of 0.244 and a highly significant p-value of 0.001. Also, there is a weak positive correlation between the integration of biodiversity conservation and students' attitudes, with an R-value of 0.135 and a p-value of 0.001. Although the relationship is weaker than that for knowledge, it is still statistically significant. However, the relationship between integrating biodiversity conservation and students' practice shows a very weak positive correlation with an R-value of 0.079 and a p-value of 0.052. This correlation is not statistically significant. This suggests that while integrating biodiversity conservation in the STS curriculum impacts knowledge and attitudes, its influence on actual conservation practices among students is minimal and not statistically confirmed. This finding underscores a persistent challenge in environmental education: the difficulty of translating knowledge and positive attitudes into tangible behaviour change (Kollmuss and Agyeman, 2002). To elaborate, Steg and Vlek (2009) argue that ineffective educational approaches may further weaken this connection. Specifically, programmes emphasising theoretical knowledge without incorporating practical applications often fail to motivate students to adopt long-term behavioral changes. Moreover, psychological barriers significantly exacerbate this issue. For instance, environmental apathy and a perceived lack of impact can deter meaningful action. Students frequently feel overwhelmed by the scale of environmental problems, resulting in a sense of helplessness and subsequent inaction (Gifford, 2011). Likewise, when students perceive their efforts as inconsequential, their willingness to engage in conservation practices diminishes (Stern, 2000).

External factors influencing students' conservation practices have identified that limited financial resources can significantly hinder students' ability to adopt conservation practices, particularly those that require monetary investment, such as purchasing sustainable products or participating in eco-friendly programmes (Jain and Kaur, 2004). Moreover, the presence or absence of institutional support plays a critical role in shaping students' conservation behaviors. For instance, schools that actively promote sustainability through initiatives like recycling programmes and provide access to green spaces tend to foster greater student engagement in pro-environmental activities (Stern, 2000). Exposure to media and digital platforms also influences students' environmental awareness and actions. Positive portrayals of conservation behaviors in media and access to educational content through technology can inspire and encourage students to adopt pro-environmental practices (Boyes et al., 2009).

Table 5: Teaching-Learning Activities of Biodiversity Conservation

Week	Intended Learning Outcomes	Learning Contents	Suggested Teaching-Learning Activities (TLAs)	Assessment Tasks (ATs)
16-17	1. Identify and assess the various natural and anthropogenic threats to biodiversity, including habitat loss, invasive species, pollution, climate change, mining, and overexploitation of natural resources. 2. Evaluate different conservation strategies to preserve biodiversity, including protected areas, sustainable resource management, habitat restoration, and captive breeding programmes. 3. Develop effective communication and advocacy skills to engage stakeholders, raise awareness about the importance of biodiversity conservation, and mobilise support for conservation initiatives.	**Biodiversity and the Healthy Society** a. Threats to Biodiversity b. Consequences of Biodiversity Loss c. Changes in Biodiversity d. Biodiversity Conservation	**Interactive discussion** on the various threats to biodiversity conservation, including habitat loss, invasive species, pollution, climate change, mining, and overexploitation of natural resources and its consequences in biodiversity loss. **Chainsaw Reporting.** The students will be divided into four groups, each evaluating the different conservation strategies for preserving biodiversity in the Philippines.	**Conservation Advocacy Campaign.** Students will design a conservation advocacy campaign to raise awareness about the importance of biodiversity conservation. This should achieve the following: **Raise awareness:** Educate the public about the importance of biodiversity and the specific threat you have identified. **Engage stakeholders:** **Identify** and target key stakeholders (e.g., policymakers, businesses, community groups) who can influence the issue. **Mobilise support**: Encourage stakeholders and the public to act in support of conservation efforts. *Criteria:* 30%- Awareness raising with clarity and coherence of campaign proposal. 25%- Creativity and effectiveness of communication materials. 25% - Engagement Techniques to mobilise support. 20% - Overall Presentation

In connection, table 5 outlines the teaching-learning activities that play a crucial role in biodiversity conservation education. Various studies emphasise the importance of integrating different disciplines and tools to enhance students' understanding and appreciation of biodiversity (Mendoza-Fernández et al., 2023). Varied teaching and learning activities will prepare students to become effective advocates for biodiversity. This approach aligns with educational research that emphasises the importance of experiential learning and real-world

problem-solving (Kolb, 1984). These teaching-learning activities will address the need to emphasise practice on biodiversity conservation.

4. Conclusion

This study was conducted to determine the integration of biodiversity conservation in the Science, Technology, and Society course towards knowledge, attitude, and practice among college students in public higher education institutions in Davao del Norte. Based on the findings of the study, the following conclusions were drawn:

The results indicate a high level of integration of biodiversity conservation in the studied context. Additionally, there is a very high level of knowledge about biodiversity conservation among the students sampled. This suggests that the efforts to educate and integrate biodiversity topics into the STS curriculum have disseminated knowledge.

In addition, participants exhibit a very positive attitude towards biodiversity conservation. This positive attitude stems from the high level of knowledge and the effective integration of conservation topics in STS, which foster an appreciation and concern for biodiversity.

Moreover, the students' consistent practice of biodiversity conservation demonstrates a strong commitment to applying their knowledge and positive attitudes in real-world actions. However, the findings also reveal a notable nuance in the relationship between knowledge, attitude, and practice.

Determining the significant difference in the level of integration of biodiversity conservation when grouped according to school suggests that some schools are more effective in integrating biodiversity conservation into their programmes than others due to differences in resources, teacher training, or institutional priorities.

Also, a significant relationship exists between biodiversity conservation integration and knowledge and attitude. This indicates that the more effectively biodiversity conservation is integrated into the curriculum or initiatives, the greater the increase in knowledge and the more positive the attitudes towards conservation.

Despite the high levels of knowledge and positive attitudes, there is no significant relationship between the integration of biodiversity conservation and the actual practice of it. This suggests that factors beyond knowledge and attitude, such as external barriers, personal motivation, or resources, influence individuals' conservation behaviors. Addressing these obstacles through more engaging, action-oriented, and contextually relevant educational interventions is crucial for bridging the gap between awareness and practice, ultimately fostering a generation of proactive environmental stewards.

Finally, teaching-learning activities on the course syllabus incorporate interactive activities to help students develop knowledge and understanding of threats to biodiversity conservation. It also suggests that the specified week on curriculum focuses on helping students identify and assess the various natural and anthropogenic threats to biodiversity, including habitat loss, invasive species, pollution, climate change, mining, and overexploitation of natural resources. The learning activities include interactive discussions about these threats and their consequences.

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References

Bijker, W. E., Hughes, T. P., & Pinch, T. J. (2012). The social construction of technological systems: New directions in the sociology and history of technology. *MIT Press.*

Boyes, E., Stanisstreet, M., & Yongling, D. (2009). The impact of media and technology on young people's understanding of environmental issues. *Environmental Education Research, 15*(4), 415-429.

Conservation International (2013). Constructing theories of change for ecosystem-based adaptation projects. *Conservation International*.

Coracero, Ericson & Facun, Mark & Gallego, Rb & Lingon, Marlon & M., Lolong & M., Lugayan & G., Montesines & R., Sangalang & Suniega, Mark John. (2022). Knowledge and perspective of students towards biodiversity and its conservation and protection. *Asian Journal of University Education*, *18*(1), 118-131.

Delector, R. T. (2023). Students' Knowledge and attitude towards biodiversity conservation. *Asian Journal of Biodiversity*, *14*(1). https://doi.org/10.7828/ajob.v14i1.1548

DENR. (2015). USAID: Global biodiversity loss at an alarming rate. *Department of Environment and Natural Resources.* https://denr.gov.ph/news-events/usaid-global-biodiversity-loss-at-an-alarming-rate/

Ebua V.B, Agwafo T.E & Fankwo,S.N (2011). Attitudes and perceptions as threats to wildlife conservation in the Bakossi area, South West Cameroon. *International Journal of Biodiversity and Conservation, 3(12), 631-636.*

Elder, J., Coffin, C., Farrior, M., (2015). Engaging the public on biodiversity - a road map for education and communication strategies. *The Biodiversity Project.*

Fytopoulou, E., et al. (2023). Environmental attitudes and behaviors of students in forestry and literature programs at a Greek university. *Sustainability in Education, 15*(6), 554. MDPI.

Gifford, R. (2011). The Dragons of inaction: Psychological barriers that limit climate change mitigation and adaptation. *American Psychologist, 66*(4), 290–302.

Hackett, E. J., Amsterdamska, O., Lynch, M., & Wajcman, J. (2008). The handbook of science and technology studies. *MIT Press.*

Holbrook, J., & Rannikmae, M. (2007). The nature of science education for enhancing scientific literacy. *International Journal of Science Education, 29*(11), 1347-1362.

Jain, A., & Kaur, P. (2004). Environmental sustainability: Issues and challenges. *International Journal of Consumer Studies, 28*(1), 75-86.

Jasanoff, S. (2004). States of knowledge: The co-production of science and social order. *Routledge.*

Jickling, B., & Wals, A. E. J. (2008). Globalization and environmental education: looking beyond sustainable development. *Journal of Curriculum Studies*, *40*(1), 1–21. https://doi.org/10.1080/00220270701684667

Kolb, D. A. (1984). Experiential learning: Experience as the source of learning and development. *Prentice Hall*.

Kollmuss, A., & Agyeman, J. (2002). Mind the gap: Why do people act environmentally and what are the barriers to pro-environmental behavior?. *Environmental Education Research*, *8*(3), 239–260. https://doi.org/10.1080/13504620220145401

Mendoza-Fernández, A. J., Martínez-Hernández, F., Salmerón-Sánchez, E., Pérez-García, F. J., Merlo, E., & Mota, J. (2023). Proposal for didactic innovation through the monitoring of threatened biodiversity. *Research Journal of Ecology and Environmental Sciences*, *3*(1), 9-17. https://doi.org/10.31586/rjees.2023.495

Monroe, M. C. (2003). Two avenues for encouraging conservation behaviors. *Human Ecology Review, 10*(2), 113-125.

Monroe, M. C., Plate, R. R., Oxarart, A., Bowers, A., & Chaves, W. A. (2019). Identifying effective climate change education strategies: a systematic review of the research. *Environmental Education Research, 25*(6), 791-812.

Official Gazette. (2008, December 12). Republic Act No. 9512. *Official Gazette.* https://www.officialgazette.gov.ph/2008/12/12/republic-act-no-9512/

Reber, U., Fischer, M., Ingold, K., Kienast, F., Hersperger, A. M., Grütter, R., & Benz, R. (2022). Integrating biodiversity: A longitudinal and cross-sectoral analysis of Swiss politics. *Policy Sciences, 55*(2), 311-335. https://doi.org/10.1007/s11077-022-09456-4

Steg, L., & Vlek, C. (2009). Encouraging pro-environmental behavior: An integrative review and research agenda. *Journal of Environmental Psychology*, *29*(3), 309-317.

Stern, P. C. (2000). Toward a coherent theory of environmentally significant behavior. *Journal of Social Issues, 56*(3), 407-424.

