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The Origin and Evolution of Sponges on Earth: A Hybrid Systematic Literature Review and Bibliometric Analysis

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Abstract: Marine sponges (Phylum Porifera) are among the earliest diverging metazoans, providing crucial insights into the origins of multicellularity and early evolutionary transitions. This study employs a hybrid systematic literature review and bibliometric analysis to investigate the origin and evolution of sponges, integrating fossil, molecular, and ecological evidence. Guided by the PRISMA framework, a total of 246 articles were initially identified, resulting in 49 representative articles from the Scopus database (2001–2024) that were analyzed to synthesize empirical findings and map research trends. Results reveal that while studies on sponge origins remain limited, research interest has increased notably since 2017, with strong contributions from European and Asian institutions. Bibliometric visualization identified four major thematic clusters: taxonomy and phylogenetics, experimental and analytical methods, biomaterials and biochemistry, and bioactive secondary metabolites. These findings demonstrate that Porifera research not only elucidates early metazoan evolution but also highlights their ecological and biotechnological significance. The study underscores the need for interdisciplinary approaches to resolve taxonomic uncertainties, bridge fossil–molecular gaps, and expand international collaboration in future sponge research.

Keywords: Evolution, sponge origin, fossil

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Introduction

Marine sponges (Porifera) represent one of the earliest diverging lineages of multicellular animals, serving as key models for understanding the origins and evolution of metazoans. Since the Proterozoic, sponges have played a pivotal role as ecosystem engineers in marine environments, despite their simple body organization lacking true tissues, while exhibiting remarkable morphological diversity and complex ecological strategies (Botting & Muir, 2018). Studies on the evolutionary origins of sponges indicate that Porifera occupy a unique phylogenetic position, with fossil evidence extending back to the Ediacaran–Cambrian boundary (Müller et al., 2007). Early Cambrian sponge fossils typically exhibit simple and weakly mineralized spicules, which later evolved into more complex skeletal structures (Hentschel et al., 2012).

Molecular clock analyses suggest that sponges diverged between 800–650 million years ago, considerably predating the earliest widely accepted fossil evidence (~535 Ma), thus creating a significant gap between

molecular estimates and the fossil record (Suarez & Leys., 2022). This discrepancy has been partially resolved by discoveries of Ediacaran sponge-like fossils such as Otavia antiqua (760–550 Ma), which, although debated, align with molecular predictions of early sponge origins (Brain et al., 2012). More recently, the description of the crown-group sponge Helicolocellus from ~550 Ma has helped bridge the "lost years" of the sponge fossil record, narrowing the gap between molecular data and paleontological evidence (Ye et al., 2025; Wang et al., 2024).

The integration of fossil data, morphological analyses, and molecular approaches—including genetic markers such as 18S, 28S, and housekeeping genes—has been crucial in reconstructing phylogenetic relationships among sponge classes (Botting & Muir, 2018). Morphological evolution in sponges has been strongly influenced by environmental factors such as low oxygen availability and hydrodynamic conditions, leading to adaptations including efficient pumping systems and biomineralization innovations (Chang et al, 2019). Moreover, genomic-scale molecular studies are increasingly resolving taxonomic conflicts that have long persisted between classical morphology and molecular phylogenies (Rossi, 2024). Understanding the evolutionary history of sponges therefore provides profound insights into the transition from unicellular to multicellular life, innovations in biomineralization, and the evolution of microbial symbioses. As both molecular and paleontological evidence converge, marine sponges remain key organisms for exploring early metazoan evolution and for assessing long-term ecological changes in marine ecosystems (Ruocco et al., 2021).

Systematic Literature Review

From the 49 papers reviewed, this study summarizes 11 key articles that were selected as representative sources for the literature review

Table 1. Definition/Discovery of Literature Review

No.	Definition/Discovery	Reference
1.	New genus and species from the Chengjiang Biota, Calliospongia chunchengia.	(Chen et al., 2023)
2.	Fossil demosponge Vauxia gracilenta (505 Ma).	(Ehrlich et al., 2013)
3.	Fossil sponge species Conciliospongia anjiensis from the Late Ordovician Formation in Anji, South China.	(Botting et al., 2017)
4.	Sponge Aplysina cavernicola, which plays a role in chemical defense systems, first report of NHase occurrence in sponges.	(Lipowicz et al., 2013)
5.	Collagens in glass sponges that play a crucial role in biomineralization.	(Ehrlick et al., 2018)
6.	Sponge Aplysina aerophoba has been proposed as an antibacterial material for water filtration applications.	(Machalowski et al., 2020)
7.	Red Sea sponge Negombata magnifica has led to the discovery	(Youssef et al., 2021)

	of novel compounds with significant biological potential.	
8.	A new species, Choiaella hexactinophora sp. nov. from the Middle Ordovician Castle Bank in Wales, reveals the presence of hexactine-based spicules..	(Botting, 2021)
9.	Aulocalycoida identified as diphyletic and Hexactinosida as paraphyletic.	(Dohrmann et al., 2017)
10.	The dried skeleton of Spongilla lacustris represents a natural biocomposite with considerable potential in the field of dermatocosmetics.	(Krupska et al., 2020)
11	The spicules of Carduispongia pedicula are preserved as calcite, a significant finding since hexactine spicules in modern sponges are typically restricted to siliceous Hexactinellida.	(Nadhira et al., 2019)

Chen et al. (2023) reported a new genus and species from the Chengjiang Biota, Calliospongia chunchengia, characterized by a unique framework of large T-shaped spicules. These features suggest potential affinity with the Ascospongiae or a transitional form between Hexactinellida and protomonaxonids. This discovery not only expands our knowledge of Cambrian sponge morphological diversity but also provides important clues for reconstructing the origin and early evolution of sponges. Fossil evidence demonstrates the presence of structural biopolymers such as chitin in the basal demosponge Vauxia gracilenta (505 Ma), underscoring the early evolutionary position of sponges (Ehrlich et al., 2013). Furthermore, spongin—a collagen/keratin-like skeletal protein characteristic of keratosan demosponges—represents a key evolutionary innovation, providing a robust fibrous framework that is chemically and thermally stable, as well as highly efficient for water filtration, a vital function since the early stages of sponge evolution. The resilience of spongin against enzymatic degradation and extreme conditions supports the interpretation that sponges developed adaptive structural strategies early in their diversification, reinforcing their value as ancient model organisms for studies in biomimetics and metazoan evolution (Ehrlich et al., 2013). A new fossil sponge species, Conciliospongia anjiensis, discovered from the Late Ordovician Anji Formation of South China, holds crucial significance for siliceous sponge evolution. The relationship between Demospongiae and Hexactinellida has long been debated, with the hypothesis that demosponges evolved from reticulosan ancestors with hexactine spicules, but clear morphological intermediates had not been identified. C. anjiensis exhibits a unique combination of features, including a reticulate skeleton of small monaxon spicules typical of Hazeliidae, while retaining hexactine spicules and a globose body form inherited from reticulosans. These transitional traits establish it as a missing link between Cyathophycus-like reticulosans and globose proto-demosponges such as Crumillospongia, providing strong palaeontological evidence that validates long-standing evolutionary models and enhances understanding of the origin and diversification of siliceous sponges (Botting et al., 2017).

Other studies report the isolation and characterization of a nitrile hydratase (NHase) from the Mediterranean sponge Aplysina cavernicola, involved in chemical defense mechanisms. This represents the first account of NHase in sponges, opening new perspectives on marine chemical defense strategies and their biotechnological

potential (Lipowicz et al., 2013). Poriferan collagens are also among the most ancient protein families in Metazoa, exhibiting remarkable structural diversity, including spongin, collagen IV-related proteins, fibrillar collagens in demosponge mesohyl, and unique collagens from glass sponges involved in biomineralization. Further research has developed three-dimensional chitosan-Ag/AgBr composites derived from the skeleton of the marine sponge Aplysina aerophoba as antibacterial materials for water filtration. Through the isolation of chitosan frameworks and deposition of silver nanoparticles by chemical reduction, nanocomposite structures were obtained that remained firmly bound to chitosan fibers and stable under water flow (Machalowski et al., 2020). Similarly, investigation of the Red Sea sponge Negombata magnifica revealed novel metabolites, including two unique alkaloids, magnificine A and B, with a tetrahydrooxazolo[3,2-a]azepine framework never previously described. Additional findings included a new β-ionone derivative, (±)-negombaionone, as well as latrunculin B and 16-epi-latrunculin B, underscoring the species' role as a source of secondary metabolites with promising antibacterial and anticancer potential (Youssef et al., 2021).

Another discovery includes Choiaella hexactinophora sp. nov. from the Middle Ordovician Castle Bank Biota in Wales, which possesses hexactine-based spicules. This finding is important as it demonstrates that hexactines are not restricted to Hexactinellida but represent a plesiomorphic feature of Porifera, later lost in other classes. The presence of hexactines in Choiaella challenges the affinity of protomonaxonids with demosponges and supports their interpretation as an extinct early-branching clade. This also reinforces the hypothesis that protomonaxonids form a monophyletic group, for which a new class, Ascospongiae, has been proposed to replace the problematic Protomonaxonida. Evolutionarily, this supports the view that hexactines are primitive characters linking basal forms such as Hyalosinica with more derived taxa (e.g., Choia and Hamptonia), thus providing new insights into the early diversification and origins of Porifera (Botting, 2021).

Understanding the origin and evolution of glass sponges (Hexactinellida) is closely tied to phylogenetic reconstruction and skeletal characters. By expanding taxon sampling and applying total-evidence analyses, recent studies have demonstrated the diphyly of Aulocalycoida and the paraphyly of Hexactinosida, leading to revisions in Linnean classification. Ancestral state reconstruction further revealed the evolutionary dynamics of major body plans and spicule types, offering new perspectives on the skeletal evolution and diversification of glass sponges (Dohrmann et al., 2017). The dried skeleton of Spongilla lacustris is known as a natural biocomposite with considerable potential in dermatocosmetics. This freshwater sponge has been used traditionally in countries such as China, Russia, Ukraine, and Thailand (Krupska et al., 2020). The Silurian sponge Carduispongia pedicula from the Herefordshire Lagerstätte provides the first evidence of calcareous hexactine spicules and a complex aquiferous system, reshaping our understanding of early Porifera evolution. Its features suggest that the Poriferan ancestor was not structurally simple, but rather a vasiform organism with spicules and unexpectedly complex soft-tissue organization (Nadhira et al., 2019).

Thus, the origin and evolution of sponges represent a crucial transition from simple life forms toward metazoan complexity, while also underscoring their continuing importance in ecology, conservation, and biotechnology.

Method

This study adopted a combined methodological approach integrating a systematic literature review (PRISMA) with bibliometric analysis. The Scopus database was designated as the primary source (2001–2024), utilizing the search keywords “sponge origin,” “sponge evolution,” and “porifera earliest fossil.” From a total of 246 retrieved articles, 49 were identified as meeting the established inclusion criteria. Subsequently, bibliometric analysis was performed using VOSviewer software to generate visualizations of citation networks, author collaboration patterns, and keyword co-occurrence structures. Guided by the PRISMA framework, this approach ensures a comprehensive and replicable review, providing a clear and transparent understanding of the subject under investigation (Hadi et al., 2020). The inclusion criteria were as follows: (1) articles published up to August 21, 2025, (2) publications written in English, and (3) a specific focus on the origin and evolution of sponges on Earth. The integration of bibliometric analysis with systematic review enables the synthesis of empirical findings and the mapping of the research landscape, including the identification of leading contributors and emerging thematic trends (Ni & Abdullah, 2025).

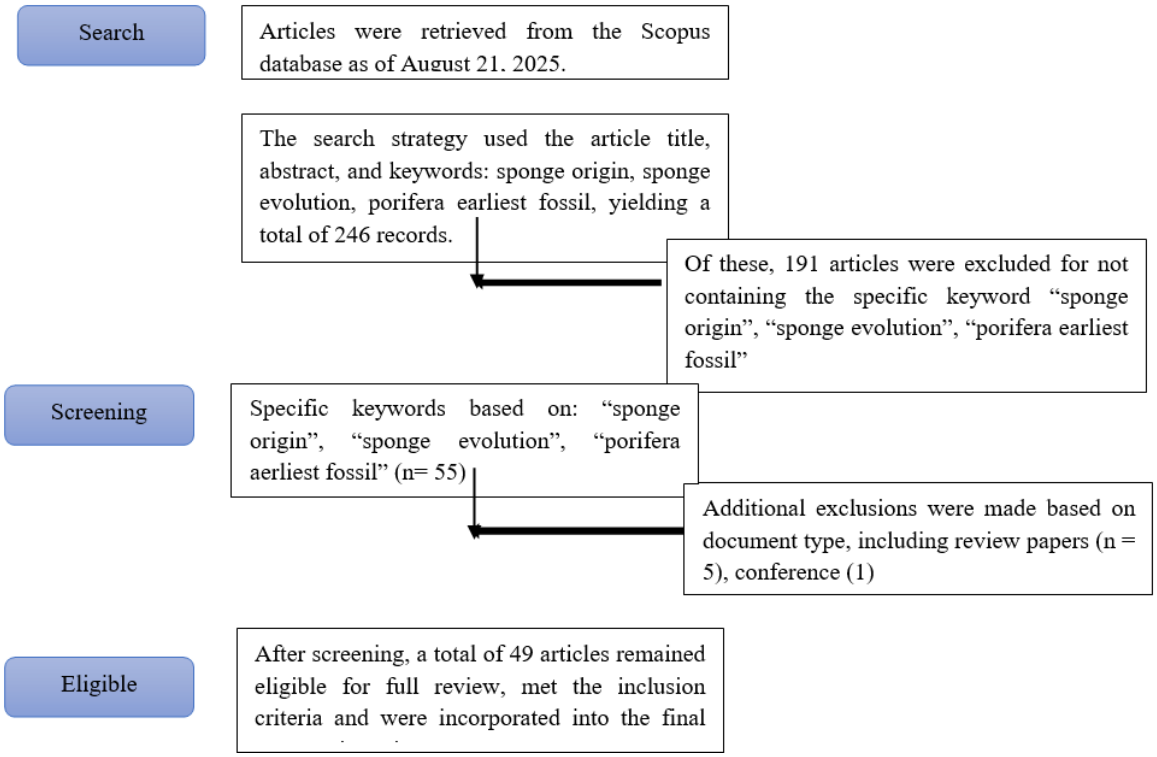


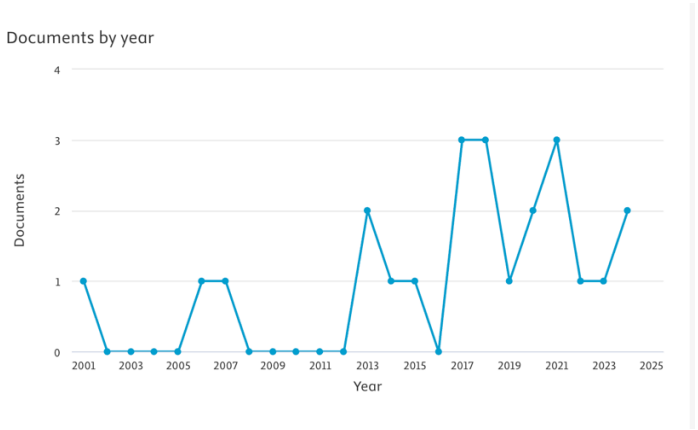
Figure 1. Sistematic Literature Review Information Flow using PRISMA

This document in then further analyzed in this study to answer RQ1 : Does the exploration of the Origin and Evolution of Sponges remain a subject of significant importance for future scholarly inquiry? RQ2: What is the allocation of research investigations related to the origin and evolution of sponges? RQ 3: How do the origin and evolution of marine sponges elucidate their diversity and phylogenetic relationships?

Results

This study analyzes 49 articles indexed in the Scopus database that discuss Sponge Origin, Sponge Evolution, and the Earliest Fossil Record of Porifera. The dataset was compiled by examining the number of published articles, publication trends over time, and journal sources. Furthermore, the study highlights the most influential aspects in these research areas, including prominent authors, institutional affiliations, and the countries contributing to this field.

The central research question (**RQ1**) addressed in this study is: Does the exploration of the Origin and Evolution of Sponges remain a subject of significant importance for future scholarly inquiry? Based on the data retrieved from the Scopus database, it has been confirmed that over the past three decades, scholarly work on the origin and evolution of sponges has remained relatively scarce, as illustrated in Figure 1. Nevertheless, research interest in this topic has shown notable growth during the last decade, with progressive development particularly evident since 2017. Based on the data retrieved from Scopus, the number of publications began to increase in 2017, 2018, and 2021. These years represent the most significant growth within the past two decades, with each recording three publications per year.