Sustainable Development Goals. (2015). *UNDP*. https://www.undp.org/sustainable-development-goals

Toomey, A. H., Knight, A. T., & Barlow, J. (2017). Navigating the space between research and implementation in conservation. *Conservation Letters, 10*(5), 619-625.

Turner, W., Spector, S., Gardiner, N., Fladeland, M., Sterling, E., & Steininger, M. (2003). Remote sensing for biodiversity science and conservation. *Trends in Ecology & Evolution, 18*(6), 306-314.

LEARNING ALGORITHMS: APPLICATION OF CONVOLUTIONAL NEURAL NETWORKS OF SELECTED TRAFFIC SIGNAGES

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ABSTRACT

This research focuses on image classification by determining the best suitable and highest possible accuracy of Convolutional Neural Network (CNN) Models for classifying image data of traffic sign images and applied statistical and machine learning algorithms such as confusion matrix and validation curve for evaluating the data result of the models. This study utilised Convolutional Neural Networks (CNN) to analye traffic signage in a quantitative experimental research design. The image dataset employed in this study and trained in the programme and different CNN models are obtained from Bing downloader and Kaggle.com. The data sets were manually imported in the said open-source website and downloader. Figure 1 shows a sample of images of traffic signages classified as: Do not block the intersection, No left turn, No right turn, No parking, No U-turn, One way, Road at work, and Stop signs. CNN models may make it simple to classify an image of a traffic sign because they employ artificial intelligence to do it. The findings highlight the superior balance offered by MobileNet, which achieves the best performance with the lowest computational cost. Inception V3 can be considered as an alternative if the task prioritises accuracy over efficiency, while ResNet50 appears unsuitable without further optimisation. These results emphasise the importance of evaluating models not just on accuracy but also on resource efficiency and practical deployability, particularly in real-world applications. Further investigation is suggested before using this backend programme in a real-life application.

Keywords: Convolutional Neural Network (CNN), data set, classification, traffic Signages

1. Introduction

Traffic signs, strategically positioned along roadways, play a pivotal role in furnishing drivers with vital information concerning road conditions and directions, thereby contributing to safer and more efficient navigation. Utilising pictorial symbols and images, these signs effectively convey messages to motorists and are categorised into distinct types based on the specific information they convey, facilitating safer and more efficient navigation (Kondamari and Itha, 2021). Traffic signs reduce the risk of accidents, giving them warnings on their way. By offering clear and visible signs to road users. The signs have various purposes, such as guiding the drivers, informing them of road conditions, regulating traffic flow, and warning of potential hazards. Traffic signage is important in maintaining road safety and ensuring clean traffic flow. By providing clear and visible signs to road users, they significantly reduce the risk of accidents by offering warnings and information about the road ahead (Megalingam et al., 2023). Despite the extensive presence of traffic signage, accidents persist due to various factors such as poor visibility, distracted driving, and insufficient awareness of traffic rules and regulations.

According to Kim (2019), in the Philippines, the issue of road safety is particularly pressing, with road accidents constituting a significant cause of mortality, especially among children. Shockingly, in Metro Manila alone, about two children die daily due to road accidents, with the metro witnessing a total of 394 fatalities in the recent year. According to the Department of Health, road accidents have surpassed diseases like dengue as a leading cause of mortality among children.

Technology advancement creates a tremendous impact on the world we are living in. The people's understanding when it comes to Artificial Intelligence becomes the main key to unlock the knowledge to address real life problems including road safety. The use of this kind of tactic enables researchers to develop different problem-solving tools in this algorithm called convolutional neural network (CNN). Image classification is one of the most important research directions in image processing, and it has become the focus of research in many years due to the diversity and complexity of picture information (Ren et al., 2017). Algorithms and models are used to identify patterns, objects, and events in photos and videos, allowing computers to understand and analyse visual data. The goal of image classification research is to create precise models and algorithms that can categorise photos into various categories (He et.al, 2020). The ability of Convolutional Neural Networks (CNNs) to directly extract hierarchical features from raw pixel data has made them effective tools for image classification tasks, such as traffic sign identification. CNNs' built-in ability to recognise complex patterns in images makes it possible for them to accurately identify traffic signs in adverse visual conditions. Moreover, multi-task learning frameworks have been provided by recent advances in CNN architectures, as demonstrated by the work of Luo et al. (2017), which allow CNN models to handle many categories of traffic signs at the same time. As a result, the integration of CNNs into traffic sign recognition systems has shown impressive outcomes, contributing to the reduction of accident severity.

To help minimise the severity of accidents, researchers are conducting a study on traffic signs classification utilising Convolutional Neural Network (CNN) models. Certain models possess various performances due to the fact they differ based on the architecture, training data, hyperparameters, and training procedure. These aspects produced varying results in terms of validating and training accuracy, which is critical for the implementation of various computer vision tasks such as image classification and object detection. Researchers' objective is to capture a variety of traffic signs under different conditions, give these images into our CNN, and assess the accuracy of its detection and recognition capabilities. This project not only tests the robustness of CNN in traffic sign recognition but also contributes to the development of more efficient and versatile automated driving assistance systems. (Cao, et.al ,2021). This hands-on methodology allows us to evaluate the model's performance in real-world conditions, including scenarios where signs may be distant, or images are somewhat blurred. Blurred images present a unique challenge for automatic recognition systems, yet they closely mimic everyday situations where clarity is compromised due to weather, speed, or lens limitations.

This study is essential for the use of CNNs in traffic sign classification because it provides significant new insights into model development, effectiveness objectives, and testing procedures for evaluating algorithmic performance in real-world applications. Convolutional neural networks (CNNs) are widely used in the classification of road signs simply because of their ability to extract spatial features from pictures. There is a notable study in this field that has proved useful in determining how well different CNN models perform while evaluating traffic signs.

This research focuses on image classification by determining the best suitable and highest possible accuracy of Convolutional Neural Network (CNN) Models for classifying image data of traffic signs and applying statistical and machine learning algorithms such as confusion matrix and validation curve for evaluating the data result of the models. This study would not extend to the advanced application of machine learning such as the development of visual

search tools and other image or object detection applications. However, the backbone structure of some of these applications covers and show relationships with one another.

2. Methodology

This study utilised Convolutional Neural Networks (CNN) to analyse traffic signage in an experimental research design. The ability to accurately recognise and interpret traffic signs is crucial for ensuring safe navigation on the roads. In this context, convolutional neural networks (CNN) present a promising method for improving the efficacy of automated traffic sign recognition systems. The research aimed to create a dependable and efficient system for automatic traffic sign identification, and its design was closely matched with these goals. It aims to improve traffic control and road safety by leveraging CNNs' ability to extract hierarchical information from images. The project seeks to provide useful advice for implementing CNN-based traffic sign classification systems in real-world contexts through the usage of these designs. This contributes to addressing significant issues in urban transportation and development (Stallkamp et.al., 2016).

In order to thoroughly evaluate the effectiveness of CNNs in traffic sign classification, the research design for this study involves experimental and quantitative research design. Through gathering numerical information on model performance parameters like computational efficiency and accuracy, the study offers insights about CNNs' potential for this kind of work (LeCun, 2015). By conducting experiments, which involve adjusting training settings, the study aims to determine the best configurations for attaining high classification accuracy. Experimental design is crucial in machine learning to validate hypotheses, evaluate performance, compare algorithms, and tune hyperparameters. It helps in systematically testing hypotheses, ensuring they hold true under different conditions. By understanding model behavior, researchers can improve model interpretability and inform future development efforts Schratz, et al. (2019).

The image dataset employed in this study and trained in the programme and different CNN models are obtained from Bing downloader and Kaggle.com. The data sets were manually imported in the said open-source website and downloader. Figure 1 shows a sample of images of traffic signages classified as: Do not block the intersection, No left turn, No right turn, No parking, No U-turn, One way, Road at work, and Stop signs.

Figure 1: A photo of Sample data sets taken from different open-source websites and downloaders.

The datasets are composed of 8 classes of traffic signs and each image is in .jpeg and .png extension randomly. The selected datasets comprise of 8 classes and a total of 2191 datasets. Now the datasets are split into training and validation data sets with 80% and 20% of the datasets respectively as shown in Table 1. Thus, there were 1828 and 363 images for training and validation sets. Utilising the pictures of the traffic signs from a total dataset of 2191 accumulated by controlled conditions

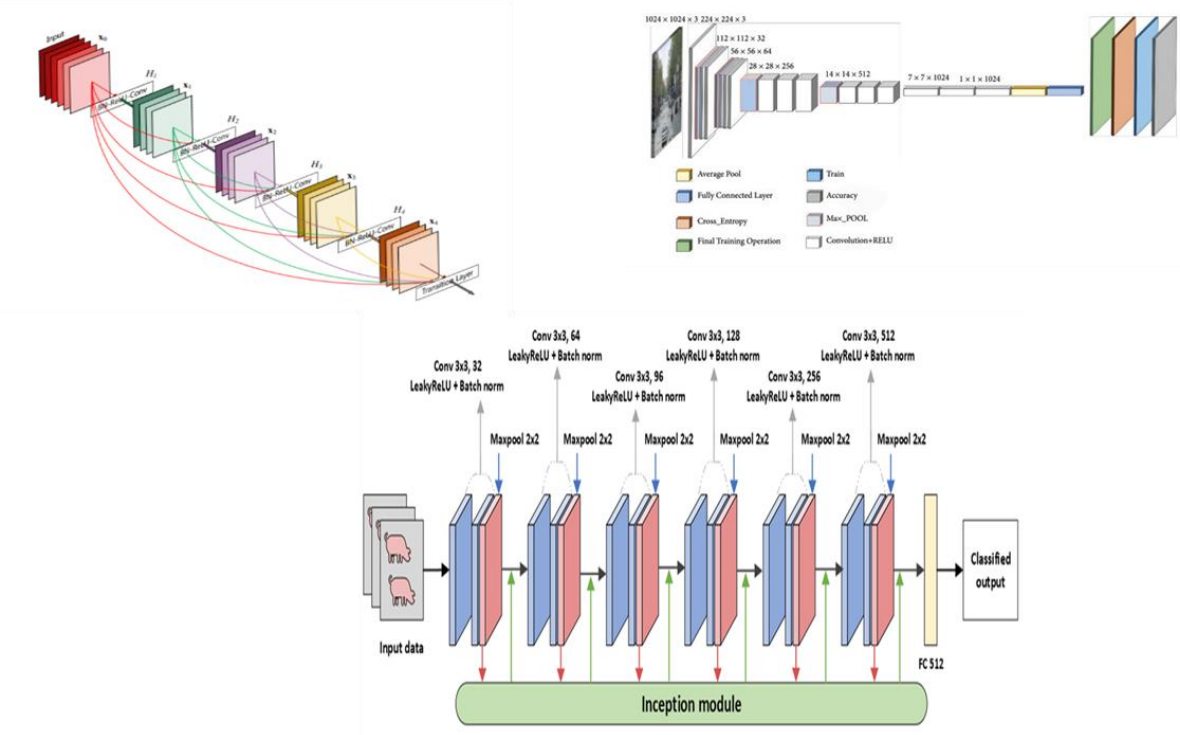
3. Results and Discussion

Table 1: Data Sets

Classification	Data Set	Train Data Set	Validations Data
No Right	237	198	39
No Left	300	250	50
Stop Sign	300	250	50
Road Work Sign	108	90	18
One Way	250	209	41
No U -Turn	249	208	41
Do Not Block the Intersection	256	213	43
No Parking	492	410	82
Total	**2191**	**1828**	**363**

The researchers utilised three CNN architecture models that help the image classification tasks and also put on a test in order to identify the best models suitable for image classification. The following models used were Resnet (Residual Network), MobileNet and Inception (GoogLeNet). ResNet is a deep neural network that uses residual learning to train deep networks effectively. It is used in scenarios like image classification, object detection, and image segmentation (Geeks for Geeks, 2023)**.** MobileNet is lightweight and efficient, particularly for mobile and embedded vision applications. It uses depthwise separable convolutions to reduce computational costs while maintaining accuracy (Team, n.d.). Inception is a famous inception module that uses multiple convolutional filters of different sizes within the same layer to efficiently capture different scales of information in input data. Inception networks are useful for tasks requiring both local and global features in input images, such as image classification, object detection, and semantic segmentation (DeepAI, 2020). Each of these architectures has its own strengths and is suitable for different scenarios based on factors such as computational efficiency, accuracy, and the depth of the network required for the task at hand.