Source: Scopus database

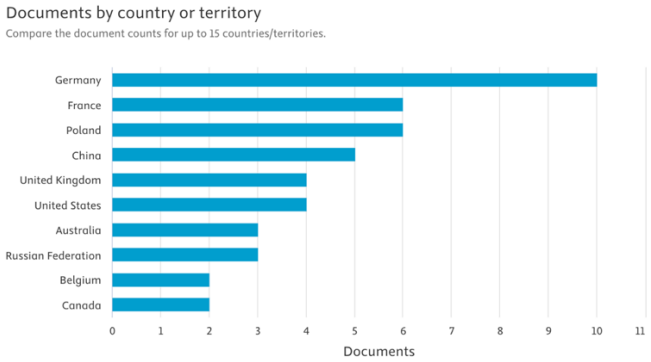
Figure 2. Number of The Origin and Evolution Sponge Publications

Since 2001, the body of literature on the origin and evolution of sponges has remained limited, largely due to the scarcity of studies published in reputable journals. This gap highlights an important opportunity for future researchers to advance scholarly contributions in this field. Addressing this issue is significant for deepening scientific understanding of sponge origin, with implications not only for the refinement of evolutionary frameworks but also for strengthening the conceptual foundations of early animal evolution. Furthermore, such research may facilitate a more comprehensive and sustainable application of knowledge related to sponge origin across diverse scientific and applied domains.

RQ2: What is the allocation of research investigations related to the origin and evolution of sponges?

The analysis of the distribution of research on sponge origin and evolution in the 49 articles was conducted by categorizing the studies according to classifications such as nation, region, affiliation, source, and author, with a limitation to the top 10 entries in each classification. Understanding the allocation of scholarly work on sponge origin is valuable for both academics and practitioners, as it helps to elucidate future research agendas, particularly in the sustainable advancement of the paradigm of sponge origin and evolution.

First, the distribution of scholarly inquiry by country or geographical region reveals that Germany leads with 10 articles, followed by France and Poland with 6 articles each. China contributes 5 articles, while the United Kingdom and the United States each account for 4 articles. Australia and Russia are represented by 3 articles each, whereas Belgium and Canada contribute 2 articles respectively (see Figure 2). This pattern indicates that research on sponge origin and evolution remains concentrated primarily in European countries, with comparatively limited contributions from other regions.

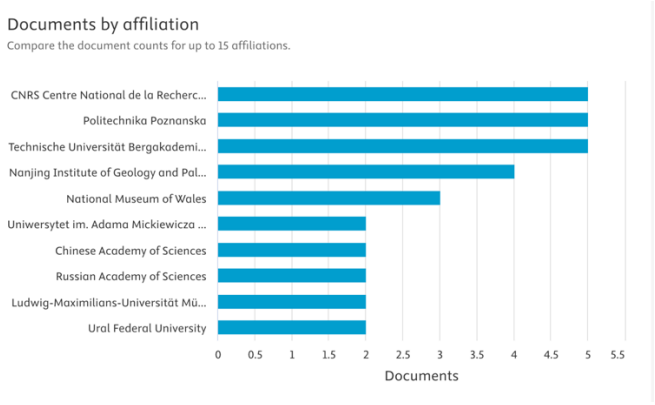


Source: Scopus database

Figure 3. Number of Articles by Country or Territory (top 10 country)

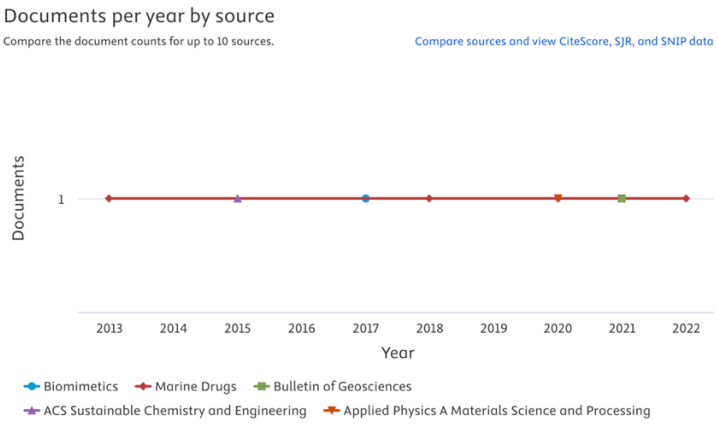
The allocation of scholarly inquiries related to the origin and evolution of sponges, categorized by nation or region, reveals Germany as the leading contributor with 10 manuscripts, followed by France and Poland with 6 manuscripts each. Other countries that have made significant contributions include China with 5 manuscripts; the United Kingdom and the United States with 4 manuscripts each; Australia and Russia with 3 manuscripts each; and Belgium and Canada with 2 manuscripts each. These findings indicate that the issue of sponge origin and evolution has attracted attention across multiple countries, reflecting its global relevance. Second, the allocation of scholarship related to sponge origin based on institutional affiliations is predominantly represented by the CNRS Centre National de la Recherche Scientifique (France) with 5 articles, Politechnika Poznańska (Poland) with 5 articles, Technische Universität Bergakademie Freiberg (Germany) with 5 articles, the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences (China) with 4 articles, the National Museum of Wales (United Kingdom) with 3 articles, Uniwersytet im. Adama Mickiewicza w Poznaniu (Poland) with 2 articles, the Chinese Academy of Sciences (China) with 2 articles, the Russian Academy of Sciences (Russia) with 2 articles, Ludwig-Maximilians-Universität München (Germany) with 2 articles, and the Ural Federal University (Russia) with 2 articles (see Figure 4).

This distribution demonstrates that research on sponge origin is concentrated within leading institutions in Europe and Asia, particularly in France, Poland, Germany, and China. Such a pattern reflects the central role of major international research organizations in advancing studies on early animal evolution. Nevertheless, institutional representation from other regions remains relatively limited, highlighting the need for broader international collaboration and capacity building in areas that have been less engaged in this field.



Source: Scopus database

Figure 4. Network of Institutional Affiliation

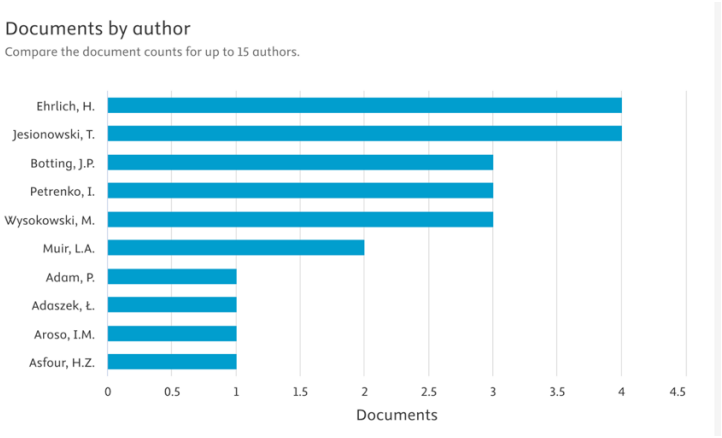


Source: Scopus database

Figure 5. Number of Articles by Source

Third, the number of articles published across different sources, as identified through Scopus analysis, is distributed as follows: Marine Drugs (1 article in 2013), ACS Sustainable Chemistry and Engineering (1 article in 2015), Biomimetics (1 article in 2017), Marine Drugs (1 article in 2018), Applied Physics A: Materials Science and Processing (1 article in 2020), Bulletin of Geosciences (1 article in 2021), and Marine Drugs (1 article in 2022). This pattern indicates that between 2013 and 2022, the publication rate of articles related to sponge origin and evolution across various journals remained stagnant, with only one article published per year. Such consistency suggests that although the topic maintains a steady scholarly presence, it has not yet

experienced a significant surge of research interest or interdisciplinary expansion. This stagnation highlights a research gap and underscores the necessity for broader scientific engagement and collaboration to advance the discourse on sponge origin and evolution.



Source: Scopus database

Figure 6. Number of Articles by Author

Based on author contributions (Top 10 Authors): Erlich, H. and Jesionowski, T. each contributed four documents, followed by Botting, J.P., Petrenko, I., and Wysokowski, M. with three documents each. Muir, L.A. produced two documents, while Adam, P., Adaszek, L., Aroso, I.M., and Asfour, H.Z. each contributed one document. These findings indicate that the number of authors engaged in research on this topic remains relatively limited. Consequently, further scholarly investigation is required to enrich the body of literature and generate more relevant findings for future research agendas.

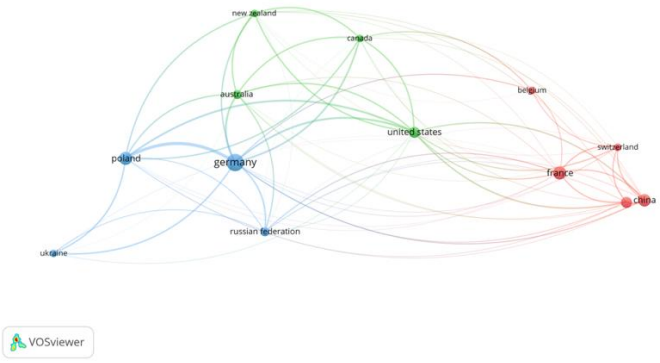


Figure 7. Network Country Visualizations

Furthermore, the interconnections among countries engaged in sponge origin and evolution research were analyzed using VOSviewer software. This analysis not only maps the collaborative networks among nations but also plays a crucial role in formulating a more systematic and forward-looking research agenda. The VOSviewer results demonstrate strong interrelations among countries investigating sponge origin and evolution,

underscoring the importance of international collaboration in strengthening and expanding the scope of research in this field (see Figure 3). Meanwhile, the "Co-authorship" analysis (Figure 3), categorized by country, reveals three major international collaboration hubs. The blue cluster, dominated by Germany, serves as a central hub in collaboration with Poland, Russia, and Ukraine. The green cluster highlights the United States as a dominant actor, with strong collaborative ties among English-speaking countries, including Canada, Australia, and New Zealand, as well as Western European nations such as France, Switzerland, and Belgium.

These patterns reveal the global nature of sponge research, with significant contributions from three major research powerhouses: the United States and other English-speaking countries, European nations, and China. Such cross-national collaborations underscore the strategic importance of sponge (Porifera) studies in advancing scientific fields such as biodiversity, biotechnology, and pharmacological applications.

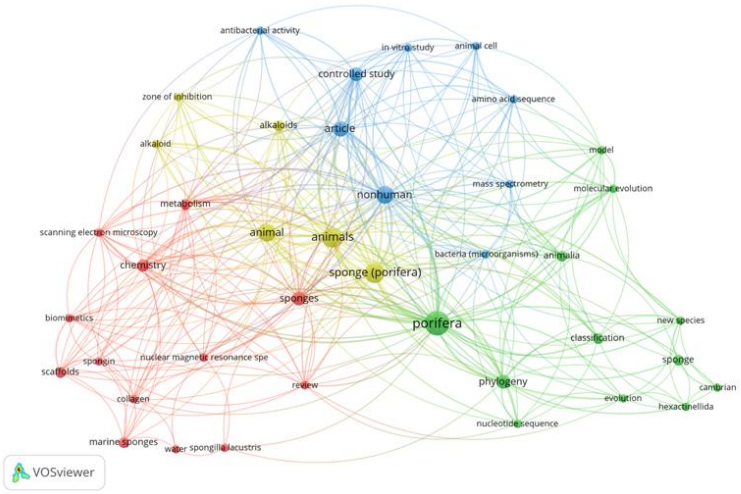


Figure 8. Co-Occurance Visualization

The results of the bibliometric analysis (Figure 7), using the "Co-occurrence" approach of the applied keywords, indicate the presence of four main clusters that represent the research directions related to marine sponges (Porifera). Aspects such as taxonomy, phylogenetics, and evolution, dominated by keywords such as Porifera, phylogeny, molecular evolution, nucleotide sequence, and new species. This suggests that studies on the origin, diversification, and discovery of new sponge species remain crucial areas for future investigation. Keywords such as controlled study, in vitro study, mass spectrometry, and animal cell, which are associated with experimental approaches and laboratory methodologies. This reflects the importance of controlled experiments and advanced analytical techniques in elucidating the cellular and molecular aspects of marine sponges.

Related to the utilization of sponge biological structures with applications in biotechnology and tissue engineering, particularly those derived from potential biomaterials such as collagen and spongin. Keywords including chemistry, collagen, scaffolds, biomimetics, and marine sponge highlight the biochemical and biomaterial dimensions of sponge studies. Alkaloids and other metabolites with pharmacological potential,

particularly as bioactive secondary metabolites of sponges. Keywords such as alkaloids, metabolism, antibacterial activity, and zone of inhibition underscore the role of sponges as a valuable source of novel drug candidates, notably with antibacterial and antimicrobial properties. Overall, the bibliometric "Co-occurrence" analysis demonstrates that research development on marine sponges follows four principal directions: taxonomy and evolution, experimental approaches, biomaterials and biochemistry, and the bioactivity of secondary metabolites.

In conclusion, the bibliometric findings not only map the current state of knowledge but also provide a strategic foundation for future research trajectories. Strengthening collaborations across clusters and expanding interdisciplinary approaches will be essential to address remaining gaps, particularly in linking evolutionary insights with practical applications in biotechnology, environmental sustainability, and drug discovery.
RQ3: How do the origin and evolution of marine sponges elucidate their diversity and phylogenetic relationships?

The evolutionary history of sponges highlights their pivotal role as both a window into the early evolution of metazoans and a cornerstone of present-day marine biodiversity. Their fossil record, rapid Cambrian diversification, and enduring microbial symbioses underscore their importance not only as ancient organisms but also as model systems for understanding evolutionary processes, ecological interactions, and potential biotechnological applications.

Types of Marine Sponges and Their Evolutionary History

Marine sponges (phylum Porifera) are a diverse group of benthic organisms with a rich evolutionary history dating back to the Ediacaran–Cambrian boundary (541 million years ago) (Muller et al., 2007). They are classified into several major classes, each with distinct characteristics and evolutionary backgrounds, including:

Calcarea(CalcareousSponges)

Members of this class possess skeletons composed of calcium carbonate. Their evolutionary history is complex, as molecular phylogenies of Calcarea often conflict with traditional morphology-based classifications (Botting & Muir, 2018).

Hexactinellida(GlassSponges)

Known as glass sponges with silica-based skeletons, this group plays a crucial role in deep-sea ecosystems. However, evolutionary understanding of their skeletal structures remains inconsistent. Nevertheless, molecular data used to reconstruct their phylogeny provide greater resolution compared to morphology-based systematics (Ye et al., 2025).

Demospongiae

The largest class of sponges, encompassing approximately 90% of all known sponge species. Their skeletons are composed of spongin, silica, or both. Phylogenetic relationships within Demospongiae are still under examination using molecular approaches, which indicate para- or polyphyletic groupings (Botting & Muir, 2018).

Homoscleromorpha

This class is less diverse and often inhabits shaded environments such as underwater caves. Evolutionary records indicate that the diversity of Homoscleromorpha remains underexplored, with new species continuing to be described (Uriz et al., 2012).

Evolutionary History

The evolutionary history of sponges can be understood through several perspectives:

Early Evolution – Sponges are regarded as the earliest extant metazoan phylum, making their evolutionary study essential for understanding the origins of early metazoans (Kalesnikov et al., 2024). They have also undergone structural adaptations over millions of years (Schuster et al., 2018).

Fossil Record – Fossil evidence reveals extinct groups and combinations of sponge traits that shed light on the origins of major lineages. For example, mineralized skeletal structures first appeared early in sponge evolution, whereas no such evidence has been found in the Precambrian, suggesting that sponges had not yet emerged during that time (Hentschel et al., 2012).

Molecular Phylogenetics – Molecular approaches have uncovered complex evolutionary relationships within and between sponge classes, often contradicting traditional morphological classifications, while offering new insights into sponge evolution (Botting & Muir, 2018).

Symbiotic Relationships – Sponges host diverse microbial communities that have co-evolved with them, playing a critical role in understanding the biological and evolutionary significance of sponge–microbe symbioses (Ruocco et al., 2021).