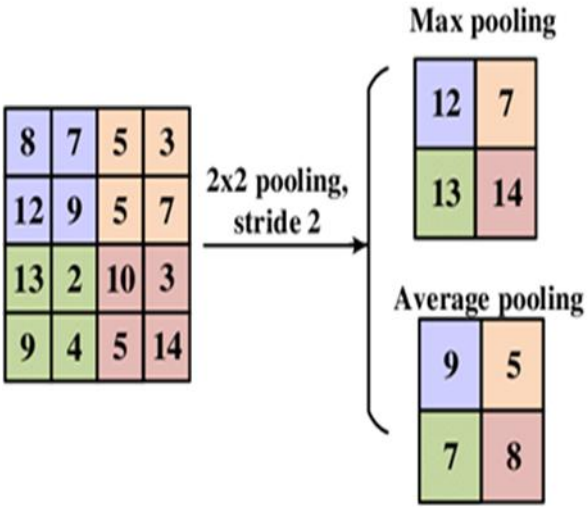
Figure 2: A photo of the model's visual representation of Resnet, Mobilenet, VGG16 and Inception



Source: https://www.researchgate.net/

This is analysed using Google Collab which allows anybody to write and execute arbitrary python code through the browser. Keras platform implemented together with the Tensorflow as the backend in coding the system. The CNN models start with convolutional layers, which apply filters to the input image to detect specific features like edges, textures, or patterns. These layers then apply an activation function to introduce non-linearity, helping these models to learn complex patterns and relationships in the data. Pooling layers follow convolutional layers to down sample feature maps while retaining important information. Common pooling operations include max pooling and average pooling, extracting the most significant features from each feature map.

Figure 3: A photo of Pooling layer operation

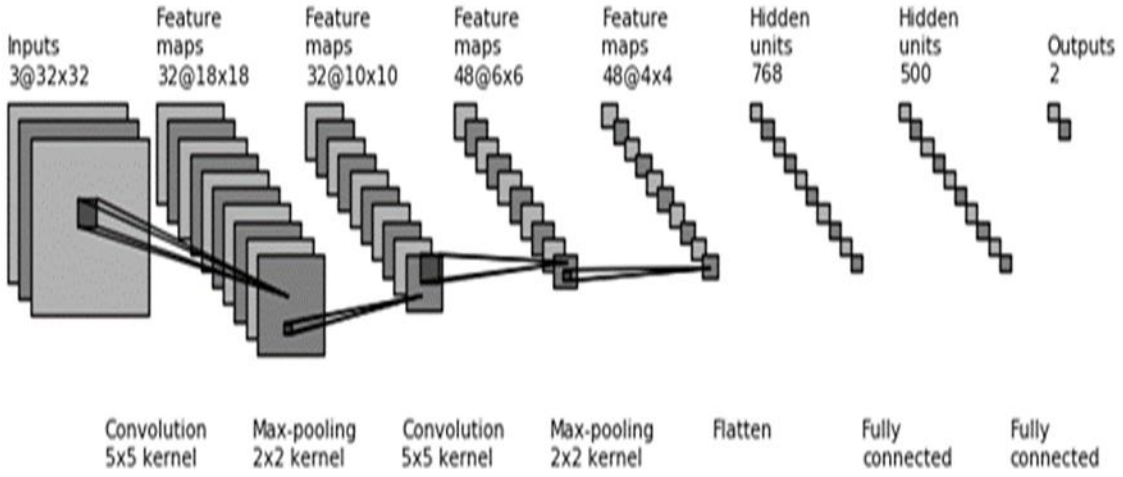


Source: https://www.researchgate.net/figure/Pooling-layer-operation-oproaches-1-Pooling-layers-For-the-function-of-decreasing-the_fig4_340812216 in 2020.

Finally, these models often end with fully connected layers, connecting every neuron in one layer to every neuron in the next, enabling high-level feature learning and classification. The output of the last fully connected layer is usually fed into a softmax activation function for classification tasks, producing probability distributions over different classes.

The models are trained using supervised learning, where labeled images are used to adjust the network's parameters through optimisation algorithms like stochastic gradient descent (SGD). During training, the network learns to minimise a loss function, which is then computed using backpropagation to update the parameters in the direction that minimises the loss, improving the model's performance. The process of convolution, pooling, and fully connected layers helps CNN models to learn hierarchical representations of features in the input images. Lower layers detect simple features like edges and textures, while higher layers detect more complex features and patterns, eventually enabling the network to classify objects in the images.

Figure 4: A photo of Backpropagation



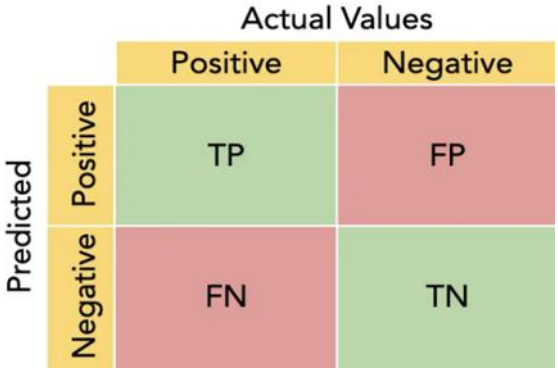
Source: https://www.jefkine.com/general/2016/09/05/backpropagation-in-convolutional-neural-networks/ in Sept. 2016

In order to interpret and to represent the results of each trained CNN model, the library of the matplotlib was implemented in order to create and to programme a visual representation to analyse the results of the trained models. The Line plot and confusion matrix is distinguished as essential statistical methods. In this study, the line plot is utilised in this study since it is a graphical tool commonly used in research and data analysis to represent quantitative trends, comparisons, or changes over a defined range, such as time, iterations, or other sequential measures. The data points, typically plotted as markers, are connected by straight lines to emphasise continuity and the progression of values within the dataset. The line plot serves to illustrate the performance of three machine learning models—ResNet50, MobileNet, and Inception V3—in terms of accuracy across successive iterations. The x-axis represents the number of iterations, which can be understood as training epochs or evaluation cycles, while the y-axis indicates the models' accuracy as a percentage. By connecting data points across iterations, the line plot effectively visualises the dynamic behavior of the models, highlighting their learning trajectories and comparative performances.

Furthermore, the model's classification results are clearly broken down by the confusion matrix, which highlights the model's strengths and weaknesses in relation to different traffic

sign classes. By computing statistical measures like True Positives (TP), True Negatives (TN), False Positives (FP), and False Negatives (FN), one can assess how good a categorisation system is. These metrics develop collectively to generate the Confusion Matrix, as illustrated in Figure #. By collecting the number of instances of TP, TN, FP, and FN in the dataset, this matrix supports understanding how well the model performs (M. and P., 2016). By the help of the confusion matrix, accuracy can be measured by the overall correctness of the model's predictions. It is calculated with the following formula: $Accuracy = \frac{tp+tn}{tp+fp+fn+tn}$

Figure 5: A photo of a Confusion matrix



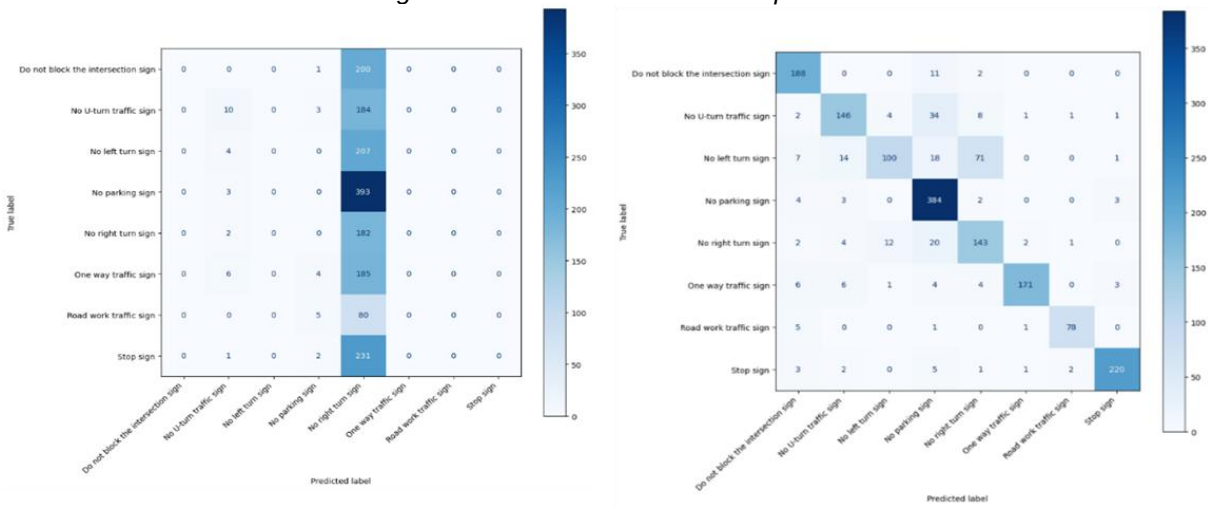
Source: https://yassineelkhal.medium.com/confusion-matrix-auc-and-roc-curve-and-gini-clearly-explained-221788618eb2 in March 2021

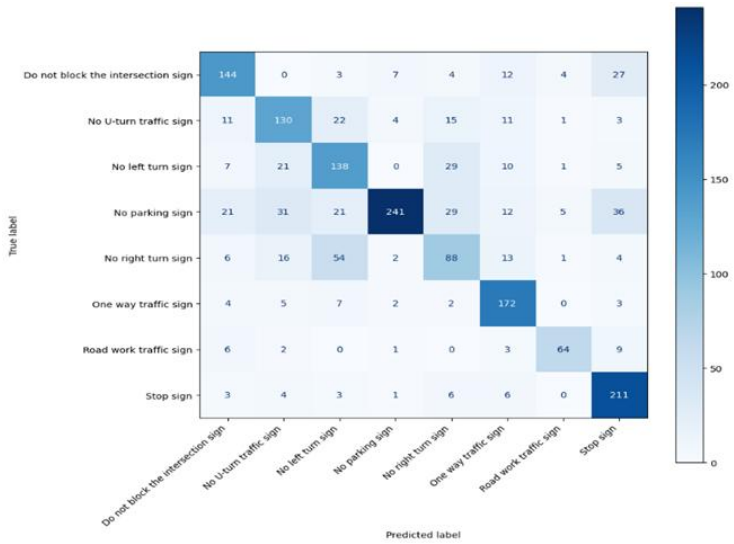
Other than the confusion matrix, the researchers used measurements that may be used to evaluate how well the signages are recognised across different traffic sign classes, with a primary focus on positive examples of precision, recall, and F-score. Recall quantifies the ratio of accurately recognised signages (true positives) to signages that were missed (false negatives). Precision measures the proportion of real positives to false positives, or signages that were incorrectly classified as positives. The F1-score ranges from 0 to 1, a value approaching 1 implies greater model performance (Zhou et al., 2020).