Comparative Evolutionary Insights

Table 2. Comparative Evolutionary Insights of Marine Sponge

Class	Skeleton Composition	Key Evolutionary Insights
Calcarea	Calcium	Research on molecular phylogeny and morphology remains

	carbonate	contradictory (Botting & Muir, 2018).
Hexactinellida	Silica	Several inconsistencies persist; however, the results are more consistent with morphology-based systematics (Ye et al., 2025).
Demospongiae	Spongin, silica, or both	Molecular-based testing is ongoing, indicating para- or polyphyletic relationships (Botting & Muir, 2018).
Homoscleromorpha	Silica	Biodiversity continues to be explored, with newly discovered species still being described (Uriz et al., 2012).

Conclusion

This study highlights that Porifera, as one of the most ancient multicellular lineages, possess a long and complex evolutionary history shaped by fossil, molecular, and ecological evidence. Despite significant progress in understanding sponge diversification, microbial symbiosis, and biomineralization, considerable challenges remain, particularly the lack of data from underrepresented regions, limited taxonomic resolution, and uncertainties in predicting sponge responses to global climate change. Addressing these challenges requires interdisciplinary approaches that integrate paleontology, genomics, ecology, and experimental research. Such efforts will be crucial for bridging knowledge gaps, forecasting evolutionary patterns, and elucidating the broader ecological roles of marine sponges in the future.

This article can made into as reference or reference for researcher or scientists who will do study more further related with topic especially in the field knowledge Marine, as well as give outlook important in the future about ecosystem sea and innovation scientific.

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Implementation of Problem Based Learning Model Based on Lesson Study to Improve Students' Critical Thinking in Salt Hydrolysis Material

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Abstract: This study aims to determine whether there is an improvement in students' critical thinking who are taught using the Problem Based Learning model based on lesson study in salt hydrolysis material, as well as to identify the most developed cognitive aspect through the implementation of the Problem Based Learning model based on lesson study in salt hydrolysis material. This research is an experimental study. The population in this study included all students of Class XI Science Specialization at SMA Negeri 1 Stabat. The sample used in this study was selected through purposive sampling using a one-group pretest-posttest design. The instrument used was a test consisting of 20 questions with a reliability of 0.845. Based on the results of parametric statistical tests, the data from the pretest, posttest, and normalized gain (N-gain) were normally distributed and homogeneous. Thus, there was an improvement in students' critical thinking who were taught using the Problem Based Learning model based on lesson study. The most developed cognitive aspect in the experimental class using the Problem Based Learning model based on lesson study in salt hydrolysis material was the cognitive aspect of application (C3), which reached 85%.

Keywords: Problem Based Learning, Lesson Study, Critical Thinking, Salt Hydrolysis

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Introduction

Education is a complex problem, so efforts are made to improve the quality of education covers in various areas including improving facilities and infrastructure, changing the curriculum and teaching and learning process, improving the quality of teachers, and other efforts included in the education component. Education is closely related to the learning process. The better the learning process, the better the quality of education. Learning is a teaching and learning activity carried out by teachers in order to create a pleasant atmosphere in the learning environment and attract students' interest to be active learners (Islamic, 2016). According to Marisyah et al

(2019), the Father of Indonesian National Education, Ki Hajar Dewantara, defines that the meaning of education is a demand in the life of growing children. What is meant by education is to guide all the natural powers that exist in children so that they, as humans and as members of society can achieve safety and the highest happiness.

Chemistry is one of the subjects included in the science family (IPA). Chemistry includes products, processes, and attitudes. Chemistry as a product includes a body of knowledge consisting of chemical facts, concepts, and principles (Larasati et al, 2016). The material on salt hydrolysis includes dimensions of factual, conceptual, and procedural. The characteristics of salt hydrolysis are factual and abstract. Factual material: an example is the symptom of a change in the color of litmus paper when it is put into a solution. acidic or basic, which can be seen using experimental methods, while abstract on the submicroscopic, which cannot be seen. This submicroscopic can be displayed through learning media that displays animation, so it can help students find a concept (Sukmadani & Suryelita, 2021; Nurfalah et al, 2023).

Various studies on the application of problem-based learning (PBL) show positive results, the results of Gijselaers' (1996) research show that the application of problem-based learning (PBL) enables students to identify information that is known and needed and the strategies needed to solve the problem. By implementing problem-based learning (PBL) allows students to become more active participants in the learning process. Learning According to Febrianti (2023), the problem-based learning (PBL) learning model describes the nature of the existence of real problems, namely as a context for students to learn to think critically and the ability to solve problems and acquire knowledge. Problem-based learning is a model that has characteristics and is very suitable to be applied to learning so as not to memorize concepts but is able to provide understanding to students to solve problems and indirectly improve students' creative thinking skills.

21st century learning challenges every individual to have several skills that must be mastered, so that in the learning process students are prepared to master these skills. The skills that must be possessed include: critical thinking skills, problem solving, creative thinking, communication, and collaboration. Mastery of each aspect of these skills is expected to realize the goals and functions of education nationally. This is in line with Permendikbud No. 22 of 2016 concerning the process standards for primary and secondary education, one of which is through the use of information technology and communication in improving the efficiency and effectiveness of learning.

A Lesson study is a complex, collaborative process of planning learning, collecting data from learning outcomes, and discussing them. Lesson study activities, where teachers collaborate in planning and implementing learning and conducting learning research, then this activity provides benefits. First, lesson study is an effective way that can improve the quality of learning in the classroom. Second, lesson study which well designed, it is hoped that it will produce professional and innovative teachers (Murtiani, 2012). In this case, lesson study seems to be able to be used as an alternative to encourage changes in learning practices in Indonesia towards a more effective.

Stages of lesson study based on the implementation guidelines for MGMP with a lesson study pattern proposed by the Directorate General for Improving the Quality of Education and Manpower (PMPTK) According to Murtiani, there are three main stages of lesson study, namely (1) Stage planning: which aims to design learning that can teach students, how to make students actively participate in the learning process. (2) Implementation stage (implementing/ doing): which aims to implement the learning design that has been formulated in planning. In planning, it has been agreed which teachers will implement it learning and the schools that will be the hosts. This step aims to test the effectiveness of the learning model that has been designed. (3) Reflection stage (reflecting/ seeing): at this stage collaborating parties plus other observers sit together to have a discussion regarding what they have just captured and observed from the implementation of the lesson plan that has been done. Then provide suggestions for improving the next learning. Based on previous research, it shows that, according to Islawati et al (2024) in the results of his research, an effective method to improve students' critical thinking skills in higher education. Literature analysis from various studies shows that. the application of PBL in the higher education curriculum is highly recommended to develop students' critical thinking skills and improve the quality of learning. The results of Ayirahma's (2023) study showed that E-LKPD, which adopted the PBL approach and used the Heyzine platform was proven to be effective in improving critical thinking skills in acid-base material. Based on the results of Nurfalah et al's (2023) study, it can be concluded that learning media Interactive power-point based on guided inquiry on the material of salt hydrolysis is said to be effective in improving student learning outcomes in the cognitive domain. The results of the relevant research by Wayuni et al (2024) showed that the discovery learning model was proven to be effective in improving students' critical thinking skills.

Method

The method in this research is quantitative research. This research has been conducted Senior High School in Stabat. The population in this study was all class XI students at Senior High School in Stabat consisting of 6 classes, and each class consists of an average of 36 students. Sampling in this study This will be done using the purposive sampling. Purposive is a sampling technique with certain considerations. The first class is a class that is taught using the problem-based model Learning is based on lesson study (experimental class), and the second class is the class that is taught with conventional model (control class). The material to be implemented is hydrolysis salt.

Data Collection Technique

The instruments used in this study consist of test instruments. Critical thinking skills students of both classes, namely the experimental and control classes, on the material on salt hydrolysis were measured by a test in the form of a pretest and a posttest in the form of an objective test (multiple choice questions), Number of questions there were 40 questions given with five answer choices (a, b, c, d, e). The pretest and posttest questions were given to both classes, namely the experimental and control classes, the same. This instrument will be used during the pretest and a posttest. The pretest is used to measure students' initial abilities in the experimental class

and control classes, while the Posttest is used to measure students' final abilities. in the experimental class and control class. The test is compiled based on Bloom's Taxonomy in the domain of cognitive, namely knowledge (C1), understanding (C2), application (C3), and analysis (C4). Data analysis the quantitative descriptive analysis used is based on n-gain calculations and before the data is analyzed with n-gain, first a normality test is carried out.

Results

Based on the data on student learning outcomes obtained in this study and after the data tabulated, the average, standard deviation, and variance of the pretest and posttest data are obtained experimental class and control class as in Table 1:

Table 1. Mean, Standard Deviation, and Variance of Pretest and Posttest Data

Class	Average		Standard Deviation		Variance	
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
Experiment		85.37	7.9702	8.1167	63.525	65.881
Control	33.25 33.37	78.87	7.957	6.952	63.317	48.317

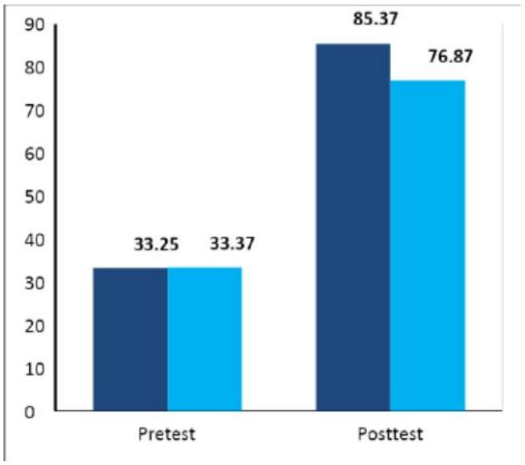

Figure 1. Critical Thinking Skills Results

From the data it can be seen that there is an increase in critical thinking skills both in the experimental and control classes. Posttest scores can increase due to the treatment of the learning model. conducted by teachers where the posttest results in the experimental class were higher compared to the control class. This shows that the problem-based learning model is based on the lesson on hydrolysis material salt contributes to improving learning outcomes in experimental classes and is better compared to the control class with conventional methods. Before the hypothesis testing was carried out, the data- The data obtained must meet the requirements, namely it must be normally distributed.

Lesson Study Indicators

The lesson study-based problem-based learning model is a combination of problem-based learning with lesson study, where in the learning activities the material on hydrolysis is delivered salt is done by presenting problems that exist in everyday life, asking questions about the material on salt hydrolysis. The dialogue was carried out by all students by making a “U” - shaped seating plan. In the lesson study learning activity, the goal is The main thing is to improve the quality of learning in the classroom with three stages, namely: 1) Planning Stage (plan), namely the stage of analyzing the material to be taught and creating the necessary learning tools such as RPP and preparing learning outcome test instruments and preparing answer keys; 2) Implementation Stage (do), namely the stage where a teacher or researchers act as model teachers implementing learning implementation plans (RPP), another teacher was appointed as an observer to conduct observations using a paper. observations that have been prepared; and 3) Reflection Stage (see), which is the stage where the teacher implementing the RPP was given the opportunity to express their impressions during carry out learning, both for himself and for students. Furthermore, the observer conveys the results of observation data analysis. Through the stages of problem-based learning based on lesson study, students can have the experience of understanding from not understanding.

Based on the results of the assessment observations obtained at the end of each meeting learning, percentage of aspects of lesson study learning activities. The aspects observed, among others: 1) students who understand the purpose of the learning form; when listening to the teacher's explanation or friends, the seating plan becomes the letter "U" and when solving the problem, the seating plan is into small groups; 2) students who are cooperative with their friends to solve problems questions or assignments; 3) students who do not understand or ask to be taught if they feel confused; 4) students who teach until finished or always care about friends who ask for help; 5) students who convey or deepen their own thoughts in group activities; 6) students who place more emphasis is on “listening” rather than “speaking” in the learning process; 7) students who maintain learning motivation by studying together with friends rather than solving problems or individual tasks; and 8) students who utilize various media and learn actively.

Table 2. Lesson Study Indicators

Meeting	Lesson Study Indicators							
	1	2	3	4	5	6	7	8
I, II, and III	100%	83%	97%	86%	94%	89%	83%	92%

Improvement of Developed Cognitive Domain Results

To find out the cognitive aspects that are developed in classes that are taught with models problem-based learning based on lesson study of salt hydrolysis material, then the gain calculation is normalized for each

cognitive aspect used in the study, namely starting from the level of knowledge (C1) 78%, understanding (C2) 76%, application (C3) 85%, and analysis (C4) 73%. In class control obtained cognitive aspects, namely the level of knowledge (C1) 67%, understanding (C2) 65%, application (C3) 70%, and (C4) analysis 63%. Then the data domains of the experimental class and control class are presented in the form of a graph as follows:

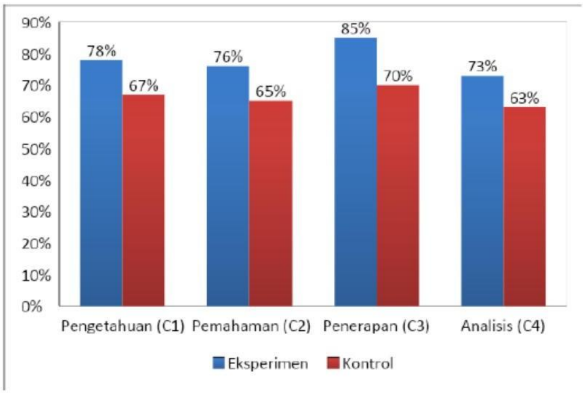

Figure 2. Developed cognitive aspects

Which cognitive aspects are most developed in this study in the experimental class? The parameters of the success of the implementation of the learning model are measured from the increase in student learning outcomes by looking at the cognitive aspects based on Bloom's Taxonomy from C1 to C4. From the results of the study obtained in the experimental class, the cognitive aspects developed at the level of knowledge (C1) 78%, understanding (C2) 76%, application (C3) 85%, and (C4) analysis 73%. From these results, the most developed is the cognitive aspect C3 (application). This is because the material in this study is material that has more calculation scope, so with the existence of a lesson- based problem-based learning model, it will make students understand more about how rules for solving existing problems.

Conclusion

Based on the research results, it can be concluded that students' critical thinking skills reviewed from the cognitive aspect which is most developed through the application of problem-based learning lesson study- based on the material of salt hydrolysis there is a significant increase in cognitive implementation (C3) as much as 85%.

This article can inspire educators to teach chemistry in schools. Teachers can explore chemistry concepts more deeply by investigating phenomena and events in their surroundings. By developing chemistry learning materials, particularly through the application of problem-based learning (PBL) combined with Lesson Study, teachers can foster critical thinking skills among students. For instance, in teaching the topic of salt hydrolysis, educators can incorporate examples from local environmental issues, such as the impact of salt production methods on water pH or soil quality. This approach not only makes the learning process more relevant and engaging but also enhances students' understanding of the role of chemistry in real-life problem-solving.

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Conducted Methodology for Experimental Study in Post-Graduation Level

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Abstract: Fatigue crack growth presents an interesting phenomenon in damage mechanics of steel and alloys. In order to quantify the fatigue crack growth damage and prevent damage level, experimental study is necessary. The main objective of this paper is to present the approach used for accomplishing the experimental work in fatigue crack growth. It is recognized that cost and experimental resources present a barrier for our laboratory in experimental. To address this problem, a convention (agreement) is established between our university (University of Tlemcen) and International center of research (Centre of Materials – Mine Paris-Tech – France). The times of experimental study through this convention is optimized for two month (one month per year) based on experimental of fatigue tests established in accord between doctoral student, supervisor in Tlemcen university and supervisor in Centre of Materials in Paris – France. The studied material is provided by Centre of Materials and the machining of test specimens is performed by the doctoral student via the University of Tlemcen. This approach applied in doctoral study allows to reduce the times study and the doctoral student defends his thesis in due times (four years) with the minimum problems. Also, the published results and corporation in research is established with the two scientific organisms (University of Tlemcen and Centre of Materials, Mines Paris-Tech, France).

Keywords: Corporation, Convention and agreement, Doctoral study, Experimental study, Fatigue tests, post-graduation level

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Introduction

Research is an essential and powerful tool in leading man towards progress. Research is also considered as the

application of scientific method in solving several problems. Several definitions of "research" have been presented by various authors. Cook [1] defines that the: "Research is an honest, exhaustive, intelligent searching for facts and their meanings or implications with reference to a given problem". Monroes [1] indicates that: "research may be defined as a method of studying problems whose solutions are to be derived partly or wholly from facts". Also, Woody define the research as: "Research comprises defining and redefining problems, formulating hypothesis or suggested solutions, collecting, organizing and evaluating data, making deductions and reaching conclusions and at last careful testing the conclusions to determine whether they fit the formulated hypothesis" [1]. In research conducted by Daniel [2] vital factors are identified which contribute to enhanced postgraduate education: the quality of supervision, institutional and departmental support, personal responsibility and accountability, and financial support availability. There are several varieties of ways through which the research is classified into different categories:

On the basis of nature of information.