Confusion matrix:

Figures 6 to 8 showed the confusion matrices of different models. By applying the formula given, this determines the accuracy of each model by simple using the confusion matrix.

Figure 8: Confusion Matrix of Inception

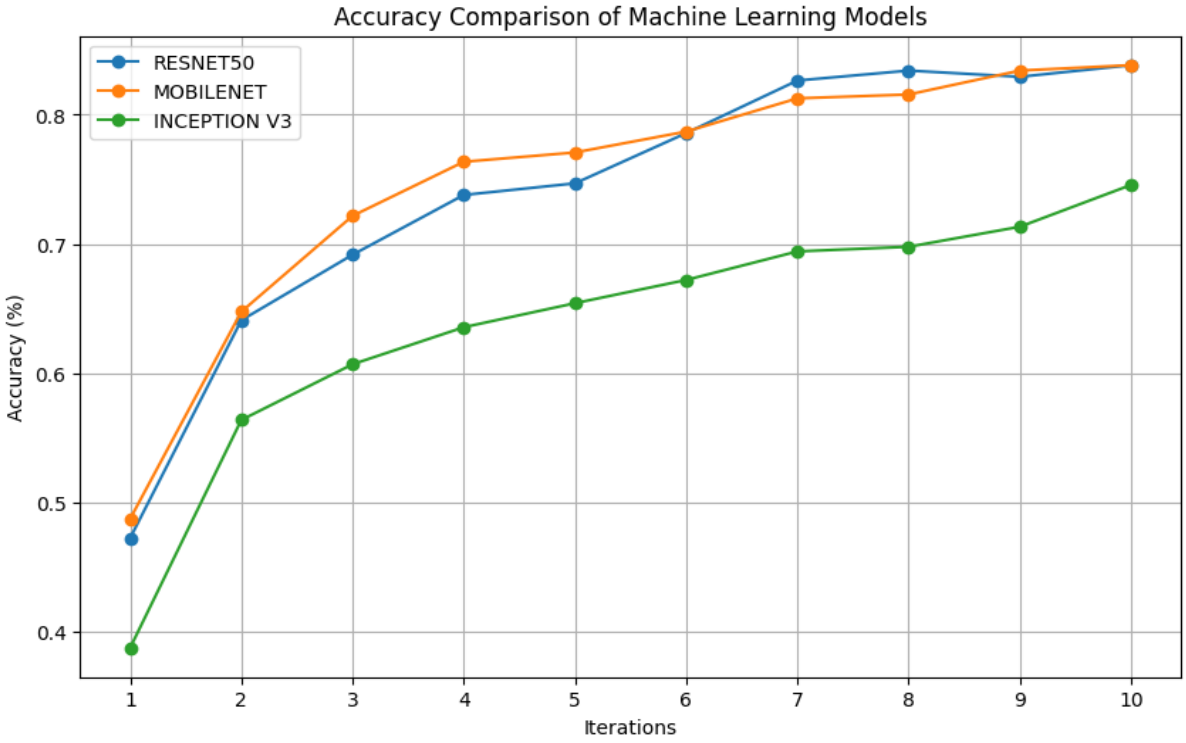




The Line Plot Accuracy Comparison:

Figure 9 shows the Accuracy Comparison of Machine learning models using Line plot diagram

Figure 9: The Line plot Accuracy Comparison



The line plot illustrates the accuracy trends of three machine learning models—MobileNet, ResNet50, and Inception V3—over ten iterations, providing a comparative analysis of their performance. MobileNet demonstrates the fastest improvement, quickly achieving high accuracy within the first three iterations and stabilising at around 85% by the 6th iteration. This rapid convergence suggests that MobileNet is highly efficient and well-suited for the given task, making it the top-performing model in this comparison.

ResNet50 follows a steady improvement trajectory, starting with moderate accuracy and gradually increasing over the iterations. By the 7th iteration, it converges to a performance level

comparable to MobileNet, achieving an accuracy of around 80-85%. Although it converges slightly slower than MobileNet, ResNet50 still exhibits strong learning potential, proving itself as a reliable and effective model.

In contrast, Inception V3 begins with the lowest accuracy, starting at approximately 40%. Its rate of improvement is more gradual compared to the other two models, reflecting slower learning progress. Nevertheless, Inception V3 consistently improves over time, reaching an accuracy of about 70% by the 10th iteration. While it does not match the performance of MobileNet orResNet50, its steady upward trend indicates potential for further optimisation.

Overall, MobileNet outperforms the other two models in terms of both accuracy and convergence speed, while ResNet50 offers competitive performance with slower convergence. Inception V3, despite lagging behind, demonstrates consistent improvement, making it a viable option with potential for refinement. This analysis highlights the importance of evaluating model efficiency and adaptability when selecting architectures for machine learning tasks.

F1 score, precision, and Recall:

Tables 2 - 4 utilised F1 score, Precision and recall which is crucial for ensuring robust performance across various classes. The analysis of ResNet, Inception V3, and MobileNet provides insights into their strengths and weaknesses when classifying traffic signs.

Table 2: F1 score, precision and recall for mobilenet

Class	Precision	Recall	F1- Score
Do not block the intersection sign	0.866359	0.935323	0.899522
No U-turn traffic sign	0.834286	0.741117	0.784946
No left turn sign	0.854701	0.473934	0.609756
No parking sign	0.805031	0.969697	0.879725
No right turn sign	0.619048	0.777174	0.689157
One way traffic sign	0.971591	0.876923	0.921833
Road work traffic sign	0.951220	0.917647	0.934132
Stop sign	0.964912	0.940171	0.952381

Table 3: F1 score, precision and recall for inception V3

Class	Precision	Recall	F1 - score
Do not block the intersection sign	0.712871	0.716418	0.714640
No U-turn traffic sign	0.622010	0.659898	0.640394
No left turn sign	0.556452	0.654028	0.601307
No parking sign	0.934109	0.608586	0.737003
No right turn sign	0.508671	0.478261	0.492997
One way traffic sign	0.719665	0.882051	0.792627
Road work traffic sign	0.842105	0.752941	0.795031
Stop sign	0.708054	0.901709	0.793233

Table 4: F1 score, precision and recall for Resnet

Class	Precision	Recall	F1 - score
Do not block the intersection sign	Undefined	0	Undefined
No U-turn traffic sign	1.0	0.05	0.095
No left turn sign	1.0	0.019	0.037
No parking sign	1.0	0.992	0.996
No right turn sign	1.0	0.989	0.994
One way traffic sign	1.0	0.949	0.974
Road work traffic sign	1.0	0.941	0.97
Stop sign	1.0	0.987	0.993

ResNet demonstrated extremely high precision across all classes except for the "Do not block the intersection sign," where it failed entirely (undefined precision and recall of 0). This indicates that the model was unable to correctly identify any instances of this class. For other classes, precision remained perfect (1.0), but the recall varied significantly. For instance, recall values for the "No U-turn traffic sign" and "No left turn sign" were very low (0.05 and 0.019, respectively), resulting in F1 scores of 0.095 and 0.037. On the other hand, ResNet excelled in detecting "No parking sign," "No right turn sign," and other signs with recall values close to or above 0.9, leading to near-perfect F1 scores for these categories. Overall, ResNet's performance indicates a tendency to overemphasise precision at the cost of recall, which may lead to significant issues in detecting rare or underrepresented classes.

Inception V3 showcased a more balanced approach compared to ResNet, with moderate precision and recall values across most classes. While its precision and recall were lower than ResNet's for well-detected classes, such as the "No parking sign," the model achieved relatively consistent results for challenging classes like the "Do not block the intersection sign" (precision: 0.71, recall: 0.72, F1: 0.71). However, its performance on "No right turn sign" (F1 score of 0.49) and "No left turn sign" (F1 score of 0.60) highlighted room for improvement. Despite these shortcomings, Inception V3 demonstrated a more reliable tradeoff between precision and recall, as reflected by its more consistent F1 scores across classes, ranging from 0.49 to 0.79.

Among the three models, MobileNet delivered the most balanced performance, particularly excelling in the "Do not block the intersection sign" class (F1 score of 0.90). MobileNet's precision and recall metrics were relatively high and consistent across classes, such as the "Stop sign" (precision: 0.96, recall: 0.94, F1: 0.95) and "Road work traffic sign" (precision: 0.95, recall: 0.91, F1: 0.93). However, it faced challenges in detecting "No right turn sign" (F1 score: 0.68) and "No left turn sign" (F1 score: 0.61), where recall values were notably lower. MobileNet's performance highlights its robustness and adaptability, as it achieved the best overall F1 score average, showcasing its capability to balance precision and recall more effectively than ResNet and Inception V3.

When comparing the models, it is evident that ResNet prioritises precision at the expense of recall, making it unsuitable for detecting underrepresented or rare traffic signs. While Inception V3 provides a more balanced tradeoff, its performance on critical classes is inconsistent, which could affect its reliability in real-world applications. MobileNet, on the other hand, strikes an optimal balance, achieving competitive precision and recall for most classes, and emerges as the most well-rounded model in this comparison.

The analysis highlights that the choice of a model depends on the specific application requirements. For scenarios where false negatives are critical (e.g., autonomous driving

systems), MobileNet would be the preferred choice due to its superior recall and balanced F1 scores. However, if minimising false positives is more critical, a hybrid approach involving ResNet could be considered, albeit with careful tuning to improve its recall.

Weight Size, Loading time and Test Accuracy:

The highest performing model is the MobileNet1 with an accuracy of 77.71% and a weight size of 87.27MB which has the highest accuracy and least size in terms of weights among the models.