On the basis of utility of content or nature of subject matter of research.

On the basis of approach of research.

On the basis of method of research.

The conduct of a research depends mainly on the selected research method, where the experimental method plays a crucial role for such success. Experimental research uses a scientific method for conducting research, employing the most methodical research design. Known as the gold standard, it involves performing experiments to reach conclusions and can be conducted based on some of the findings from previous forms of research. How do I decide which research methods to use? The research methods you use depend on the type of data you need to answer your research question. If you want to measure something or test a hypothesis, use quantitative methods. If you want to explore ideas, thoughts and meanings, use qualitative methods. Guo et al. [3] have conducted experimental study in fatigue crack growth and confirm that experimental study is an effective means to evaluate the FCGP and fatigue life of HSS. However, the cycle of the FCGR test is long and requires a lot of human and material resources. İn recent study an experimental research was conducted by Li et al. [4] for investigation fatigue crack propagation behavior and reliability evaluation of steel bridge. It is conclude that a quantitative relationship between the magnetic characteristic parameters and the fatigue crack growth length was established.

The aim of this paper is to present experience in research and shown the applied methodology for conducting experimental research through corporation and convention between University of Tlemcen (Algeria) and Centre of Materials – Mines Paris-Tech (France).

Research Process

In our experimental study (Fatigue crack growth tests) is it necessary to define conducted Research Process. Research Process consists of steps necessary to effectively carry out research. These actions or steps are:

Formulating the research Problem

Developing the Research Hypothesis
Preparing the research Design
Determining the research Design
Collecting the experimental Data
Synthesis of experimental of Data
Discussion and Interpretation of the results
Preparing of the manuscrit and presentation of the final result in thesis.

Research Design

Research design is defined as the plan, structure and strategy of the experimental investigation conceived so as to obtain answers to research questions.
The most important requirement of best research design is that it should provide adequate information so that the research problem can be analyzed on a wide perspective. In our case an ideal design should take into account important factors like:
Identifying the exact research problem to be studied: Effetct of residual stress on fatigue crack growth of Aluminium alloy 2024 T351
The objective of the research: Doctorat thesis
The process of obtaining information: Fatigue crack growth tests
The availability of adequate and skilled manpower: Technical staff in Centre of Materials (France)
The availability of adequate financial resources for carrying research (University of Tlemcen and Personnel contribution).
The fatigue tests are conducted in Centre of Materials (France) under the direction of Professor André Pineau [4]. The material used in experimental study is listed below:
A computer
Tensile testing machine
Polishing machines
Optical microscope
Chemical product for metallographic analysis
Servo-hydraulic machine
Scanning electron microscope (MEB)

Method

In order to accomplish the experimental study in Centre of Materials, agreement (convention) is signed between university of Tlemcen and Centre of Materials – Mines Paris-Tech with consist for mutual visit in France and Algeria of professors and PhD students. The objective of the visit of Phd students is to conduct theoretical study (bibliography research) and limited experimental study (fatigue tests and MEB analysis).

Based on this agreement, bibliographic research is conducted in two 15-day courses in 2024 and 2005 and the continuity of this research is finished in Tlemcen University. From February 2006, the experimental research is started in Tlemcen University by preparing the experimental procedures according to ASTM standard of fatigue tests. In the same times, the specimens of fatigue tests are machined in France with the personnel contribution. The cost is about 650 Euro of twelve specimens [4].

The times of experimental study through the agreement (convention) is optimized for two month (one month per year) based on experimental of fatigue tests established in accord between doctoral student, supervisor in Tlemcen university and supervisor in Centre of Materials in Paris – France. One month is November 2006 and one month in January 2008. The studied material (2024 T351) is provided by ALCAN society to Centre of Materials.

Results

The experimental data were analyzed in Tlemcen University. The fatigue life curves and fatigue crack growth rates are plotted in absence and presence of residual stress dues to the fourth plastic bending tests.
After the fatigue tests, the fractured surface was analyzed by MEB. The microscopic fatigue crack growth is obtained from the analysis of the fatigue streaks and compared to macroscopic fatigue crack growth. A final report is presented to supervisor in Tlemcen and Sidi Bel Abbes University and supervisor in Centre of Materials for validation. In December 2008, a defense of thesis is programmed.

Conclusion

In this paper, a conductance methodology is presented for conduction of experimental study in Phd research (doctorate). An agreement is established between University of Tlemcen (Algeria) and Centre of Materials of Mines Paris-Tech (France). From this agreement:
Part of the theoretical research is conducted in Centre of Materials.
Fatigue crack growth tests are conducted fully in Centre of Materials.
The examination of the fractured surface by fatigue is established in Centre of Materials.
The analysis of the experimental results is conducted in Tlemcen and Sidi Bel Abbes University.
A part of the theoretical research is also conducted Tlemcen Univeristy.
A final report is established in Tlemcen University and validated by supervisors in University of Sidi Bel Abbes and Tlemcen, and Supervisor in Centre of Materials (A. Pineau).
In general, this research is conducted in fixed time (four years) and the experimental study is conducted in two month with rigorous preparation in University of Tlemcen of research design.

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First-Principles Study of the Structural, Mechanical, Dynamical, and Electronic Properties of the B-Phase ZnPAu Half-Heusler Compound

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Abstract: In this study, we present the first ab initio investigation of the half-Heusler compound ZnPAu, focusing on its structural, mechanical, dynamical, and electronic properties. Using Density Functional Theory (DFT) within the plane-wave formalism, we predict that ZnPAu crystallizes in the β-phase with a lattice parameter of approximately 6.03 Å. The calculated elastic constants satisfy the mechanical stability criteria, confirming the robustness of this material. Phonon dispersion calculations further demonstrate its dynamical stability, as no imaginary frequencies are detected. The electronic band structure reveals a semiconducting nature with a well-defined band gap, suggesting potential applications in electronic and thermoelectric devices. These results provide essential insights into the intrinsic stability and characteristics of ZnPAu, positioning it as a promising compound for future experimental validation. Moreover, the findings emphasize the effectiveness of first-principles approaches in predicting the behavior of previously unexplored half-Heusler systems. Overall, this study establishes a solid foundation for future investigations on ZnPAu and related materials, supporting the advancement of new functional materials for emerging technological applications.

Keywords: ab initio, ZnPAu, electronic, DFT

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Introduction

Half-Heusler (HH) compounds have gained remarkable attention due to their rich spectrum of electronic,

magnetic, and thermoelectric properties, enabling applications in energy harvesting, spintronics, and optoelectronic technologies [1–3]. Structurally, HH phases crystallize in the cubic C1b structure (space group F4̄3m), corresponding to the general chemical formula XYZ, where X and Y are typically transition or post-transition metals and Z is a main-group element [4, 5]. Their flexible electronic structure allows semiconducting, metallic, or half-metallic behaviors, depending on the valence electron count and atomic arrangement [6–8]. Recent studies have reported that HH materials with 8–18 valence electrons can display tunable band gaps, high Seebeck coefficients, and low lattice thermal conductivities, making them excellent thermoelectric candidates [9–11]. Gruhn [12] performed a systematic ab initio screening of 648 HH compounds and identified several potential semiconductors suitable for buffer layers in thin-film solar cells. Likewise, Carrete et al. [13] and Galanakis et al. [14] have emphasized the role of lattice matching and band engineering in optimizing HH performance.

Despite intensive research, many HH systems remain unexplored. ZnPAu, a member of the I–II–V family, has been scarcely investigated. To our knowledge, only Gruhn [12] briefly reported its lattice constant without further analysis. No comprehensive data exist on its structural, mechanical, phonon, and electronic features. Understanding these properties is crucial for assessing its feasibility in technological applications. In this study, we employ DFT and density functional perturbation theory (DFPT) to explore the β-phase ZnPAu compound. We systematically analyze its structural, mechanical, and vibrational stability, and we elucidate its electronic characteristics to provide insight into its potential as a functional and conductive half-Heusler compound.

Computational Methodology

All first-principles calculations were performed using the Quantum ESPRESSO package [15]. The exchange–correlation potential was treated within the generalized gradient approximation (GGA) in the Perdew–Burke–Ernzerhof (PBE) scheme [16]. Norm-conserving pseudopotentials were used for Zn ($3d^{10}4s^2$), P ($3s^23p^3$), and Au ($5d^{10}6s^1$). The kinetic energy cutoff was fixed at 80 Ry, and the Brillouin zone was sampled by an 8×8×8 Monkhorst–Pack k-point mesh [17].

Structural relaxations were carried out using the BFGS minimization algorithm [18, 19] with convergence thresholds of 10^{-4} Ry/Bohr for forces and 10^{-8} Ry for total energy. The β-phase of the HH structure (Wyckoff sites Zn(4a), P(4b), Au(4c)) was identified as the most stable by total-energy comparison among the α, β, and γ configurations [20].

Elastic constants were determined using the finite-strain method implemented in thermo_pw [21]. The polycrystalline bulk (B), shear (G), and Young's (E) moduli were computed via the Voigt–Reuss–Hill (VRH) averaging scheme [22, 23]. Phonon dispersion and density of states were obtained from DFPT [24] using a 4×4×4 q-point mesh. Electronic structures were calculated along high-symmetry directions with a 24×24×24 k-grid for accurate Fermi-level sampling.

Results and Discussion

Structural Properties

The total-energy minimization shows that the β-phase is the most stable configuration of ZnPAu, where Zn, P, and Au occupy (4a, 4b, 4c) positions, respectively (Figure 1). The optimized lattice constant a_0 = 6.12 Å agrees well with earlier theoretical data [12]. The formation energy per atom, computed as

$$E_f = E_{ZnPAu} - (E_{Zn} + E_P + E_{Au})$$

was found to be –0.92 eV/atom, confirming thermodynamic stability. The bulk modulus derived from the Birch–Murnaghan equation of state is 104.3 GPa, with a pressure derivative B_0' = 4.41. These values suggest moderately soft bonding, typical of half-Heusler systems [25–27].

Mechanical Properties

The calculated elastic constants (C_{11} = 161.7 GPa, C_{12} = 83.2 GPa, C_{44} = 72.6 GPa) fulfill the Born–Huang stability criteria ($C_{11}–C_{12} > 0$, $C_{11} + 2C_{12} > 0$, $C_{44} > 0$), confirming mechanical stability. The polycrystalline moduli derived from the VRH averaging are B = 109.4 GPa, G = 63.8 GPa, and E = 165.2 GPa. The Poisson ratio ν = 0.27 and the Pugh ratio B/G = 1.71 indicate ductility [28, 29]. The anisotropy factor $A = 2C_{44}/(C_{11}–C_{12})$ = 1.89 suggests noticeable elastic anisotropy, a common feature in metallic HH compounds [30, 31]. This anisotropy may influence their response under uniaxial stress, relevant for thin-film or multilayer applications.

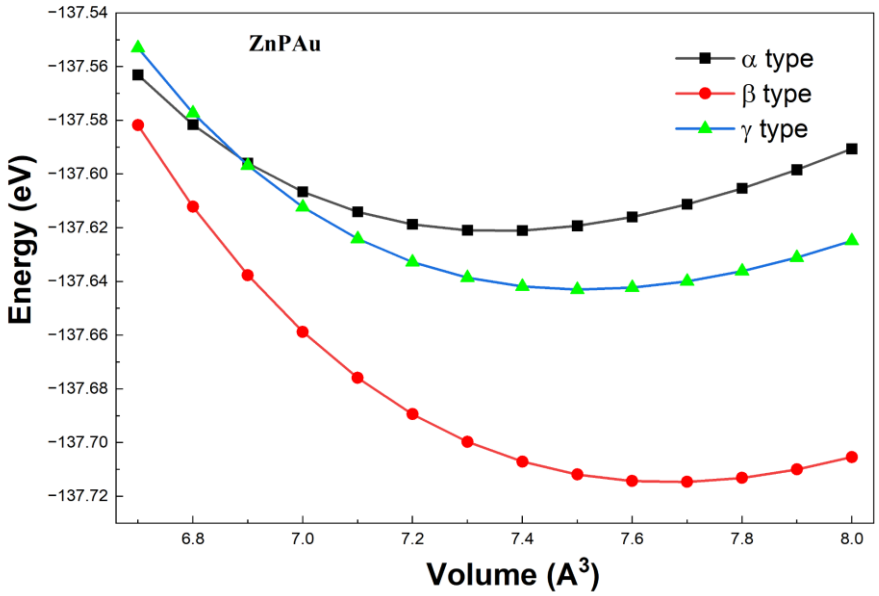

Figure 1. Total energy as a function of volume

Dynamical Properties

Phonon dispersion relations were computed along the high-symmetry directions of the Brillouin zone. The

absence of imaginary frequencies throughout the spectrum indicates dynamic stability of the β-phase (Figure 2). The phonon spectrum extends up to 8.4 THz, consistent with other Zn- or Au-containing HH compounds [32, 33].

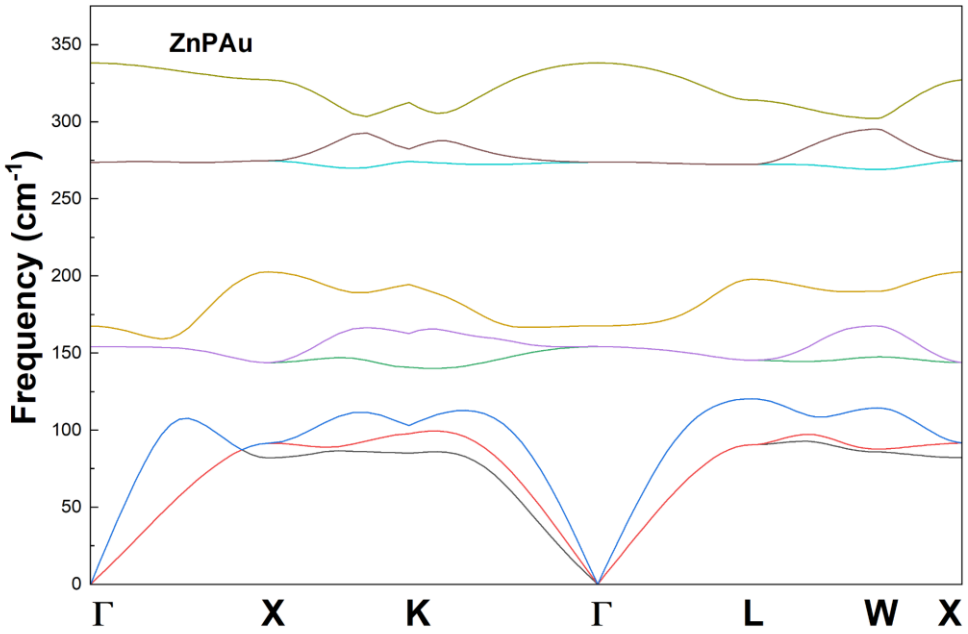

Figure 2. The phonon band diagram

The acoustic modes, dominated by Zn vibrations, exhibit a clear gap from the optical branches associated with Au and P atoms. This gap (~0.8 THz) may limit phonon–phonon scattering, potentially reducing lattice thermal conductivity [34, 35].

Electronic Properties

Contrary to an initial assumption of metallic behavior, the band structure of β-ZnPAu (Figure 3) reveals a semiconducting character with an indirect band gap of approximately 0.75 eV. The band gap transition occurs between the valence band maximum at the Gamma (Γ) point and the conduction band minimum at the X point. This semiconducting nature is primarily governed by the p-d hybridization between the orbitals of gold and phosphorus. While this type of hybridization is often observed in metallic Half-Heusler systems [36–39], it results here in the opening of a band gap.

The electronic states near the Fermi level, which form the valence and conduction bands, are dominated by Au 5d and P 3p states. This pronounced p-d hybridization enhances electron delocalization, a property that could confer good charge carrier mobility and promising intrinsic electrical conductivity for a doped material. The presence of an indirect band gap, combined with this favorable hybridization, positions ZnPAu as an interesting candidate for applications in optoelectronics or thermoelectrics.