Table 5: Evaluation of each Models by its Weight Size, Loading Time, Test Accuracy and Loss

Models	Weight Size (MB)	Loading Time (Minutes)	Test Accuracy (%)	Loss
Resnet50	107.67	72.2	10.91	2.8165
Mobile Net	87.27	41.9	77.71	0.5926
InceptionV3	143.7	100.2	76.06	0.6620

The evaluation of ResNet50, MobileNet, and Inception V3 based on weight size, loading time, test accuracy, and loss highlights significant differences in their performance and efficiency. Among the three models, MobileNet emerges as the most efficient and effective option. It achieves the highest test accuracy of 77.71%, paired with the smallest weight size (87.27 MB) and the shortest loading time (41.9 minutes). Its low loss value (0.5926) further underscores its ability to generalise well, making it an ideal choice for applications where computational efficiency and high accuracy are critical, especially in resource-constrained environments.

Inception V3 demonstrates competitive performance with a test accuracy of 76.06%, close to MobileNet's, but its efficiency is hindered by its large weight size (143.7 MB) and the longest loading time (100.2 minutes). While the model shows promise in terms of accuracy, its higher loss value (0.6620) compared to MobileNet and its substantial resource demands make it less practical for scenarios requiring rapid deployment or minimal hardware requirements. It may still be suitable for tasks where accuracy is prioritised over computational constraints.

ResNet50, however, underperforms significantly in this evaluation. With a test accuracy of only 10.91% and a very high loss value (2.8165), the model struggles to generalise effectively for the given dataset or task. While its weight size (107.67 MB) and loading time (72.2 minutes) are moderate compared to Inception V3, its poor accuracy renders it an impractical choice without substantial tuning or adaptation to the problem.

Overall, the findings highlight the superior balance offered by MobileNet, which achieves the best performance with the lowest computational cost. Inception V3 can be considered as an alternative if the task prioritises accuracy over efficiency, while ResNet50 appears unsuitable without further optimisation. These results emphasise the importance of evaluating models not just on accuracy but also on resource efficiency and practical deployability, particularly in real-world applications.

4. Conclusion

The study used CNN models to classify various traffic sign images. CNN models may make it simple to classify an image of a traffic sign because they employ artificial intelligence to do it. As we can see from the results, Mobile Net is the best model for classifying traffic signs. Further investigation is suggested before using this backend programme in a real-life application.

The comparative evaluation of CNN architectures—MobileNet, ResNet50, and InceptionV3—showed that MobileNet is the most efficient and effective model for classifying images of traffic signs. MobileNet excelled over other models in computational efficiency and classification accuracy, boasting the highest test accuracy (77.71%), the smallest weight size (87.27 MB), and the quickest loading time (41.9 minutes). It also showed a well-rounded performance regarding precision, recall, and F1-score, which makes it appropriate for practical use cases where resource limitations and accuracy are vital.

ResNet50 focused on precision but faced challenges with recall and accuracy, making it less effective for classifying traffic signs unless optimised further. InceptionV3, although attaining a competitive accuracy of 76.06%, demanded considerably greater computational resources, rendering it less feasible for environments with limited resources.

This research emphasises the capabilities of CNN models, especially MobileNet, in advancing traffic sign recognition systems, aiding in better road safety and effective navigation. Future studies ought to investigate practical testing, incorporation with advanced technologies such as self-driving cars, and enhancement for identifying underrepresented or difficult traffic sign categories.

References

Boesch, G. (2024, March 12). VGG Very Deep Convolutional Networks (VGGNet) – What you need to know. *viso.ai*. https://viso. ai/deep-learning/vgg-very-deep-convolutional-networks

Cao, J., Zhang, J., & Jin, X. (2021). A traffic-sign detection algorithm based on improved sparse r-cnn. *IEEE Access*, 9, 122774-122788.

Deep AI. (2020, June 25). Inception Module. *DeepAI*. https://deepai.org/machine-learning-glossary-and-terms/inception-module

Geeks for Geeks. (2023, January 10). Residual Networks (ResNet) Deep learning. *Geeks for Geeks.*

He, Z., Nan, F., Li, X., Lee, S. J., & Yang, Y. (2020). Traffic sign recognition by combining global and local features based on semi-supervised classification. *IET Intelligent Transport Systems, 14*(5), 323-330. https://doi.org/10.1049/iet-its.2019.0409

Kim, C. (2019, September 19). Car accidents in the Philippines: causes, facts & latest statistics. *philkotse.com*. https://philkotse.com/safe-driving/road-accidents-in-the-philippines-causes-facts-latest-statistics-5455

Kondamari, P.S. & Itha, A. (2021). A deep learning application for traffic sign classification. [Thesis]. *Faculty of Computing, Blekinge Institute of Technology*. https://www.diva portal.org/smash/get/diva2:1575390/FULLTEXT02.pdf

LeCun, Y., Bengio, Y., & Hinton, G. E. (2015). Deep learning. *nature*, 521(7553), 436-444. https://doi.org/10.1038/nature14539

Luo, H., Yang, Y., Tong, B., Wu, F., & Fan, B. (2017). Traffic sign recognition using a multi task convolutional neural network. *IEEE Transactions on Intelligent Transportation Systems, 19*(4), 1100-1111.

Megalingam, R. K., Thanigundala, K., Musani, S. R., Nidamanuru, H., & Gadde, L. (2023). Indian traffic sign detection and recognition using deep learning. *International Journal of Transportation Science and Technology, 12*(3), 683-699. https://doi.org/10.1016/j.ijtst.2022.06.002

Ren, X., Guo, H., Li, S., Wang, S., & Li, J. (2017). A novel image classification method with CNN-XGBoost model. *Lecture Notes in Computer Science, 10431,* 378–390. https://doi.org/10.1007/978-3-319-64185-0_28

Stallkamp, J., Schlipsing, M., Salmen, J., & Igel, C. (2016). Man vs. computer: Benchmarking machine learning algorithms for traffic sign recognition. *Neural networks*, 32, 323-332.

Team, K., (n.d.). Keras documentation: MobileNet, MobileNetV2, and MobileNetV3.

World Health Organization: (2023, December 13). Road traffic injuries. *World Health Organization.* https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries

Zhou, X., Lu, P., Zheng, Z., Tolliver, D., & Keramati, A. (2020). Accident prediction accuracy assessment for highway-rail grade crossings using random forest algorithm compared with decision tree. *Reliability Engineering & System Safety, 200,* 106931.

L-PRICE: UTILISING LINEAR PROGRAMMING IN OPTIMISING RICE (ORYZA SATIVA) PROFIT THROUGH PRODUCTION COST AND RETURN IN CENTRAL LUZON

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ABSTRACT

The contribution of the agricultural sector to the Philippine Gross Domestic Product has declined due to rising costs of fuel, pesticides, seeds, and equipment. Despite an increase in rice production in Central Luzon in 2023, provinces like Aurora, Bataan, Bulacan, and Tarlac experienced production decreases of 35.9%, 2.4%, 5.6%, and 1.3% (Tecson, 2023). This study aims to develop an optimal solution for maximising rice profits in Central Luzon while minimising production costs, using 2022 data from the Philippine Statistical Authority and linear programming. Production costs were categorised into cash, non-cash, and imputed, focusing on rainfed and irrigated palay. The optimal solution is modelled by the objective function $z=21{,}054x_1 + 25{,}063x_2$, where x_1 and x_2 correspond to rainfed and irrigated palay. Based on assumptions of proportionality, additivity, certainty, divisibility, and non-negative variables, the objective function is subject to the constraints cash, non-cash, imputed cost and yield per hectare. Applying Gauss computation, the optimal solution for x_1 and x_2 was 0 and 1.865683, respectively. These values were substituted into the inequalities showing it minimises palay production costs while maximising profit. Through sensitivity analysis, the cost of x_1 can vary between negative infinity and 21,696.61, and x_2 between 24,320.69 and positive infinity. Constraint1 is fully utilised, with a dual value of 0.67, showing 1-unit increase in its RHS raises the objective function by 0.67. Constraints 2, 3, and 4 are non-binding, with slack and dual values of 0, indicating changes to RHS within the range of the objective function. The results indicate that irrigated palay must be the focus of resources, with 186.5683% increase production cost, net profit, and yield per hectare. Validation using QM for Windows and evaluation metrics (MAE=0.03, MAPE=0.03, RMSE=3.33) confirmed the solution accuracy. The results demonstrate an effective model that minimises rice production costs while maximising profits in Central Luzon.

Keywords: Linear Programming, Optimisation, Profit, and Simplex Method.

1. Introduction

The Philippines remains one of the world's top rice producers, producing 19.76 million tonnes in 2022 (Statista Research Department, 2023). Rice cultivation employs 10 million Filipino farmers and roughly 100 million Filipinos who rely on rice as their primary source of sustenance (Dejaresco, 2019). Rice is an important crop in Filipino culture and daily life. As a result, rice is grown in every farming region in the Philippines because it is one of the most essential crops in the country. Central Luzon remained the highest rice producer among the regions, accounting for 19.8 per cent of total palay output (Philippine Statistics Authority, 2020). Although the rice production of Central Luzon in 2023 was higher compared to the year

2022 in Aurora, Bataan, Bulacan, and Tarlac rice production decreased by 35.9 per cent, 2.4 per cent, 5.6 per cent, and 1.3 per cent, respectively (Tecson, 2023).

The Philippine economic performance is determined by the year-on-year increase in Gross Domestic Product, which quantifies the output of goods and services over an accounting period of the country. However, the contribution of the agricultural sector to the GDP in the Philippines has declined in recent years and is now at 8.5% (Redaktion, 2022).Though agriculture is the primary generator of the economy in rural areas where a large proportion of Filipinos live, it is vital for inclusive economic growth. According to Bantay Bigas estimation, rice farmers suffered a P206 billion loss in income as a result of the rice crisis and imported rice (Chi, 2023). As a result, rice farmers have yet to recoup the significant income loss caused by rising fuel prices, which increased the cost of pesticides, seeds, and other farming essentials. Thus, making them not only lose money but also have their purchasing power weakened. Last year, the average palay production cost in the Philippines reached a seven-year high, outpacing the growth in palay overall costs of farmers, which inched up by 1.57 % on an annual basis (Arcalas, 2023).

The Department of Agriculture has developed the Philippine Rice Industry Roadmap 2030 (PRIR 2030) to address the challenges in rice production and ensure its long-term security. This roadmap outlines key strategies aimed at increasing yields, reducing production costs, enhancing resilience to disasters and climate risks, and ensuring the safety and nutritional quality of rice. The implementation of PRIR 2030 is divided into three phases: improving competitiveness, enhancing resilience to climate-related risks and disasters, and ensuring access to safe and nutritious rice. In relation to this study, the goal of the improving competitiveness phase is to increase rice yields and lower production costs from current levels to improve the efficiency and sustainability of rice production across the country. However, uncertainties such as climate change, unavailability of resources, and irrigation, risk management plays an important role in achieving the PRIR 2030 goals. Through this study, key constraints are identified, and flexibility of resources is taken into account, which in turn allow the Department of Agriculture to come up with data-driven decisions, some of which are, developing plans and prioritising proper resource allocation. Overall, apart from the optimal solution serving as a foundation for planning, it also addresses the risks, and enhances the resilience and sustainability of rice production in Central Luzon.

Linear programming is a mathematical modelling approach that maximises or minimises a linear function while considering various constraints. This technique has proven effective in directing quantitative judgements in multiple domains, including business planning, industrial engineering, and, to a lesser extent, social and physical sciences (Vedatu, 2023). Linear programming, often known as linear optimisation, is a strategy for reaching the best feasible result in a mathematical model where linear connections give the criteria (Avcontentteam, 2023). It entails determining the best solution to a problem with linear relationships between the choice factors and the constraints. This strategy has applications in a wide range of sectors and fields, from production planning to logistics optimisation, and it is a powerful tool for making data-driven decisions that can lead to increased efficiency and cost savings (Kashyap, 2023).

Linear programming was applied in Ethiopia in the rural areas to propose a crop management plan in which researchers examined the structure of existing crops and calculated their irrigation needs, fertilisation requirements, and working hours to calculate the optimal solution that would make the best use of available resources and increase crop yield (Fytilis, 2022). The simplex linear technique is an efficient method since it does not compute the value of the objective function at every point and performs well for most optimisation problems when compared to Karmarkar algorithm (Sekhon and Bloom, 2022). The simplex linear technique is particularly useful in optimising problems in the agriculture sector in various areas given that

it can optimise the net income of farm and productivity under available resources such as cultivated acreage, labour, fertilisers, seeds, water supply, energy, and so on (Alotaibi, 2021).

This study primarily aimed to evaluate the effectiveness of the generated optimal solution to optimise rice profit through production cost and return in Central Luzon compared to the unoptimised net return rice production dates from 2022.

2. Methodology

Phase 1 - Gathering of Materials

In this study, the researchers utilised the annual average production cost of rice in Central Luzon from the database of the Philippine Statistics Authority (PSA). In the development of the linear programming model and for the validation process the researchers utilised the latest data from the PSA which is from the year 2022. The researchers utilised the QM for Windows for the mathematical analysis and graphing of the equations and Microsoft Excel to organise the data.

Phase 2 - Actual Experimentation

2.1 Classification and Organisation of Data

The data obtained from the database of the PSA was divided into two kinds of palay, mainly rainfed and irrigated. The researchers also included data on the average production cost of rainfed and irrigated palay. Using Microsoft Excel, the annual average production cost of different types of rice was categorised into three cost classifications: Cash Cost, Non-Cash Cost, and Imputed Cost. The cash cost pertains to direct cash expenditures or cash payments for utilising various manufacturing elements (Tuovila, 2021). This classification includes the costs of seed, fertiliser, pesticides, hired labour, caretaker/overseer's wages, land tax, rentals, transport cost of inputs, sacks and tying materials/needles, food expense, and repair cost. Moreover, this study included the non-cash cost of production. In contrast to cash cost, non-cash cost classification is a cost of doing business that 28 does not include paying cash and expenditures that are paid in kind (Nicole, 2024). The data used in this study under non-cash cost are seeds, the share of the harvester, and the share of the sheller. The last cost classification from the data acquired is the imputed cost. Imputed cost arises from using an asset rather than investing it or pursuing another course of action (Kenton, 2021), including seeds, operator labour, family labour, depreciation, interest on operating capital, rental value of owned land, and land tax.

2.2 Assumptions of Linear Programming Model

After classifying the datasets, the assumptions of the linear programming model were set. These are the parameters and the relation shown by the constraints and the objective function is linear. Considering that this study used the simplex method in solving the linear programming model, the researchers made the following implicit assumptions: proportionality, additivity, certainty, divisibility, and non-negative variables. These assumptions are the essential variables that were considered before solving the linear programming problem to ensure that the best alternative is selected.

2.2.1 Assumption of Proportionality

The contribution of the variables to the objective function and restrictions is proportionally tied to their worth. To put it another way, doubling a value of a variable doubles its contribution to the objective function and any restrictions in which it appears. Using this assumption in this study indicated that if production costs rise, implying that farmers use more seed, fertiliser, insecticides, and so on, overall yields rise as well, favourably affecting profit.

2.2.2 Assumption of Additivity

The term "additivity" refers to the notion that the individual contributions of each variable are combined to get the overall value of the objective function as well as each constraint function. The restrictions outlined in this study primarily include cash costs, non-cash costs, and imputed costs, which represent the total costs of all necessary components involved in production under each cost classification.

2.2.3 Assumption of Certainty

The parameter values of the model are considered to be known with or, at the very least, to be treated as such. The discovered optimal solution is ideal for the specific challenge at hand. If the parameter values are incorrect, the solution given is of limited utility. The unit of measurement for the objective function and constraints in this study is the Philippine peso per kilogram of palay yields in one hectare.

2.2.4 Assumption of Divisibility

The assumption of divisibility in linear programming dictates that the solution obtained must be in whole numbers (integers). The researchers assumed that the decision variable may have any value, even non-integer values, provided that the functional and non-negativity conditions are satisfied. Within a range determined by the constraints, the decision variables may take on any real numerical values. In other words, integer values are not required for the variables.

2.2.5 Assumption of Non-negative Variable

In this study, all outcomes or variables must satisfy the linear programming premise that they are all non-negative. This assumption applies in the sense that physical quantities cannot have negative values. It is impossible for a production issue, specifically rice production, to have a negative output.

2.3 Model Formulation

2.3.1 Identification of Decision Variable

The decision variables are the unidentified elements of the problem statement that must be identified to be solved. A crucial component of creating a linear optimisation model is properly defining decision variables. The decision variables in this study are the rainfed and irrigated palay. In this study, the decision variables were represented as x_1 and x_2 whereas, x_1 is defined as the rainfed palay and x_2 is the irrigated palay.

2.3.2 Formulation of Objective Function

The desired problem statement, which reveals the decision-maker's primary objective, serves as the objective function. Furthermore, it is important to precisely establish the relationships between the objective and decision factors. It should be emphasised that the function is not permitted to contain any nonlinear elements, such as exponentials, variables with roots, products, or divisions of variables. Only the linear sum or difference of all variables is required. The objective function used in this study is the net profit of Central Luzon from the total palay yield in each type. The objective function was represented as Maximise $z = ax_1 + ax_2$.

2.3.3 Formulation of Constraints

Constraints provide the conditions that the desired problem must satisfy and can take the form of equalities (=) or inequalities (≤, ≥). In this study, the limitations utilised are the cost classification in the data collected and the overall yield of palay per hectare of each kind. This study specifically used four restrictions, including cash cost, non-cash cost, imputed cost, and kilograms of grain produced per acre.

2.3.4 Linear Programming Model Optimisation

Sensitivity analysis is a crucial part of the model optimisation phase. It focuses on learning more information about how the optimal solution behaves when the model's parameters are changed. When it is impossible to estimate the model’s parameters accurately, sensitivity analysis is essential. In these cases, it is vital to look at how the optimum solution performs when the parameter estimates are considered.

Considering that the main modelling method used in this study to achieve the goals is linear programming. To process the data that was collected and proceed to arrive at the best possible figure for the rice profit, the researchers used manual or traditional computation. To get a more precise and workable conclusion and reduce computation mistakes, the researchers also used "QM for Windows," a computer programme or application. The mathematical analysis provided by QM for Windows can be useful for operations management, quantitative techniques, or management science. The software was used to validate human computations for accuracy including the results of the sensitivity analysis.

2.4 Model Development

To help solve the optimisation problems, slack variables, tableaus, and pivot variables are used in the Simplex method. The Simplex method is a method for manually resolving linear programming models and makes use of variables. An approach for attaining the best results was to use a linear programme, which uses a maximum or minimum equation with linear constraints.

Phase 3 - Evaluation Metrics

The comparison of the previous data and the data of the model is a common method of validation utilised in this study. It is considered valid if the model reasonably presents a lower value compared to the original data. Using Microsoft Excel, the Mean Absolute Error, Mean Absolute Percentage Error, Root Mean Square Error of both values were calculated.

3.1 Mean Absolute Error (MAE)

The Mean Absolute Error (MAE) measured the average difference between significant figures and forecasted quantities of the same dataset. It follows the formula shown in equation 1;

wherein n is the amount of data points and y_i is the ground truth value for the i^{th} image. The lower the MAE of the model or result, the better performance it has.

3.2 Mean Absolute Percentage Error

The Mean Absolute Percentage Error (MAPE) is a metrics commonly used for validating the model, where positive and negative values do not offset each other. The MAPE is found by the formula shown in formula 2; wherein n represents the total number of observations, a represents the actual data, and b represents the forecasted data. The MAPE was applied by subtracting computed data from the actual data and dividing by the actual data. The absolute value of all data pairs was summed up and multiplied by 100 percent.

3.3 Root Mean Squared Error

The Root Mean Square Error (RMSE) was used as a statistical analysis for forecasted outcomes. It uses a similar methodology to the Mean Squared Error (MSE), but it applies a different idea for calculating the values' square roots (Singla et al., 2022). The RMSE was calculated through the formula shown in Equation 3; wherein N represents the total number of observations, x_i is the obtained outcome, and y actual is the actual data. The RMSE was applied by squaring the difference of paired data, being the obtained data and the actual data, and summing all data pairs up so that it can be divided by the total number of observations. Afterward, the result was square-rooted to get the final RMSE metrics.

3. Results and Discussion

This chapter discussed the effectiveness of utilising linear programming to find optimised solutions, specifically, the maximisation of rice profit in Central Luzon through production cost and return for the betterment of government allocations. The assumptions and iterations done in the simplex tableau to the data based on the Public Statistics Authority (PSA), which was segregated by the PSA through a survey and determining whether the palay is irrigated if the area has irrigation facilities supplying water through artificial means like gravity, force/power, pump, etc. Rainfed if the Palay grown on this ecosystem has dikes that retain water and is solely dependent upon rainfall for its water supply. The result from the combination of four government organisations, namely the National Statistical Coordination Board (NSCB), the National Statistics Office (NSO), the Bureau of Labor and Employment Statistics (BLES) of the Department of Labor and Employment (DOLE), and the Bureau of Agricultural Statistics (BAS) of the Department of Agriculture (DA), showed the pivotal role in defining the variables, constraints, and objectives of the model, which provided a realistic framework for the optimisation. The identification of the effects of the developed optimal solution to rice production in terms of cash cost, non-cash cost, and imputed cost done by the researchers was critical in addressing challenges and was crucial to ensure the efficiency of linear programming and the simplex method. Furthermore, this chapter presents the accuracy of the computations by using the three evaluation metrics tests: mean absolute error (MAE), mean absolute percentage error (MAPE), and root mean squared error (RMSE). and the simplex method. Furthermore, this chapter presents the accuracy of the computations by using the three evaluation metrics tests: mean absolute error (MAE), mean absolute percentage error (MAPE), and root mean squared error (RMSE).

Table 1: Portion Of The Palay Production Cost And Return Data From PSA.