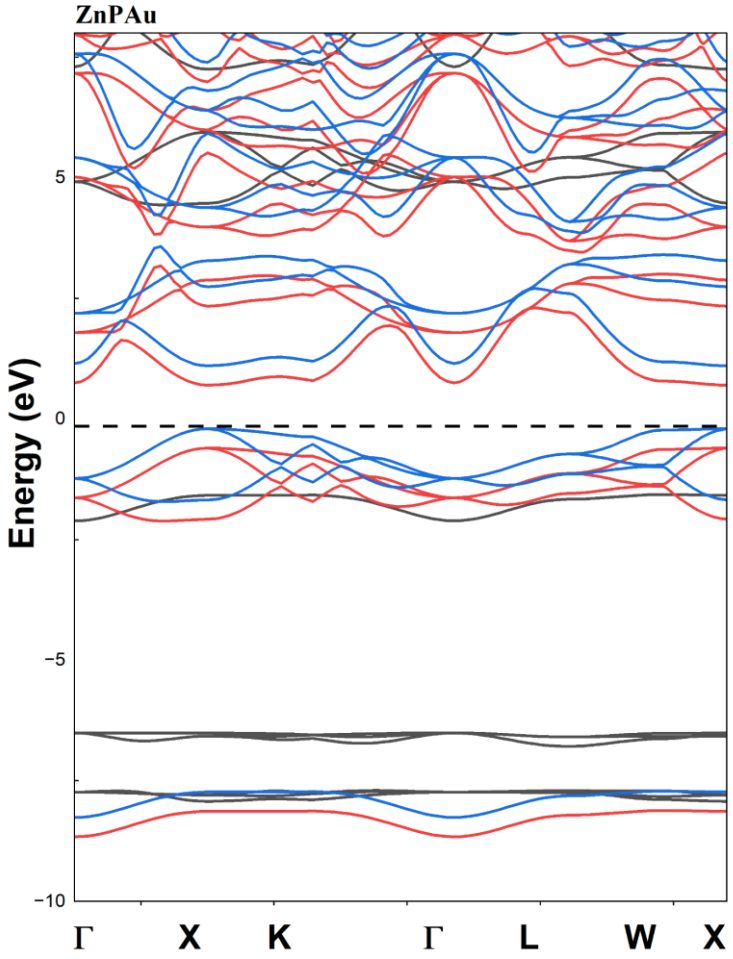

Figure 3. Band structure of ZnPAu

Conclusion

In summary, this comprehensive first-principles investigation elucidates the fundamental properties of the hitherto unexplored β-phase ZnPAu half-Heusler compound. Our calculations confirm its thermodynamic, mechanical, and dynamical stability, establishing it as a viable candidate for experimental synthesis. The compound exhibits ductile mechanical behavior and significant elastic anisotropy, which is advantageous for applications in flexible electronics or as thin-film coatings. Crucially, the electronic structure analysis reveals that β-ZnPAu is a semiconductor with an indirect band gap of approximately 0.75 eV, a finding that corrects the initial presumption of metallic character. This semiconducting nature is governed by a strong p-d hybridization between Au and P states near the Fermi level. Furthermore, the observed phonon band gap suggests an inherently low lattice thermal conductivity.

Collectively, these properties a moderate band gap, favourable electronic hybridization, ductility, and potentially

low lattice thermal conductivity position ZnPAu as a promising material for energy conversion applications. It emerges as a compelling candidate for further research in thermoelectrics or as an active layer in optoelectronic devices. These theoretical predictions provide a solid foundation and call for future experimental studies to validate these properties and explore its practical potential.

Propriété	Symbole / Unité	β-ZnPAu
Lattice constant	(a_0) (Å)	6.12
Formation energy	(E_f) (eV/atom)	−0.92
Bulk modulus	(B_0) (GPa)	104.3
Elastic constants	C_{11}, C_{12}, C_{44} (GPa)	161.7, 83.2, 72.6
Pugh's ratio	(B/G)	1.71
Poisson's ratio	ν)	0.27
Anisotropy factor	(A)	1.89
Maximum phonon frequency	(THz)	8.4
Electronic character	Eg (eV)	0.75

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Bridging Digital Health Literacy Gaps in South Africa's Community Health Centers: A Scoping Review on the Role and Capacity of Community Health Workers

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Abstract: Digital health technologies are crucial for improving healthcare access, patient engagement, and health outcomes. However, their success depends on the digital health literacy of users, which remains a significant barrier in South Africa. Community Health Workers (CHWs), as part of Ward-Based Primary Healthcare Outreach Teams (WBPHCOTs), play a crucial role in bridging these gaps by serving as intermediaries between formal health systems and communities. This paper presents a scoping review to examine the role of CHWs in improving digital health literacy and supporting the effective implementation of digital health interventions within Community Health Centers (CHCs). Findings reveal that CHWs face challenges, including limited digital skills, poor connectivity, system complexity, and resistance to digital adoption. Despite these barriers, they actively mitigate challenges through peer mentoring, patient education, and adaptive workflows. Drawing on international case studies, the review highlights strategies such as continuous digital literacy training, culturally adapted tools, mentorship programs, and sustained technical support to enhance CHW effectiveness. Strengthening CHW capacity can close the digital divide, improve data quality, and ensure equitable healthcare delivery. This paper recommends targeted investments in CHWs and digital infrastructure to optimise South Africa's digital health ecosystem and improve primary healthcare outcomes.

Keywords: Community Health Workers, Digital health literacy, Digital Health Intervention

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Introduction

Digital health technologies are transforming healthcare delivery globally by improving access, improving patient engagement, and improving health outcomes. In South Africa, these technologies, including mobile

health applications, electronic health records, and data management systems, offer significant potential to enhance communication between healthcare providers and communities while streamlining service delivery (Yuen et al., 2024; Sulistya Azahra, Pirdaus & Prabowo, 2024). However, the effectiveness of these interventions depends on the digital health literacy of users, defined as the ability to locate, understand, evaluate, and apply health information from digital sources. High levels of digital literacy are critical for informed health decision-making, combating misinformation, and promoting equitable healthcare (Yuen et al., 2024; Sulistya Azahra, Pirdaus & Prabowo, 2024). Despite widespread adoption of digital health systems, disparities in access and digital literacy persist, particularly in rural and underserved communities where socio-economic barriers and limited infrastructure constrain the use of information and communication technologies (Mwansa, Ngandu & Mkwambi, 2025). Vulnerable populations, including the elderly and residents in remote areas, are disproportionately affected, exacerbating existing health inequities (Aboye, Simegn & Aerts, 2024).

CHWs, embedded within South Africa's Ward-Based Primary Healthcare Outreach Teams (WBPHCOTs), serve as critical intermediaries between formal health systems and communities (Murphy et al., 2020). Their roles, range from formal health aides to volunteer peer educators, include delivering health education, facilitating access to care, and promoting community engagement (Rodrigues et al., 2022). Emerging research shows that CHWs recognise the potential of digital tools to enhance their impact, despite challenges such as high device costs, limited connectivity, and varying levels of digital literacy (Blondino et al., 2024).

CHCs, which act as primary hubs for healthcare delivery, increasingly rely on digital systems such as the Health Patient Registration System (HPRS), District Health Information System 2 (DHIS2), and mHealth applications to manage patient data and service delivery (Wright, O'Mahony & Cilliers, 2017; Mekebo et al., 2022). However, limited digital literacy among CHWs can hinder effective use of these systems, affecting data quality and service efficiency. Strengthening digital competencies among CHWs through training, mentorship, and access to culturally adapted tools is essential to bridging these gaps, enhancing service delivery, and promoting equitable healthcare outcomes across South Africa (Eggum & Aslam, 2024).

Problem statement

Despite the rapid growth of digital health technologies in South Africa, significant gaps persist in their use within CHCs due to varying levels of digital health literacy among CHWs and staff. While systems such as the HPRS, mHealth applications, and disease-specific registers have been implemented, CHWs often face limited access to devices, poor connectivity, low digital skills, and high administrative workloads. These challenges hinder effective service delivery, reduce data quality, and exacerbate health disparities, particularly between urban and rural areas.

Understanding how digital health literacy gaps impact CHW performance is crucial for optimising primary healthcare delivery. This study aims to synthesise existing evidence on the role of CHWs in enhancing digital health literacy and supporting digital health interventions. By identifying strategies to strengthen CHW capacity,

the review seeks to inform policymakers and healthcare stakeholders about targeted investments and interventions that can close the digital divide and improve healthcare equity in South Africa.

Methodology

This study employed a scoping review methodology, which is well-suited for mapping existing literature on broad and emerging topics. Unlike systematic reviews, which focus on synthesising evidence from all published and unpublished studies on a narrowly defined question, a scoping review is designed to identify knowledge gaps, examine how research is conducted, and provide an overview of the current evidence base (Peters et al., 2020). This approach was appropriate given the evolving nature of digital health systems and their impact on CHWs in South Africa.

The review aimed to explore how CHWs contribute to bridging digital health literacy gaps within Community CHCs. A structured search strategy was applied across multiple academic databases, including IEEE Xplore, ScienceDirect, Google Scholar, and Scopus, to ensure comprehensive coverage of relevant literature. Boolean operators and keywords such as “digital health,” “community health workers,” “digital literacy,” and “South Africa” were used to refine the search. A total of 98639 articles were identified and screened using predefined eligibility criteria, as outlined in Table 1.

Table 1. Eligibility Assessment Questions for Inclusion

No	Eligibility assessment question	Response
1	The study is written in English	Include
2	Addressed digital health interventions implemented in South Africa	Include
3	Discussed the role of CHWs in bridging digital health literacy gaps	Include
4	Explored strategies to optimise CHWs’ roles in closing these gaps within CHCs	Include
5	Does the title of the article suggest relevancy to the record?	Include
6	Is the article relevant with reference to the abstract?	Include

The screening process involved a two-step assessment:
Title and abstract screening to exclude non-relevant studies.
Full-text review to evaluate relevance against the research objectives.
Only articles that met the following conditions were included:

This rigorous process ensured that the review focused on high-quality, contextually relevant evidence, enabling a clear understanding of current digital health interventions, challenges, and opportunities for strengthening CHW involvement in digital transformation. The screening process identified a total of 22 articles that were deemed eligible for inclusion in the study, and these are presented in the results section.

Literature Review

This section examines digital health interventions in South Africa, focusing on their implementation at national and provincial levels and their implications for CHWs. It highlights the complexity of digital systems embedded in CHCs and the dual role these tools play in either bridging or widening digital health literacy gaps among CHWs. International case studies also provide comparative insights into how CHWs in other contexts have addressed digital health literacy challenges, offering lessons for optimising South Africa's digital health strategies.

Digital Health Interventions in South Africa (Nationally and Provincially)

Nationally, South Africa has deployed a comprehensive suite of systems across maternal and child health, youth engagement, referrals, disease management, laboratory integration, pharmaceutical supply chains, immunisation campaigns, and health information reporting (Jahan, 2020; Kachimanga et al., 2024; Agency, 2022; Dimagi, 2020). Maternal and youth-focused platforms include MomConnect, delivering SMS-based health information and appointment reminders to pregnant women (Jahan, 2020; Kachimanga et al., 2024), and B-Wise, a youth-centred platform providing sexual and reproductive health, HIV/TB, wellness, and mental health resources (Agency, 2022). For frontline operations, the WBPHCOT mHealth system, built on CommCare, enables CHWs to register households, monitor clients, and manage care, while educational video pilots enhance maternal and child health awareness despite persistent digital health literacy barriers among some CHWs (Dimagi, 2020; Greuel et al., 2023). Referral pathways are strengthened through Vula Mobile, linking CHWs and primary care staff to specialists, reducing patient travel and improving case management (Gloster, Mash & Swartz, 2021; Steyn, Mash & Hendricks, 2022). Campaign-level systems such as the Electronic Vaccination Data System (EVDS, 2021) support client registration and vaccine coverage tracking (Hofisi & Chigova, 2021; Rahmadhan & Handayani, 2023), while the Health Patient Registration System / Patient Master Index (HPRS/PMI, 2021) underpins a "one-patient-one-record" approach (National Department of Health, 2021).

Disease surveillance and management are facilitated by electronic registers such as TIER.Net for HIV and TB monitoring (Murphy et al., 2022; Digital Square, 2022) and EDRWeb for drug-resistant TB (Masuku et al., 2020; Kansiime et al., 2024), with CHWs contributing household and clinic-level data. Laboratory processes are digitised through Labtrak, enabling indirect CHW interaction for timely test requests and results (Mabumbe, 2024). Pharmaceutical management is supported through the Stock Visibility System (SVS, 2014) for medicine tracking (Global Health Supply Chain Program, 2020; VillageReach, 2024), RxSolution for inventory control and dispensing (Management Sciences for Health, 2020; Mash et al., 2022), and CCMDD/SyNCH (2016) for chronic medication enrolment, adherence monitoring, and decentralised distribution (Lewis et al., 2023). At the health information level, District Health Information System 2 (DHIS2) consolidates CHW-collected data for reporting and programme monitoring (Mekebo et al., 2022; Thomas et al., 2025), while the Western Cape Provincial Health Data Centre (PHDC, 2012) integrates patient-level records to support longitudinal care (Boulle et al., 2019).

Table 2. Overview of the provinces in which these systems are implemented within CHCs

Digital Health Intervention	WC	GP	KZN	EC	FS	LP	NW	MP	NC	CHW Interaction
PHDC (Provincial Health Data Centre)	✔	✘	✘	✘	✘	✘	✘	✘	✘	Indirect: CHW data feeds into PHDC via mHealth/other systems
Vula is documented in local workflows	✔	✔	✔	✔	✔	✔	✔	✔	✔	Indirect/Direct: depends on local policy
Patient file digitisation (cloud)	✘	✔	✘	✘	✘	✘	✘	✘	✘	Indirect: CHWs benefit from quicker record retrieval
HIV performance dashboards	✘	✔	✘	✘	✘	✘	✘	✘	✘	Indirect: informs CHW targeting, but no direct use
HPRS large-scale provincial adoption stats	✘	✔	✔	✔	✔	✔	✔	✔	✔	Indirect: same as above for HPRS
Provincial formulary-aligned CCMDD/SyNCH	✔	✔	✔	✔	✔	✔	✔	✔	✔	Indirect: CHWs support patient adherence and collection coordination

As demonstrated in Table 2, the implementation of health data systems in South Africa demonstrates significant variability across provinces. The Western Cape and Gauteng are at the forefront, utilising advanced integration and cloud-based systems to enhance healthcare delivery. In contrast, provinces such as KwaZulu-Natal and the Eastern Cape face considerable connectivity challenges, particularly in rural and underserved areas. The Free State has shown notable progress in the adoption of the HPRS, while most other provinces continue to rely primarily on national platforms. Additionally, CHWs directly or indirectly interact with the systems by fulfilling a wide range of functions, including patient registration and health education. However, their effectiveness is often hindered by challenges such as limited digital health literacy, inadequate training opportunities, and persistent connectivity issues. Digital health tools, such as MomConnect and DHIS2, have proven valuable in enhancing CHW efficiency and service delivery. Nonetheless, the long-term success of these tools relies on sustained institutional support, equitable access to technology, and comprehensive capacity-building initiatives aimed at strengthening the digital health workforce.

South Africa's CHCs have adopted various digital health technologies, with this paper focusing on key systems due to their national relevance and direct use by CHWs. The selected systems, as demonstrated in the table above, serve as essential infrastructures for primary healthcare delivery at the community level, chosen for three main reasons. Firstly, strategic alignment with national health priorities is crucial for South Africa's digital health strategy. These systems support key public health programs, including maternal and child health, HIV/TB management, immunisation, chronic medication distribution, and health data reporting. Their role is vital for meeting national targets, improving disease surveillance, and promoting accountability through data-driven

decision-making. Secondly, CHWs directly interact with mHealth platforms like WBPHCOT for household registrations and patient referrals through Vula Mobile, and indirectly through systems like DHIS2 or PHDC. This role makes CHWs crucial for digital health implementation, highlighting the importance of addressing digital health literacy challenges. Thirdly, these platforms span multiple provinces and demonstrate different levels of digital health maturity, from advanced integration in the Western Cape to emerging use in rural areas. This study provides a representative view of the digital landscape while recognising the existence of pilot programs at the facility or district levels. Many digital systems have been developed, but many are context-specific or limited in geographic reach, making them less suitable for national-level analysis. This selection balances practicality and focus, addressing the digital health literacy challenges faced by CHWs while considering South Africa's diverse digital health ecosystem.

International case studies of the Role of Community Health Workers in Bridging Digital Health Literacy Gaps: lessons learned for South Africa International experience shows that CHWs can effectively address digital health literacy gaps and enhance primary healthcare delivery. In Rwanda, the Community Health Worker Digital Platform (RapidSMS) allowed CHWs to track maternal and child health data in real time using basic mobile phones (Hategeka, Ruton & Law, 2019). This program significantly improved health outcomes and reduced maternal mortality, highlighting that structured training enables CHWs to become effective data reporters. In South Africa, this emphasises the importance of mobile-friendly digital training for managing community health data in low-connectivity areas.

In India, Accredited Social Health Activists (ASHA) used mobile apps for maternal health tracking, immunisation reminders, and COVID-19 contact tracing (Charanthimath et al., 2021). Despite challenges like low digital health literacy and infrastructure issues, ongoing peer mentoring and localised interfaces boosted adoption. For South Africa, the key takeaway is the importance of continuous support, mentorship, and cultural adaptation of digital tools to ensure sustained usage. Ethiopia’s Health Extension Workers implemented the electronic Community Health Information System (eCHIS), replacing paper registers with tablets for real-time documentation (Bogale et al., 2023). Initial issues included technical breakdowns, internet access problems, and low digital skills. However, improved maintenance support and local troubleshooting teams enhanced performance. This case emphasises the importance of ongoing technical support and decentralised problem-solving to maintain confidence and prevent digital burnout among Community Health Workers in South Africa. In Malawi, smartphone mHealth tools helped CHWs diagnose and manage childhood illnesses in remote areas, using decision-support algorithms and reporting systems (Kachimanga et al., 2024). Initially, older CHWs struggled, especially those with limited education, but pairing them with digitally skilled younger peers improved adoption. This suggests that in South Africa, intergenerational pairing and targeted support for older CHWs can bridge digital health literacy gaps and enhance system uptake.

International experiences show that CHWs can drive digital transformation in primary healthcare when they receive structured training, ongoing technical support, locally adapted tools, and peer learning. Applying these insights can enhance CHWs' abilities in South Africa, bridge digital health literacy gaps, and improve

efficiency, accuracy, and equity in community health services.

Results

To summarise the roles of CHWs in addressing digital health challenges in South Africa, Table 3 outlines the main obstacles faced in key digital health systems, the strategies employed by CHWs to overcome these challenges, and recommendations for enhancing their effectiveness. The table emphasises CHWs as frontline implementers and problem-solvers, ensuring continuity of care, data integrity, and effective service delivery despite limitations in technology, infrastructure, and workflows.

Table 3. Challenges of digital health literacy and the recommended solutions

Digital Health Challenge	Systems Affected	Current CHW Mitigation	Recommendations to Fully Eliminate the Challenge Using CHWs	Authors
Limited digital literacy, especially among older CHWs	WBPHCOT mHealth, educational video pilots, Vula Mobile, TIER.Net, EDRWeb	Participate in training, peer mentoring, on-the-job learning, and intergenerational support (pairing with younger tech-savvy CHWs)	Implement continuous structured digital health literacy programs; integrate mentorship schemes; use simplified, mobile-friendly interfaces and culturally adapted tools	(Dimagi, 2020), (Greuel et al., 2023), (Kachimanga et al., 2024), (Schneider et al. (2021)
Connectivity and network issues	MomConnect, B-Wise, WBPHCOT mHealth, EVDS, HPRS/PMI	Use offline functionality, SMS-based reporting, or paper backups; plan visits around connectivity availability	Advocate for offline-capable tools, expand local network infrastructure, provide data subsidies or portable hotspots, and establish community-based troubleshooting support	(Jahan, 2020), (Agency, 2022), (Hofisi & Chigova, 2021), (NDoH, 2021)
System complexity and usability	HPRS/PMI, TIER.Net, EDRWeb, Labtrak, DHIS2	Support peers in navigation, translate outputs into actionable tasks, provide feedback to supervisors, share informal troubleshooting strategies	Involve CHWs in system design and usability testing; simplify interfaces; provide ongoing refresher training and real-time helpdesk support	(Murphy et al., 2022), (Masuku et al., 2020), (Mabumbe, 2024), (GHSC,2020).
High administrative workload and multiple reporting	DHIS2, EVDS, SVS, RxSolution, CCMDD/SyNCH	Prioritise critical tasks, combine service delivery with reporting, streamline household visit workflows	Integrate systems to reduce duplication; automate routine reporting; assign dedicated CHW roles for data management; balance workloads through staffing	(Lewis et al., 2023), (Thomas et al., 2025), (Hofisi & Chigova, 2021)

Digital Health Challenge	Systems Affected	Current CHW Mitigation	Recommendations to Fully Eliminate the Challenge Using CHWs	Authors
requirements			adjustments	
Data accuracy and completeness issues	HPRS/PMI, TIER.Net, EVDS, DHIS2	Verify patient information during visits, cross-check records, follow up with clients, escalate complex cases	Standardise data entry protocols; implement supervisory audits; use real-time feedback and validation within digital tools; incentivise accurate reporting	(Boulle et al., 2019), (Thomas et al., 2025), (Kirk et al,2020)
Patient or peer resistance to digital adoption	MomConnect, B-Wise, WBPHCOT mHealth	Act as advocates and role models, educate clients and colleagues, assist with registration and system use	Conduct structured community engagement campaigns; provide incentives for adoption; co-create culturally relevant content; ensure CHWs are trained to support behavioural change	(O'Donovan et al., 2018), (Rutebemberwa et al., 2024)
Technical breakdowns or system downtime	EVDS, HPRS/PMI, Vula Mobile, TIER.Net, EDRWeb	Maintain paper backups, report issues, provide temporary workarounds to continue services	Train CHWs in basic troubleshooting; establish rapid-response IT support; schedule regular maintenance; integrate contingency workflows to maintain service continuity	(Kansiime et al., 2024), (Rahmadhan & Handayani, 2023)

The table highlights evidence from various digital health initiatives in South Africa, such as MomConnect and TIER.Net, emphasising the crucial role of CHWs in direct tasks (like patient monitoring) and indirect contributions (like data reporting). By documenting current strategies and recommendations, it offers a framework to optimise CHW engagement, enhance digital health literacy, and improve the effectiveness of primary healthcare digital interventions.

Discussion

This scoping review emphasises the vital role of CHWs in improving digital health literacy within South Africa's CHCs. While CHWs engage with various digital health tools like WBPHCOT mHealth and MomConnect, they face significant challenges such as limited digital literacy, poor connectivity, complex systems, heavy workloads, and technical issues. If these obstacles remain unresolved, they could undermine primary healthcare delivery and the quality of health data needed for informed decision-making. CHWs actively engage with digital tools, using peer mentoring and support to overcome operational challenges. Case studies from Rwanda, India, Ethiopia, and Malawi highlight the importance of structured training, culturally adapted tools, mentorship, and ongoing technical support for successful digital adoption. These insights are especially relevant to rural and underserved areas of South Africa, where digital infrastructure is inconsistent.

This review highlights a gap in integrating CHWs into the design and evaluation of digital health interventions. While essential for implementation, their insights are often overlooked, limiting the relevance and usability of digital solutions. Enhancing CHWs' digital health literacy skills can improve technology uptake, patient engagement, data quality, and overall health service efficiency. The findings emphasise that CHWs can promote health equity by providing tailored digital health literacy support to vulnerable populations. This helps reduce disparities caused by socioeconomic and infrastructural inequalities, positioning CHWs as key players in achieving South Africa's digital health strategy goals of enhanced service delivery, disease surveillance, and health outcomes.

Conclusion

Effectively addressing digital health literacy gaps among CHWs requires strategies that are tailored to account for factors such as age, geographic location, resource availability, and mental health. This must be complemented by simplified, user-friendly technology, continuous and context-sensitive training, on-the-job support, and strong organisational reinforcement. Implementing these measures enables CHWs to engage confidently and efficiently with digital health interventions, ensuring both high-quality service delivery and the integrity of health data. South Africa must recognise the critical role of CHWs and leverage evidence-based solutions and lessons from international experiences to empower this workforce. Doing so will not only strengthen the sustainability of digital health interventions but also enhance healthcare delivery, bridge the digital health literacy gap, and generate lasting impact for communities across the country.

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Operational Readiness for e-Governance in Local Government: A Case Study of the City of Mbombela with a Focus on e-Participation

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Abstract: This paper assesses the operational readiness of the City of Mbombela for implementing e-Governance, focusing specifically on e-Participation to improve service delivery. Using a qualitative case study design approach, the research involves document analysis, secondary data, and key informant interviews to evaluate four readiness areas: digital infrastructure, institutional capacity, legal frameworks, and stakeholder engagement. Findings reveal that while Mbombela demonstrates policy alignment and partial ICT adoption, challenges persist in bridging the digital divide, strengthening interdepartmental coordination, and promoting inclusive citizen participation. Comparative insights from global examples like Seoul, Nairobi, Reykjavik, Cape Town, and Estonia suggest adaptable strategies such as mobile-first platforms, community access points, participatory budgeting, and open data dashboards. Building on these lessons, the paper proposes a phased roadmap for Mbombela, including broadband expansion, pilot digital engagement programs, digital literacy initiatives, and multi-stakeholder partnerships. The study contributes to e-Governance scholarship by contextualising operational readiness within the realities of South African municipalities, offering both a conceptual framework and practical strategies for institutionalising inclusive e-Participation. The paper concludes that sustainable e-Governance in Mbombela requires bridging technical, social, and institutional gaps while embedding citizen engagement into governance structures.

Keywords: E-governance, E-participation, Operational readiness, Service delivery

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Introduction

The rapid growth of information and communication technologies (ICT) has reshaped how organisations provide services and information, especially in service delivery. The emergence of e-government has enabled governments to distribute services and information more efficiently, simplifying workflows, improving public service delivery, and managing data, information, human resources, and financial resources (Kumar, 2024).

Since the 1960s, the South African government has invested in ICT to automate government services and enhance accessibility (Mofokeng et al., 2025). In the evolving landscape of public administration, e-Governance has emerged as a transformative tool for enhancing transparency, accountability, and efficiency in service delivery. In South Africa, municipalities are increasingly adopting digital platforms to streamline operations and improve citizen engagement (Shibambu, 2024). However, the slow adoption of digital transformation, influenced by financial constraints, skills gaps, and political will, has limited the ability of local governments to align with international governance standards (Mofokeng et al., 2025).

The city of Mbombela is a local municipality in South Africa, governed by the Municipal Structures Act and Municipal Systems Act (Thusi et al., 2023). It comprises a Municipal Council, Executive Mayor, Municipal Manager, and various departments that handle service delivery such as water, sanitation, electricity, roads, housing, and community services. The city of Mbombela has established a Public Participation Strategy, which facilitates community involvement through a Ward Committee System. This system is managed by the Public Participation Unit situated in the Office of the Speaker and the Integrated Development Plan (IDP) Representative Forum (The City of Mbombela, 2020a). Mbombela local municipality is a key urban center tasked with delivering essential services such as water, sanitation, electricity, and waste management to a diverse population. Despite its strategic importance, Mbombela faces persistent challenges in service delivery, including infrastructure deficits, administrative inefficiencies, and limited responsiveness to citizen grievances (Chakwizira, 2024).

There is still heavy reliance on the traditional methods of public participation in policy development and service delivery between the municipality and its citizens. Public participation in the municipality takes place through community meetings, zonal meetings, mayoral Imbizo(s), speaker’s outreach programs, business and commercial stakeholders' engagements and traditional leaders' engagements. Pre-and-post-COVID 19 pandemic the municipality had to introduce other mechanisms of public engagement such as virtual meetings, drop-in boxes, central email, radio stations and social media platforms (Meta, Instagram, WhatsApp) (The City of Mbombela, 2020b).

Integrating e-Governance tools, such as online grievance platforms and monitoring dashboards, could significantly enhance these processes, addressing common issues faced by South African municipalities (Juta & Mello, 2023). e-Participation can empower citizens to engage in policy processes without the constraints of time and location, significantly enhancing governmental transparency. On a national scale, there is a substantial effort from both the public and private sectors to foster the development of a capable developmental state, and eParticipation directly contributes to this goal. Not only will e-Participation assist municipalities in delivering services more effectively, but it also has the potential to promote "enabled digital citizenship." Therefore, the paper aims to investigate the role of operational readiness for e-Governance in the city of Mbombela and explore how e-Participation can enhance service delivery with the focus on digital infrastructure, citizen engagement, institutional capacity, and policy frameworks.

Methodology

A qualitative case study approach is a research method that focuses on a specific case within its real-world context over a sustained period using multiple data sources like interviews, observations, and documents (Creswell & Creswell, 2018). This study employs a qualitative case study approach to examine the e-Governance structure and service delivery challenges in the city Mbombela. The methodology integrates document analysis, secondary data review, and, where applicable, key informant interviews to provide a comprehensive understanding of the municipality's administrative dynamics. Primary sources included the integrated development plans (IDPs), annual performance reports, audit reports from the Auditor-General of South Africa, and legislative frameworks such as the Municipal Structures Act and Municipal Systems Act. These documents provided insight into the formal governance structure, strategic priorities and institutional performance. The secondary data review involved the analysis of reports from Cooperative Governance, Human Settlements, and Traditional Affairs (CoGSTHA), South African Local Government Association (SALGA), and Municipal IQ and academic literature on local governance and service delivery in South Africa. The exercise assisted in contextualising the city of Mbombela's challenges within boarder national trends. Furthermore, key informant semi-structured interviews with municipal officials offered lived experiences, perception of goverance and service delivery realities. Observations at the ward councilor's meeting provided insights into the challenges faced by ward councilors when engaging with communities, and interaction with community leaders reflected shared experiences and realities of service delivery in engagement with local municipalities. The study used thematic analysis to identify recurring patterns and issues in e-Governance and service delivery. A comparative lens was applied to benchmark the city of Mbombela against other municipalities and triangulation ensured the reliability of findings by cross-verifying data from multiple sources. Ethical considerations were employed. The research got ethical approval from the CSIR ethics committee for the study. Informed consent was obtained from all interview participants, anonymity and confidentiality was maintained at all times and only publicly available data was used for document analysis. Limitations included limited access to internal municipal data, potential bias in secondary sources and challenges in securing interviews with key stakeholders due to availability or political sensitivity.

Literature Review

This section provides a detailed overview of e-Governance, e-Participation tools of global case studies and operational readiness for e-Governance to enable e-Participation in the city of Mbombela.

e-Governance

e-Governance broadly refers to the strategic use of ICTs, particularly the internet and digital platforms to enhance government service delivery, strengthen administrative efficiency, promote transparency, accountability, and citizen engagement in public affairs (Grigalashvili, 2022). Within the South African context,

legislative frameworks such as the Municipal Systems Act (2000) explicitly encourage municipalities to adopt innovative approaches to service delivery, including the deployment of digital platforms that align with principles of accessibility and responsiveness (Thusi et al., 2023). The effectiveness of e-Governance, however, is not determined by technology alone. As Myeong and Bokhari (2023) emphasise, its success depends on institutional readiness, robust technological infrastructure, and meaningful stakeholder engagement. When these elements are in place, e-Governance transforms the interaction between government and society, enabling not only efficient internal processes but also deeper forms of accountability and inclusivity. Crucially, e-Governance extends beyond administrative modernisation. Its true value emerges when digital tools are leveraged to strengthen democratic practices by opening new avenues for citizen involvement in decision-making. This is where e-Participation, a critical dimension of e-Governance becomes essential. By enabling citizens to engage directly with local government processes, e-Participation bridges the gap between digital service provision and active democratic engagement. The following section therefore explores e-Participation in greater depth, examining its role in fostering participatory governance and its specific relevance for the City of Mbombela.

e-Participation: Tools, Benefits, and Challenges.

In South Africa, e-Participation is increasingly recognised as a mechanism to strengthen citizen engagement and improve evidence-based policymaking, both of which are central to responsive and accountable local governance. By creating digital spaces through online surveys, mobile applications, social media platforms, and interactive portals, municipalities can gather citizen input on policies, service delivery, and development priorities, thereby deepening participatory democracy. The value of e-Participation lies in its ability to enhance transparency, inclusivity, efficiency, accountability, and empowerment. It builds trust by making government processes more visible, ensures marginalised and rural communities have a voice, aligns resource allocation with actual community needs, and empowers residents to actively shape the development of their municipality. Global best practices illustrate how e-Participation can effectively complement e-Governance by addressing challenges of trust, access, and inclusivity. For instance, Seoul's mVoting platform enabled residents to vote on local issues using mobile technology, directly linking citizens to decision-making processes and strengthening transparency. Seoul's mVoting platform has seen significant user engagement, with over 280,000 downloads as of June 2016; Over 1.1 million citizens have participated in votes, with 4,404 proposals submitted and of which 88.3% were from citizens; and 181 proposals have been officially accepted and implemented by the Seoul Metropolitan Government (Holzer & Kang, 2017).