Costs Classification	Irrigated	Rainfed
	Total production Cost and Return in PhP	
Cash Costs	37,404	32,380
Non-Cash Costs	8,766	7,864
Imputed Costs	14,979	14,807

Table 1 illustrates the production cost and return of palay in Central Luzon in the year 2022 provided by PSA. The data given by the PSA also includes irrigated palay, non-irrigated palay, as well as the cash cost, non-cash cost, and imputed cost of the palay. The information given by the PSA was gathered from the rice fields of Central Luzon, namely Aurora, Bataan, Bulacan, Nueva Ecija, Pampanga, Tarlac, and Zambales.

Table 2: Starting Iteration: The Simplex Tableau

Basic	z	x_1	x_2	s_1	s_2	s_3	s_4	Solution
z	1	-21,054	-25, 063	0	0	0	0	0
s_1	0	32,380	37,404	1	0	0	0	69,784
s_2	0	7,864	8,766	0	1	0	0	16,630
s_3	0	14,807	14,979	0	0	1	0	29,786
s_4	0	55,052	61,150	0	0	0	1	116,202

Table 2 is the initial iteration obtained by applying the simplex method, which is also referred to as the "Simplex Tableau." The values in the simplex tableau are derived from the study's established objective function and restrictions. At the start of each iteration, the solution is automatically provided by the simplex tableau arrangement. The beginning point is the origin [(x_1, x_2) = (0, 0)], which designates the non-basic variables as (x_1, x_2) and the fundamental variables as (s_1, s_2, s_3, s_4). By translating the inequalities from the constraints given in this study into equations with non-negative right-hand sides, the fundamental variables (s_1, s_2, s_3, s_4) are derived. An equation is created by adding a non-negative slack variable to the left side of the constraint in an inequality. After the objective function is equated to zero, the values in the z-row, or second row, of the table represent the coefficient of the objective function. Finally, the right-hand side of the equations in the model, which are presented easily by beginning at the origin, may be found in the rightmost column of the table, which is also the column containing the solution.

Table 3: Second Iteration using the Simplex Method

Basic	Entering	Solution	Ratio
s_1	37,404	69,784	x_2 = 69,784 / 37,404 = 1.865683 (minimum)
s_2	8,766	16,630	x_2 = 16,630 / 8,766 = 1.897102
s_3	14,979	29,786	x_2 = 29,786 / 14,979 = 1.988517
s_4	61,150	123,162	x_2= 123,162 / 61,150 = 1.900278

As the nonbasic variable with the greatest negative coefficient in the objective function, x_2 was entered in the second iteration, which is shown in table 3. The simplex feasibility condition was applied during this iteration. Similarly, the pivot column of the iteration with -25063 is the column of x_2. Conversely, the simplex optimality condition is used to determine the leaving variable in the iteration. When the simplex optimality criterion is applied, the pivot row or leaving variable is determined by dividing the solution by the pivot column coefficients; the ratio with the lowest non-zero value qualifies. Similarly, the pivot row in this iteration is the s_4, which has a ratio of 1.865683. Additionally, the table demonstrates that the pivot element was regarded as 37, 404, which is the intersection of the pivot row and pivot column.

Table 4: End Iteration: Optimal (Maximised) Solution Tableau using Simplex

Basic	z	x_1	x_2	s_1	s_2	s_3	s_4	Solution
z	1	642.61	0	0	0	0	0	46, 759.61
s_1	0	0.87	1	0	0	0	0	1.87
s_2	0	275.42	0	-0. 25	1	0	0	275.42
s_3	0	1,839.93	0	-0.4194	0	1	0	1,839.93
s_4	0	2,115.48	0	-1.71	0	0	1	2115.49

The maximised model or optimal solution for this study, which is regarded as the final iteration of the simplex method, is shown in table 4. The Gauss-Jordan computation, which consists of two approaches—one for the pivot row and another for all other rows, including the z-row—is required to produce the subsequent iteration. These calculations are made with reference to the previous tableau. First, the entering variable (x_2) will be replaced by the leaving variable (s_4) in the basic column. Second, the values of the current pivot row (0, 32380, 37404, 1, 0, 0, 69784) are divided by the pivot element, which is 37, 404, to determine the new pivot row. As a result, the values that are obtained for the new pivot row are (0, 0.865683, 1, 0.000028, 0, 0, 0, 1.865683). Subsequently, to complete the next iteration, all other rows including the z-row must be calculated by subtracting the product of new pivot row coefficients times the row's pivot column coefficients from the current row coefficient. Thus, the new z-row is replaced with the new values obtained which are (1, 643, 0, 0, 0, 0, 0, 46759.61303) and the same operation was done on the following rows.

The researchers then utilised QM for Windows to verify data and provide a visual representation of the obtained data. All of the gathered data was introduced to the programme, where all of the computations of each iteration were calculated again automatically; the results of the programme were the same as the results that were done manually which verified that the calculations of the researchers were correct. Then the programme provided a visual representation of the data, where it showed that the data produced was linear, which further verified the results generated by the researchers.

Table 5: Final Values for Optimal Solution

	x_1	x_2	Sum/Solution
Net Returns	21,054(0)	25,063(1.865683)	46,759.61
Cash Cost	32,380(0)	37,404(1.865683)	69,784.01
Non-Cash Cost	7,864(0)	8,766(1.865683)	16,354.58
Imputed Cost	12,807(0)	14,979(1.865683)	27,946.07
Yield Per Hectare	55,052(0)	61,150(1.865683)	114,086.52

In the process of optimisation, researchers identified the optimal solution for each constraint; Cash cost, Non-cash cost, Imputed cost, and Yield per hectare with values of $x_1 = 0$ and $x_2 = 1.865683$ from the minimum value of the second iteration. By substituting these values to the Gross returns, z = 21, 054(0) + 25063(1.865683), the optimal solution became the Php 46,759.61. The optimal solution acquired for each constraint is Php 69,784.01, Php 16,354.58, Php 27,946.07, and 114,086.52kg, respectively.

Figure 1: Linear programming results from QM for Windows V5

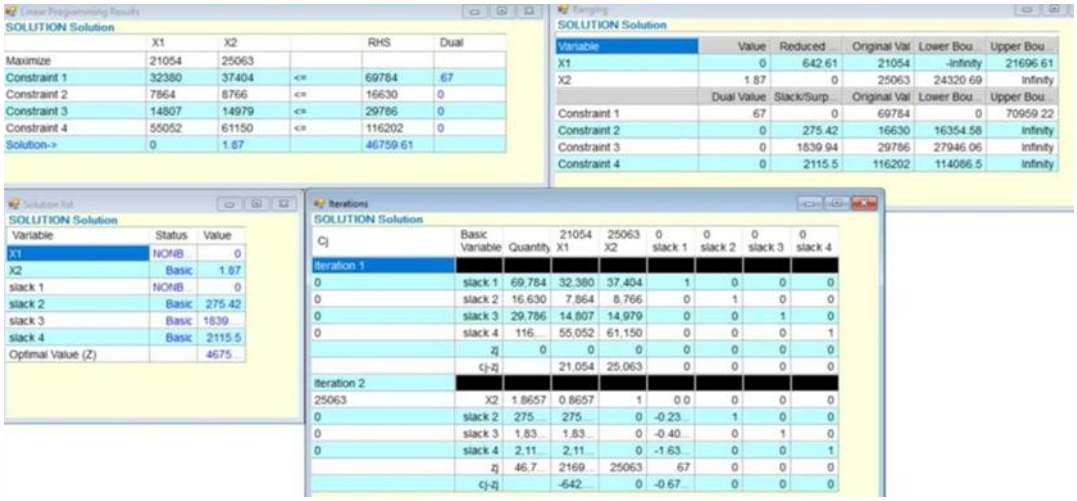

Figure 1 present results from QM Windows version 5. The maximum profit is found in the top-right corner of the table. or RHS (Right Hand Side), is 46,759.64. For the dual or shadow prices at the right of each constraint, the profit would increase by 0.67 for constraint 1. The information presented in Tab. 4 is the solutions' reduced cost, original objective value coefficient, and the lower and upper bounds (range) for the variables, and Tab. 5 is the steps taken during the simplex method for solving the problem. The values for the solution remain 0 and 0.87.

Figure 2: Graphical Linear Programming Solution from QM for Windows V5

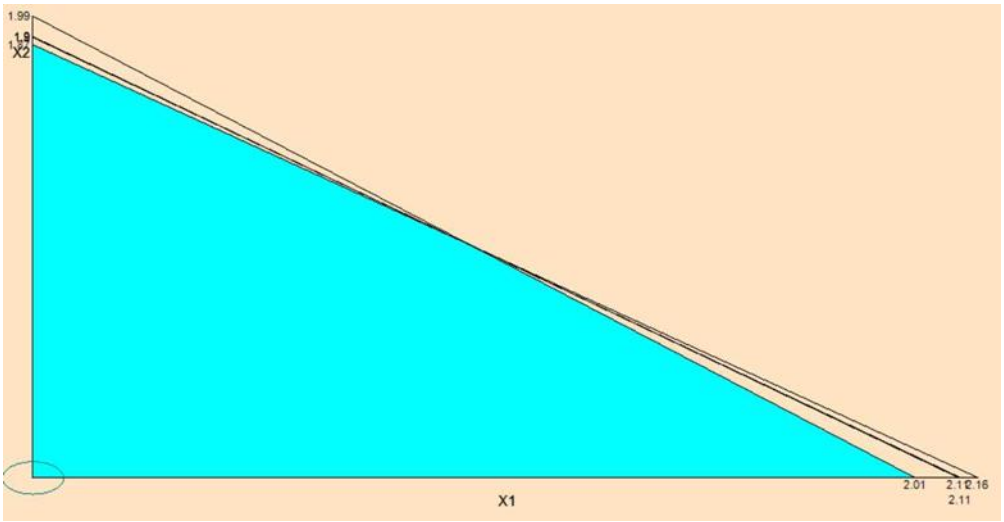

Figure 2 is a representation of the solution, wherein the rainfed palay and irrigated palay are represented by the horizontal axis (x_1) and the vertical axis (x_2), respectively. The diagonal lines on the graph depict the constraints given in the problem. The shaded region represents the feasible solution space, which is the overlap of the valid regions from each constraint line. In this graph, x_1 is equal to 0, and x_2 is equal to 1.87.