Nairobi's Huduma centers and portal streamlined service delivery and reduced corruption by integrating citizen feedback mechanisms and ensuring accountability through real-time monitoring. Huduma platforms serve over 51 million citizens, with 52 centers operating nationwide, offering 21+ services from 12 ministries and agencies (MyGov, 2023). Huduma has a high level of user awareness and satisfaction, with users using them for passport applications and tax registration (Kemboi & Premanandam, 2025). In their study Kemboi and Premanandam (2025) reveal that 64% of users believe digital platforms have helped reduce corruption, while 69% believe Huduma and e-Gov can support better governance under current reforms. However, digital inclusion, digital

literacy, infrastructure gaps, and rural connectivity remain a challenge. 72% of users emphasised the need for more digital literacy programs, while 56% cited poor Internet and rural access as major barriers. Furthermore, only one-third of Kenyans had Internet access, with rural areas significantly underserved (Kemboi & Premanandam, 2025). Despite these challenges, Huduma and e-Gov platforms are seen as valuable tools for improving governance.

Reykjavik's Better Reykjavik platform empowered residents to propose and vote on community projects, demonstrating how citizen input can be systematically integrated into urban governance. Better Reykjavik is an e-Participation platform developed by the Citizens Foundation in collaboration with the City of Reykjavik to crowdsource solutions for urban challenges and improve public service delivery. Launched in May 2010, the platform aims to restore public trust post-2008 financial crisis by enabling citizens to directly influence municipal decision-making (Lackaff, 2015). Its functions include agenda setting, participatory budgeting, policy crowdsourcing, and education policy co-creation. The platform has a user penetration rate of over 58%, with over 70,000 participants out of 120,000 residents (Council of Europe, 2025). Over 10,000 ideas have been submitted, with around 21,000 debate points for and against proposals. The platform has seen significant improvements in all 10 neighbourhoods and improved trust between citizens and local government (Lackaff, 2015). Innovative features include an open-source platform using "Your Priorities" software, multimedia submissions, an AI-enhanced user experience, a unique debate system for structured dialogue, and a crowd-law model where citizens co-create laws and policies (Council of Europe, 2025).

Cape Town's SmartCape initiative addressed the digital divide by improving access to digital literacy and free internet services, enabling broader participation from marginalised groups. SmartCape is a free public Internet access program offered at 102 public libraries in Cape Town, aiming to bridge the digital divide and enhance e-participation in public service delivery by providing 500MB of monthly internet access to registered users, enabling them to access government services, educational resources, and job opportunities (City of Cape Town, 2025). Libraries like Harare and Nazeema Isaacs recorded over 1,000 sessions per month, with high usage among ages 11-18 (City of Cape Town, 2025). The most used feature is the Internet, with word processing being used in over 400 sessions at some libraries. The program's impact on service delivery includes access to e-government, education and employment, and community empowerment. The technical and social infrastructure uses open-source software to reduce costs, and each access point includes six Internet-enabled computers. Challenges include digital literacy gaps, gender disparity in usage, and the need for targeted outreach (Zondi & Ndebele, 2024).

Estonia's nationwide digital governance system, which includes e-Residency and e-Voting, institutionalised e-Participation by embedding citizen engagement directly into state functions, overcoming barriers of distance and efficiency. The core infrastructure includes mandatory digital ID cards, a secure data exchange system, and strong data protection laws (Vassil, 2015). The system has a once-only principle, preventing citizens from re-submitting data already held by the government. Key statistics show that 100% of public services are available online and paperless, with over 80 million authentications and 35 million digital transactions in 2014 (Vassil,

2015). Tax filing is done online in 3-5 minutes, and one-third of citizens voted online in recent elections. The system has a high user satisfaction rate, with a satisfaction rate of 83%. Digital signatures save approximately 2% of the gross domestic product (GDP) on staff time annually. Digital cabinet meetings and citizen participation platforms further enhance transparency, accountability, and community participation (Souigat, 2025).

These examples show that when e-Participation is designed inclusively and backed by strong institutional commitment, it not only enhances citizen-government interaction but also addresses common challenges such as limited access, corruption, inefficiency, and low trust. At the same time, challenges such as the digital divide, low Internet penetration in certain areas, limited digital literacy, and concerns around data security and institutional readiness must still be addressed for e-Participation to succeed in South Africa. These barriers are particularly relevant in local government contexts like the city of Mbombela, where diverse socio-economic conditions shape access to and use of digital platforms. Positioning e-Participation as more than a technical exercise, but rather as a democratic practice, is critical for the city of Mbombela. Its adoption has the potential not only to improve service delivery but also to foster stronger, more inclusive citizen government relations, which is an essential step toward achieving sustainable e-Governance at the local level. However, the successful implementation of e-Participation depends on operational readiness, the extent to which municipalities are institutionally, technologically, and socially prepared to adopt and sustain such systems. This includes the availability of reliable ICT infrastructure, adequate funding, skilled personnel, supportive policies, and citizen digital literacy. Without these conditions, e-Participation risks becoming symbolic rather than transformative. For the city of Mbombela, assessing operational readiness is therefore critical. It provides the foundation for understanding whether e-Participation can be effectively integrated into local governance processes in a way that not only improves service delivery but also fosters stronger, more inclusive democratic engagement.

Operational Readiness: Key Dimensions—Technical Infrastructure, Human Resources, Legal Frameworks, and Stakeholder Engagement.

Operational readiness for e-Governance is a crucial concept that outlines a municipality or government's readiness to implement and sustain digital governance initiatives. This is especially important for projects involving citizen participation, service delivery, and administrative efficiency enhancement. Key dimensions of operational readiness include reliable connectivity, government ICT resources, security measures, system integration, skilled personnel, dedicated roles, change management strategies, legal and policy frameworks, stakeholder engagement, collaboration with civil society, private sector partnerships, and internal coordination. Technical infrastructure is essential for ensuring citizens can access digital services without interruptions. Government offices should be equipped with the necessary hardware and software for supporting various digital tasks and services. Security measures should be implemented to safeguard citizen information and build trust in digital services. System integration with existing systems can create streamlined operations and enhance service delivery. Human resources are also crucial for e-Governance initiatives. Staff training in digital tools, data management practices, and citizen engagement is essential. Dedicated roles and change management strategies

can help manage citizen engagement in the digital realm. Legal and policy frameworks should ensure adherence to data protection laws, develop supportive policies, and incorporate technology into service delivery through technology-driven procurement. Stakeholder engagement is vital for citizen participation and ensuring diverse voices are heard in the digital space. Collaboration with civil society, private sector partnerships, and internal coordination can leverage expertise and resources to enhance e-Governance initiatives. Without proper operational readiness, e-Governance initiatives may struggle to be sustainable and scalable, undermining the potential benefits of digital transformation for public administration. Operational readiness is paramount; without it, initiatives aimed at improving digital governance may face significant challenges. Ineffective adoption of digital tools could lead to service failures due to technical issues, while a lack of citizen trust may result in low engagement with available platforms. Furthermore, inadequate data management practices can expose sensitive information to security risks. Ultimately, without proper operational readiness, e-Governance initiatives struggle to be sustainable and scalable, undermining the potential benefits of digital transformation for public administration.

Discussion

The discussion session provides insights to the current state of e-Goverance in the city of Mbomela to gain a deeper understanding of the progress of e-Governance and challenges encountered when implementing e-Participation.

Current State of e-Governance in Mbombela

The city of Mbombela is making notable strides toward e-Governance, yet it is still grappling with several structural and socio-economic challenges that hinder its operational effectiveness. Improvements in digital infrastructure are evident, particularly with enhanced broadband connectivity in urban areas and the implementation of modern ICT tools such as Microsoft Office 365, aimed at optimising internal operations. Nevertheless, rural regions continue to experience inadequate connectivity, and significant disparities in access to smartphones and data among low-income residents which pose barriers to equitable participation in digital initiatives. The policy landscape also supports these efforts, with frameworks like the Integrated Development Plan (IDP) in alignment with national digital transformation goals. These frameworks focus on promoting transparency, innovation, and active citizen participation. Compliance with the Protection of Personal Information Act (POPIA) offers a foundation for data protection; however, challenges persist in terms of enforcement and public awareness. While there is acknowledgment of the need for digital inclusion strategies, initiatives intended to expand public Wi-Fi access and enhance digital literacy are still in the early stages of development. There is institutional capacity benefits from ongoing training programs and substantial budget allocations directed towards ICT upgrades. However, deficiencies in advanced ICT skills, ineffective interdepartmental collaboration, and a sluggish response to issues continue to hinder operational efficiency and implementation efforts. Citizen engagement primarily relies on traditional community structures such as ward committees and IDP forums, while the use of digital platforms remains limited. Public trust in government

fluctuates, marked by dissatisfaction surrounding slow service delivery and the circulation of outdated information. Additionally, low levels of digital literacy, particularly in rural and low-income areas, restrict meaningful engagement and participation. In summary, while the city of Mbombela shows a strong commitment to digital transformation through various investments and policy alignment, it is not yet fully operationally ready. To build a more inclusive and responsive e-Governance framework, it is crucial to address existing infrastructure gaps, improve institutional coordination, foster citizen trust, and prioritise digital inclusion initiatives.

Results

The results sections draws on lessons learnt from global best practices, the city of Mbombela has a unique opportunity to strengthen e-Participation by adapting proven models to its local context. The table below outlines practical strategies, and detailed adaptation approaches from real-world examples.

Table 3. Challenges of digital health literacy and the recommended solutions

Case Study	Key Feature	Benefit/ Outcome	Challenges/ Limitations	Relevance for Mbombela	Author
Seoul (mVoting)	Mobile voting & decision-making app	1.1M+ citizens engaged; proposals implemented; strengthened transparency	Ensuring sustained citizen engagement	High mobile penetration in Mbombela makes mobile-first feasible	(Holzer & Kang, 2017)
Nairobi (Huduma Centers)	One-stop service centers + portal	Reduced corruption, 51M citizens served; improved service delivery	Limited Internet access; rural inclusion gaps	Streamlined service delivery and feedback models can be adapted	(MyGov, 2023); (Kemboi & Premanandam, 2025).
Reykjavik (Better Reykjavik)	Online participatory budgeting & policy crowdsourcing	70,000 users (58% penetration); 10k+ ideas submitted; improved trust	Risk of elite capture; requires political will	Can empower Mbombela residents to co-decide on budgets	(Lackaff, 2015); (Council of Europe, 2025)
Cape Town (SmartCape)	Free Internet access in libraries; digital literacy support	Improved access for marginalised groups; uneven youth engagement	Digital literacy gaps; uneven uptake	Addresses Mbombela's digital divide in rural/low-income areas	(City of Cape Town, 2025); (Zondi & Ndebele, 2024)
Estonia (e-Governance system)	Digital ID, e-Residency, e-Voting, once-only principle	100% services e-online; 2% GDP savings; high satisfaction	Requires strong infrastructure & laws	Long-term vision: institutionalise e-Participation into governance	(Vassil, 2015); (Souigat, 2025)

The comparative review highlights that successful e-Participation initiatives share three common features: inclusivity, institutional commitment, and integration with existing governance processes. While the tools vary from mobile voting in Seoul to digital literacy initiatives in Cape Town, the underlying principle is that technology must be embedded within supportive institutional and social environments. For the city of Mbombela, four key lessons emerge:

Mobile-First Engagement (Seoul, Nairobi)

Mobile platforms are effective where mobile phone penetration is high, even in low-income settings.

The city of Mbombela can adopt lightweight mobile and USSD/SMS systems to enable real-time reporting of service issues (e.g., potholes, electricity outages) and citizen feedback.

Bridging the Digital Divide (Cape Town)

Free access points and digital literacy training are crucial for ensuring equity in participation.

Community libraries, schools, and municipal offices can be leveraged as digital hubs to expand inclusion in the city of Mbombela's rural and underserved communities.

Institutionalising Participation (Reykjavik)

Participatory budgeting and structured feedback platforms strengthen transparency and trust.

For the city of Mbombela, piloting a participatory budgeting portal within the Integrated Development Plan (IDP) process would legitimise citizen input in resource allocation.

Embedding Participation in Governance Structures (Estonia)

Sustainable e-Participation requires strong legal, policy, and institutional frameworks.

The city of Mbombela must develop a dedicated e-Participation policy, strengthen POPIA compliance, and establish a Digital Governance Unit to institutionalise citizen engagement.

To implement e-Participation initiatives, the city of Mbombela could start small by piloting them in a single ward or specific service area. Collaborate with community leaders, youth organisations, and NGOs to foster grassroots involvement. Monitor and iterate by collecting user feedback for continuous improvements. Ensure inclusivity by translating content into local languages and adapting resources for low-literacy users, making e-Participation efforts accessible to all community members. By embracing these detailed strategies and focusing on local adaptation, the city of Mbombela can effectively increase citizen engagement and foster a more participatory governance model that reflects the values and needs of its residents.

Recommendations for Mbombela's e-Participation

To establish a sustainable and effective e-Participation framework, the city of Mbombela should embed digital citizen engagement within its Integrated Development Plan (IDP) and create dedicated structures, including a Digital Governance Unit and a Citizen Innovation Lab.

Digital Infrastructure

To strengthen digital participation, the municipality should enhance connectivity by expanding broadband access in underserved rural areas and establishing public Wi-Fi zones in municipal offices, libraries, and

schools. Developing mobile-first tools, including lightweight mobile apps and USSD/SMS systems, will enable citizens to report issues, track service delivery, and provide feedback conveniently. Additionally, it is essential to strengthen ICT systems and security, ensuring robust data protection, seamless system integration, and secure digital platforms to maintain citizen trust. Establishing community access points, such as digital kiosks in strategic locations, can further bridge the digital divide and make digital services more accessible to all residents.

Institutional Capacity

Building institutional capacity is critical for effective digital governance. Establishing a dedicated Digital Governance Unit will provide focused staff responsible for managing digital participation initiatives. Municipal officials should undergo regular training programs on digital tools, data management, and participatory engagement to enhance their competence. The municipality should also cultivate a capacity for innovation by piloting e-Participation initiatives in selected wards to test their effectiveness before scaling them across the municipality. Finally, ensuring adequate budget allocation for ICT infrastructure, training, and the maintenance of digital services will provide the necessary resources to sustain these initiatives.

Legal & Policy Frameworks

Updating policies and by-laws to clearly define citizen rights, roles, and responsibilities in digital participation is essential for transparency and clarity. Municipal digital initiatives should align with national strategies, including compliance with POPIA and other national digital governance frameworks. Embedding transparency and accountability in municipal planning, budgeting, and reporting processes will reinforce public trust, while open-data initiatives such as publicly accessible dashboards displaying service performance and citizen feedback can further enhance engagement and oversight.

Stakeholder Engagement

Effective digital participation requires inclusive and multi-channel engagement. Combining traditional methods, such as ward meetings, with digital channels like mobile apps, social media, and online portals ensures broader citizen reach. Establishing citizen feedback loops, where residents are informed of how their input influences decisions, strengthens trust and responsiveness. Collaboration with civil society organisations, universities, technology firms, and NGOs can support innovation, training, and outreach. Finally, implementing digital literacy programs will empower communities with the skills needed to engage effectively in digital governance initiatives.

By adopting these strategies, the city of Mbombela can ensure that e-Participation is institutionalised, inclusive, and sustainable, fostering stronger citizen engagement, improving service delivery, and supporting long-term participatory governance.