Table 6: Sensitivity Analysis of the Variable from QM for Windows V5

Kinds of Palay	Variable	Value	Reduced Cost	Original Value	Lower Bound	Upper Bound
Non-Irrigated	x_1	*0*	*642.61*	*21054*	*-Infinity*	*21696.61*
irrigated	x_2	*1.87*	*0*	*25063*	*24320. 69*	*Infinity*

Table 6 is the overall sensitivity analysis of the variables providing information on the optimal solution and its flexibility to changes in the objective function and constraints within the model. The optimal solution, (x_1) equates to 0, indicating that it does not contribute to the solution. The analysis reveals how changes in the profitability or costs associated with each type of palay (irrigated and non-irrigated) can influence the optimal solution. This information will help the government and the farmers assess the potential impact of market price fluctuations, changes in input costs, or policy interventions. Table 6 shows the reduced cost for non-irrigated palay (x1), which is not included in the current solution. If the profitability of non-irrigated palay can be increased to offset this reduced cost by at least 642.61, it could be part of the optimal solution. This provides a target for improvement strategies. Studies have consistently shown that irrigated palay farming is more productive than non-irrigated farming. In India, research was done to compare the irrigated and non-irrigated areas of farming practices and showed that irrigated farming areas contribute to a higher productivity and sustainability of rice farming (Rhondi et al., 2024). Additionally, a study analysing the impact of canal irrigation projects for smallholders highlighted that irrigation infrastructure significantly boosts farm productivity, particularly in rice cultivation (Bravo-Ureta et al., 2020). Recognising the benefits of irrigation, the Philippine government has undertaken various initiatives to enhance irrigation infrastructure. The National Irrigation Administration (NIA) has projected a need for approximately ₱220 billion per year to irrigate 1.2 million hectares of farmland, aiming to boost rice productivity and ensure food security (National Irrigation Administration, 2024). Furthermore in 2023, the DA and NIA collaborated to distribute 141 excavators worth ₱776 million to irrigator associations nationwide, enhancing the desilting and maintenance of irrigation canals, thereby improving water distribution efficiency and boosting rice productivity (Department of Agriculture, 2023). These initiatives aim to boost rice productivity, ensure food security, and improve the livelihoods of Filipino farmers by addressing the challenges associated with non-irrigated farming.

Table 7: *Sensitivity Analysis of the Constraints from QM for Windows V5*

Resources	Unit	Symbols	Lower Boundary	Current Value	Upper Boundary
Cash Cost	Php	s_1	0	69784	70959.22
Non-Cash Cost	Php	s_2	16354.58	16630	Infinity
Imputed Cost	Php	s_3	27947.06	29786	Infinity
Yield Per Hectare	Kg	s_4	114086.5	116202	Infinity

In table 7, constraint 1 is fully utilised as it binds with the optimal solution without the need for slack variables. With 0.67 being its dual value, it indicates increasing 1 unit to the right-hand side (RHS), the objective function will increase by 0.67. The RHS of Constraint 1 can vary between 69784 Php and 70959.22 Php without affecting the optimal solution or the dual value. This provides a range of flexibility in terms of cash availability. Moreover, the following

constraints such, as 2,3, and 4, are considered non-binding with each having a slack value of 275.42, 1839.94, and 2115.5, respectively. These constraints have a dual value of 0 which shows that fluctuations in non-cash costs, imputed costs or yield per hectare are currently not limiting the optimal solution.

Overall, the current optimal solution will continue to be valid if the objective function coefficients for the variables vary within their permitted ranges. However, changes outside of these ranges may cause the optimal solution to alter, resulting in recalculation to find new values for the decision variables. The availability of resources or production limits may also be impacted by changes in the RHS values of the constraints, which may alter the constraints' binding status and affect the dual values or shadow prices. In contrast, an increase in the RHS of a binding constraint may improve the objective function by the amount of the dual value per unit increase, while non-binding constraints with zero dual values will have no effect unless the RHS changes enough to make them binding.

Table 8: Validation of Each Value

Actual	QM	Difference	RMSE	MAE	MAPE
1.87	1.87	0	0.00333333	0.00333333	3.33333334
275.42	275.42	0			
1839.93	1839.93	0			
2115.49	2116.49	0			
46759.61	46759.61	0			
69784	69784	0			
27946.06	27946.07	-0.01			
114086.5	114086.5	0			
46759.61	46759.61	0			

Table 9: Difference of Each Value

Actual	Optimised	Difference
69,784	69,784.01	-0.01
16,630	16,354.58	275.42
29,786	27,946.07	1,839.93
116,202	114,086.52	2,115.48
46,117	46,759.61	-642.61

Table 8 represents the results of the evaluation metrics MAE, MAPE, and RMSE between the manual computation of data using the simplex method and the computation utilising QM for Windows. The obtained value for MAE and MAPE is 0, which concludes that there is no deviation between the two values indicating the model has made its calculations correctly. For RMSE, the obtained value is 0.03, which suggests that the values generated by the model are close to the actual value as the difference between predicted and actual values is small. The differences from the actual to the optimised data are -0.01, 275.42, 1839.93,2115.48, and -642.61. This means the optimised values provided a decrease in all aspects of cost classification and an increase in net returns. This implies that the obtained optimal solution optimises the rice profit in Central Luzon.

Additionally, the obtained optimised values could significantly benefit the PRIR 2030 in terms of their goal in competitiveness, particularly in reducing production costs and improving the

harvested yields. With an effective allocation of funds, the PRIR 2030 can adjust and strengthen farmer support programmes to meet the needed farming equipment and resources dictated by the optimal solution, reducing an unnecessary surplus of materials or increasing the lack of materials which leads to lowering production costs while improving yields. Moreover, in terms of market stability, optimising the budget allocation would reduce post-harvest losses while stabilising and maintaining rice prices, benefiting both the consumer and producer.

Most importantly, the sensitivity analysis emphasises the key risks and opportunities for handling various risks such as climate change, irrigation, and resource availability. With constraint 1(s1) representing the cash cost, wherein it is fully utilised, factors such as changes in cash cost due to inflation, increased prices, and many more may affect the plan based on the optimal solution. To mitigate the risk, the Department of Agriculture may allot subsidies and help the farmers to optimise certain resources such as fertilisers. By keeping constraint 1(s1) within its range through these assessments, it can be assured that financial resources are efficiently used, and the plan based on the optimal solution is still viable. Pre-emptive planning such as allocating emergency funds, utilising predictive data systems, and focusing on sustainable resource management, while still being guided by the proposed optimal solution, can reduce the effects of these uncertainties.

4. Conclusion

Over the past 10 years, Central Luzon has been recognised as the top rice producer in the Philippines. However, despite this recognition, some provinces have been recorded to have a lower rice production percentage compared to other provinces within this region. This is mainly due to lack of knowledge with regards to properly allocating the funds for resources to be used by farmers. Thus, there has been a need to find a method capable of assisting the government in allocating funds for resources that can also minimise expenditures and maximise profit. This study concludes by demonstrating the potential of linear programming as a reliable method for maximising rice profits in Central Luzon. The conducted research aimed to utilise linear programming and determine the optimal values to optimise rice profit in Central Luzon. To further understand the variables involved, the palay present in Central Luzon are irrigated and rainfed palay. Irrigated palay is the type of palay maintained with regular water pumps and artificial additives. On the other hand, rainfed palay relies solely on rainfall. The effect of the developed optimal solution has presented that resources should be solely allocated to irrigated palay and there must be a 1.87 increase in the 3 types of cost classification, which are cash cost, non-cash cost, and imputed cost. Furthermore, the rice farming operations in Central Luzon may become much more profitable and sustainable by utilising a linear programming systematic approach to decision-making, which integrates variables including production cost and constraints.

References

Alotaibi, A. and Nadeem, F. (2021). A review of applications of linear programming to optimize agricultural solutions. *International Journal of Information Engineering and Electronic Business, 13*(2), 11–21. https://doi.org/10.5815/ijieeb.2021.02.02

Arcalas, J. Y. (2022, November 3). Average rice production cost hits 7-year high. *Business Mirror.* https://businessmirror.com.ph/2022/11/03/average-rice-production-cost-hits-7-year-high/

Asia Fund Managers. (2023, April). Philippine Economy. *AsiaFundManagers.* www.asiafundmanagers.com/us/philippines-economy/#:~:text=Lastly%2C%20the%20agricultural%20sector%E2%80%99s%20contribution,25%25%20of%20the%20labour%20force

Avcontentteam (2023, June). What is linear programming? definition, methods and problems for data scientists. *Analytics Vidhya*. https://www.analyticsvidhya.com/blog/2017/02/lintroductory-guide-on-linear-programming-explained-in-simple-english/

Bravo-Ureta, B., Higgins, D., and Arslan, A. (2020, November). Irrigation Infrastructure and farm productivity in the Philippines: A stochastic meta-frontier analysis. *World Development*, *135*, 105073. https://www.researchgate.net/publication/343213135_Irrigation_infrastructure_and_farm_productivity_in_the_Philippines_A_stochastic_Meta-Frontier_analysis

Chi, C. (2023, February 15). 4 Years since rice tariffication: Farmers' income per hectare shrank by 40%. *Philstar.com*. www.philstar.com/headlines/2023/02/15/2245174/4-years-rice-tariffication-fbamers-income-hectare-shrank-40

Dejaresco, Z, and Dejaresco, Z. (2019, September 12). The Tragedy of the Filipin Rice Farmers. *Business Mirror.* https://businessmirror.com.ph/2019/09/12/the-tragedy-of-the-filipino-rice-farmers/

Fytilis, K., Kontogeorgos, A., Michailidis, A., & Semos, A. (2022). Crop structure optimisation for maximising yield within environmental constraints in a rural area. *International Journal of Sustainable Agricultural Management and Informatics*, *8*(2), 200-217. https://doi.org/10.1504/ijsami.2022.124579

Kenton, W. (2021, August 31). Imputed cost: An accounting term for opportunity cost. *Investopedia.* https://www.investopedia.com/terms/i/imputed-cost.asp

National Irrigation Administration. (2024, January 23). Gearing up to more improved irrigation infrastructures. *National Irrigation Administration.* https://www.nia.gov.ph/content/gearing-more-improved-irrigation-infrastructures-0?utm_source=chatgpt.com

National Irrigation Administration. (2024, December 20). *Ph needs P220B annually to achieve rice sufficiency*. *National Irrigation Administration.* https://www.nia.gov.ph/content/ph-needs-p220b-annually-achieve-rice-sufficiency

Philippines Statistics Authority. (2023, January 26). Conduct of the second round (January2023) Survey on costs and returns (SCR) of Palay production in Occidental Mindoro. *Philippine Statistics Authority. https://rssomimaropa.psa.gov.ph/content/conduct-second-round-january-2023-survey-costs-and-returns-scr-palay-production-occidental*

Philippine Statistics Authority (2020, April 29). Crops. *Philippine Statistics Authority-Cordillera Administrative Region.* https://rssocar.psa.gov.ph/crops/2019%20Palay%20Performance%20in%20the%20

Sekhon, R., and Bloom, R. (July 2022). 4.2: Maximization by the simplex method. *Libre Text Mathematics.* https://math.libretexts.org/Bookshelves/Applied_Mathematics/Applied_Finite_Mathematics_(Sekhon_and_Bloom)/04%3A_Linear_Programming_The_Simplex_Method/4.02%3A_Maximization_By_The_Simplex_Method

Tecson, Z. (2022, June 6). Central Luzon remains ph's top palay producer in Q1. Philippine News Agency. https://www.pna.gov.ph/articles/1175948

Tuovila, A. (2021, June 25). Cash cost: Meaning, advantages and disadvantages. *Investopedia.* https://www.investopedia.com/terms/c/cashcost.asp

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