Conclusion

This study assessed the operational readiness of the city of Mbombela for e-Governance, with a particular emphasis on e-Participation as a tool for strengthening service delivery. The findings indicate that while the city of Mbombela has begun aligning with national digital policies and has partially adopted ICT systems, significant gaps remain in digital infrastructure, institutional capacity, legal clarity, and citizen inclusivity. Without addressing these gaps, e-Participation risks being fragmented, elitist, or unsustainable. The paper contributes to e-Governance scholarship in two keyways. First, it develops a four-dimensional operational readiness framework covering infrastructure, capacity, policy, and stakeholder engagement that provides a practical tool for assessing e-Participation readiness in local governments across the Global South. Second, by synthesising lessons from global case studies, it demonstrates how municipalities can adapt proven practices such as mobile-first platforms, participatory budgeting, and digital literacy initiatives to their own socio-political contexts. For the city of Mbombela, the path forward lies in adopting a phased approach: expanding broadband and access points, piloting mobile-based engagement tools, embedding participation within the Integrated Development Plan, and institutionalising a dedicated Digital Governance Unit. More broadly, the South African local government sector can leverage this framework to guide digital transformation in ways that prioritise inclusivity, accountability, and citizen trust. Future research should explore longitudinal studies of pilot initiatives in the city of Mbombela, comparative analysis across municipalities, and the role of emerging technologies (such as AI and blockchain) in expanding e-Participation. Such work would enrich understanding of how digital governance can be localised to achieve both democratic deepening and improved service delivery

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Technological Developments and Military Issues

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Abstract: The revitalization of the military-industrial sector is essential for adapting to the evolving regional and global security environment. The security environment is shaped by two core components: a country's national interests and the respective alliance interests or other regional and international organizations. Today's technological developments are often detrimental to countries that have experienced disruption (stagnation) and cannot expect a timely return of their military industrial base, but rather a minimally evolutionary approach to these developments. While historical military-industrial traditions can inform the restoration of institutional memory and capabilities, future trajectories must be progressive. Traditionally, the military industry functioned in alignment with security policy and doctrine oriented towards protecting territorial integrity through conventional means. However, shifts in the power architecture, particularly through non-military instruments of national power and expanded missions for armed forces, have transformed these operating tools. Changes in the country's core documents on the approach to security and those of the armed forces in particular already seem to have clarified some questions regarding technological advances in the field of military industry for the future. Currently, as technological developments continue to progress, the central question that naturally arises is: Should the technological doctrine drive technological change, or should technological development lead to revisions in the military doctrine? The analysis here focuses on the interdependence among security policy, military doctrine, and technological development.

Keywords: technological development; military innovation; military doctrine; security policy

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Introduction

Technology fully conveys the concept and way of fighting for both military and other operations. It penetrates the reason why we are fighting, what we hope to achieve from the war, and how we view our relationship with the nation we serve. Technology penetrates the planning, preparation and execution of any operation. Objectives, methods, combat capability, command and direction, strategy, doctrines and tactics, are not and cannot be immune to technology. In today’s approach to fighting, according to (Clausewitz’s, 1984) theory, war

is the product of critical analysis, eva'uation, and interpretation, and is the reality o' modern operational art. Technology and technological change, more than just a battlefield device, represent a universal system of knowledge, attitude towards war, and a method for solving operational and tactical problems. While strategies represent the interaction of elements of national power, doctrines represent theories and rules of action that are essential in the chaos of war, linking strategy, history, technology, and the adversary to create conditions for achieving the desired final state.

Views on Historical and Technological Developments in Military Matters

The way the war was waged has sparked debate among scholars about how historical and technological developments have led to changes in military affairs. The debate involves discussions on paradigms about which historical development, which technologies, or strategies cause them?

There are several currents of researchers in this field with the corresponding paradigms that are in summary, Paradigm "Social Wave" where (Toffler, 1993), they explore the social, political, and economic changes that affect military transformations and the ways society organizes and conducts wars. Even the author (Liaropoulos, 2004) supports the idea that military changes are the product of deep social, political and economic changes that are supported by historical facts. Paradigm "Revolution to Revolution" represented by Murray and Knox, who argue that there are military changes that are composed in themselves of military technological revolutions. This revolution, according to them, is composed of several phenomena, including the development of firearms and railway systems.

Paradigm "Continuity and Evolution", according to (Black, 2005), innovation and transformation are an ongoing process that confronts the chaotic nature of war. They place great importance on military innovation and radical change but recognize that developments occur regularly throughout the cycle of historical development. According to him, innovations often do not find spread and do not adapt to the complexity and chaotic nature of war, they are not translated and implemented in doctrine, training, education and technology.
Researchers, in addition to the differences they have, also find many points in common; they agree that technology is a necessary but not decisive factor for significant developments. They also agree on the acceptance of the fact that the key to success lies in the way and the manner in which strategy and doctrine are applied in technological developments, whether old or new. Even (Cooper, 1994) emphasizes more awareness to be careful especially in exaggerating the role that only technology can play, stressing that the focus should be on strategy, doctrines and operational innovation.

Researchers suggest that the development of technology and the ongoing social differences and antagonism between states increase the possibility that war and revolutions in military affairs will play a central role in modern-day wars. According to Murray and Knox's, there are five Military Revolutions that have brought about radical changes in the history of the West: the Early Modern Revolution took place with the creation of modern nation-states in the 17th century, which brought about powerful military organizations, disciplined and in scale

and broad scope; The French Revolution of the late 18th century, which merged and intertwined politics and war; The Industrial Revolution of the late 18th century ensured that massive armies were deployed and engaged on the war fronts quickly, where the troops were already armed, clothed and well paid; The World War I that combined the legacy of the French Revolution and the Industrial Revolution and laid the foundations of the 20th and last century war, Nuclear Weapons, which caused the Cold War to remain cold in the main European theaters and in the North-Eastern Asian theaters.

The above evolutions have had their impact on war theories. They also influenced the two main pillars of this theory, the nature and character of the war. We all acknowledge that the nature of war has not changed, while its character has been flexible. The character of the war in any given period is formed, created, and often directed by a great deal from the political, social, and strategic context, rather than being changed by the necessary advancements in military science. (Gray, 2011) emphasizes that some conditions should be taken into account for the character of the war, one of which is, do not neglect the political, social and cultural context of war. Fortunately, we are really well educated or informed about this issue by Clausewitz, Sun Tzu and Thucydides. (Clausewitz, 1994) points out, “All wars are subject to “of the same nature””, advising that nature objective hers is permanent and she subjective It is subject to constant changes.

War technology during the Industrial Revolution was a precursor, surpassing strategies, doctrines, tactics, and structural organizations. In some cases, technology develops and evolves rapidly, affecting combat means more than combat methods and development modalities. Many elements of doctrine and tactics remained undetected as a result of these developments, which in many cases affected the fundamental aspects of tactical organization, such as attack lines, starting bases, and the placement of combat elements. Another advantage was that such advances significantly reduced the time required for preparing the armed forces. For advanced armed forces, technology is guiding them towards forces that are neither too professional nor too small, as they are oriented towards precision weapons, high-speed networks of communication, and information exchange to achieve cohesion and cooperation. However, this approach is more costly to maintain their operational effectiveness.

The Influence of Technology on Doctrine

Technological superiority increases the space for decision-making and operational development. The role of the armed forces, to realize as best as possible the mission assigned to it, has been very important in shaping technologies, productive activities and power relations with modern society. This superiority, viewed in the long term, synergistically promotes new doctrines and technologies for the future.

Innovations or technological developments may be tangible in terms of tools or weapons, but if the relevant doctrine does not support these, this technology loses effectiveness. Napoleon, one of the most significant contributors to military art, among others exalted the development of the artillery weapon, organizing the divisions into a superior structure such as the corps. With Napoleon, artillery became the basis of French military art, and battlefield war tactics became more aggressive. Artillery from weapons to support took a

decisive and destructive role on the war front. These innovations of the modern French army ensured victories against the archaic armies of Prussia, Austria, and Russia. In another form, the boom in economic development through industrialization emerged at the beginning of the 19th century, particularly in Britain. Technology put previously unimaginable resources in the hands of the leaders of the British Empire. Despite the significant industrial development and technological advancements, their impact was felt very late in the ranks of the armed forces and on the battlefield.

A similar doctrinal development occurred in Germany. During World War I (2025, 10 October), “to break the deadlock of war in the trenches, to overcome trenches and barbed wire, to protect soldiers from enemy fire, and to ensure mobility and firepower on the battlefield, in 1915 the first tank prototypes emerged from the British. . The German military began experimenting with tanks in the early 1920s and it took nearly two decades to develop the doctrine of “Blitzkrieg”. The Germans analyzed and applied efficiently all the lessons learned from the battlefield of World War I, giving the war a new face through this doctrine and other technological developments.

The aircraft is a clear example of how technology evolves from curiosity to strategic power. Although the first flight was carried out on December 17, 1903, the military aircraft was born out of an urgent need to utilize air power on the battlefield, and it developed in parallel with the advancement of civil aviation. Airplanes and radios were devices possessed by all the powers participating in World War II, but only the Germans understood their potential and introduced them to a new doctrine and explored their potential during this war. According to (Buckley, 2006), from the first use of aviation for military purposes in the Italo-Turkish war in 1911, the doctrinal requirements for reconnaissance, support of ground forces, troop transport, or the need for strikes thousands of kilometers away from their deployment, only during the World War II was it accompanied by the doctrinal evolution of their use.

The same request was made before the aircraft carriers. The history of vessels is a history of over 5000 years and beyond these tools have been used in various fields, including the military one almost from its beginnings. Strategic reasons necessitated doctrinal solutions: The Navy could deploy fighter jets anywhere, without relying on land-based airports, to enable a country to project its military force in every corner of the globe. This was especially important for states or empires that had their national interests extended beyond their basic territorial boundaries. Friedman (1988) concluded that the British therefore adapted a transport ship to the aircraft carrier in 1918 and then the Japanese built a real aircraft carrier.

Military history has shown that, in some cases, technological superiority does not yield the desired result. The most controversial case is the War in Vietnam and then the one in Afghanistan, where the strategy known as Dau Tranh Strategy. As in Afghanistan, also in cases of conducting operations Desert Shield AND Desert Storm, it is evident that in a short conventional campaign, technological superiority is a key component to a quick and complete victory and having a minimum loss of human life. In the long term, technological superiority did not have the desired effect. However, these operations marked a turning point in modern military

history, and their impact was felt in many subsequent conflicts, particularly in the use of technology in warfare. In this operation, satellite-driven missiles, such as Tomahawk and “intelligent” bombs, F-117 “Stealth” and AWACS aircraft dominated airspace; Advanced satellite systems enabled synchronized operations.

Military requirements have a profound and often decisive impact on the development of technological inventions or innovations. In some cases, the armed force has required more effective, lighter and more efficient equipment, thus promoting the development of materials that enable this. In other cases, it has sought to conduct operations without endangering people’s lives, which has encouraged the development of drones, exploration robots, and other automated systems that have since been used for civilian purposes. The Internet and GPS were initially developed for military purposes. They were born as a decentralized communication network (ARPANET), while GPS was created for accurate navigation for air and naval forces. Hybrid threats and information warfare have driven the development of digital defense systems, which are now integrated across all areas. Mass production of armaments has led to improvements in production lines, which in turn affect the efficiency of heavy industry as a whole and the demands on other sectors.

The logic of war and the logic of technological equire rity have inconsistencies with each other. The logic of war is not linear but paradoxical; the same course of action will not always lead to the same result. The opposite is closer to the truth. If you have an opponent who can implement “lessons learn”, there is a real risk that, an action cannot succeed twice in a row. The logic of technology is based on efficiency, which creates standardized and centralized systems, increasing its chance of success. This tendency towards standardization and centralized control is at odds with the reality of modern warfare, where the coordination of forces and weapons is vastly different, and where operational realities require flexibility and initiative.

The application of technologies requires a resilient doctrine that can be compiled in a way that minimizes, if not eliminates, the innovative impact of technology on the doctrine. Since the end of the nineteenth century, the many changes in weaponry and technology have led to a heterogeneously trained armed force, adapting to the developments of different technological eras. This problem has more to do with insufficient logistical support in technical terms than maneuvering and firepower. Logistics routes are more necessary to support a force with heterogeneous technology than a force with homogeneous technology.

From the perspective of the armed forces’ current functioning, where there is a pronounced interaction between types of weapons and ammunition, we can expect innovations or new inventions in armaments to lead to equally significant turbulence in doctrine, training, organization, and personnel structure. Judging by the increase in the degree of operationality of units or departments on the one hand, as well as of the various forces that may be part of an operation, we think that we should be cautious, as continuous technological changes will also led to a decrease in the degree of cohesion between the above units. In addition, when they occur continuously and over a medium-term period, according to (Dornstauder, 1993), we may also experience fluctuations in the identity of the unit or force, where its resultant, together with cohesion, may reduce the degree of operationality.

Although technology plays an important role, other factors play a decisive role. Researchers argue that those states that have not been affected by the wave of revolutions cannot use new technological developments and that they will get stuck in her traps. Saddam Hussein, through Iraq's underground assets, managed to buy weapons and equipment from the Soviets, the French and the Americans. Still, this equipment did not avoid the loss (if not complete neutralization) of his army. Only with weaponry and technology can success on the battlefield be ensured. Iraqi troops recruited from a society that had not inherited a modern state in its entirety did not have the capacity and skills to adapt with the necessary knowledge of the use of new technology and industrial developments.

For this reason, it is worth noting that a technological approach based on doctrine, both logically and historically, will guide both technological progress within the armed forces and in the civil sector. This is a practical approach in leading technological advances towards final and sustainable solutions.

Innovations in technology enable a military evolution, but the real revolution occurs in the birth and development of new operational concepts and the creation of new military structures, where technological advances are effectively applied. Creating these new organizations and doctrinal changes is a lengthy process that takes considerable time to unfold. This inhibition arises due to dilemmas about the impact they will have on structure, organization, combat effectiveness, and military personnel.

Armed Forces and Military Industry. Case study: Armed Forces of the Republic of Albania

The revitalization of the military industry, in our view, should be examined from two main perspectives: national and allied. From a national point of view, it is initiated by national strategic documents, such as the National Security Strategy of the Republic of Albania, the National Military Strategy (NMS), Allied Joint Publication (AJP)-01, and those of other levels, the Long-Term Development Plan of the Armed Forces of Albania, etc. In these documents, particularly in the Military Strategy, the primary principles for utilizing the Armed Forces (AF) are outlined. Judging from the national point of view, it is normal that its essence has to do with Article Three of NATO, which is known as the article on raising and keeping ready the necessary national capacities for response until the activation of Article 5 when the situation requires it, and specifically (NMS, 2024) defines, to achieve the goals of this treaty the parties more effectively... will maintain and develop their individual and collective ability to withstand armed attack.

Clearly, the Treaty emphasizes the need to address increasing individual national military capabilities in response to internal security challenges, which must be able to withstand the threat of a specific period. Judging in this way, (NMS, 2024), in point 2.5, "Threats, Risks, and Challenges of the Security Environment," exhaustively foresees threats and risks. In their first part, which concerns conventional threats, the combination of national development with that of the alliance is in almost complete symbiosis. According to (NMS, 2024)

although the risk of military aggression against the territory of Albania is considered low, the current situation of international security at the eastern borders of the Alliance has increased the possibility....to involve Albania in a conventional conflict, both within Article Three and Article Five of NATO, the AF have already received the relevant certifications. In the chapter Capacities of AF, in Combat Capacities, the priority of modernization will be the development and increase of the operational capabilities of the AF, with a focus on the further development of the capacities of the Light Infantry Group and Special Forces, continuing completion with weaponry, ammunition and communication equipment, in addition to increasing mobility, maneuverability and troop protection capacities, increasing firepower capacities and achieving full operational capacities of the current structure and reserve component.

(NMS, 2024) defines the priorities of modernization, and thus it is an accurate guide on where technical developments and advances in the defense industry should be focused. As an Armed Force based on doctrine, the (NATO, 2017), as an AF strategic-level document, reflects the dynamics and variety of current and future operations, separately or within the framework of NATO or a multinational coalition. This document specifies that AF must develop and create operational capacities that enable them to react effectively and successfully to any risk that may arise in the shortest possible time. Likewise, (NATO, 2024) clearly defines general doctrinal principles, the use of AF in combat and non-combat operations, as well as its combat power and development. The construction of the future force in the above documents is consistently indicated and preceded by the Long-Term Development Plan of the AF of Albania or the Strategic Defense Review (SDR), which provides more specific concretization. Clear definition of objectives for the short term, objectives for the medium term, objectives for the long term as well as structures that will go into full operationality for each of the above time periods.

The direction of the construction or reconstruction of the military industry requires innovation not only In technology but also in forecasting. Until a few years ago, military technology had the advantage of being operational over 30, 40, or 50 years: the F-16 has “celebrated” 50th Anniversary Marcus (2007) since its official flight in 1974 and is still in demand by many countries; The F-35 aircraft, manufactured in 2006, remains one of the most sought-after aircraft by many countries; The Leopard 2 tank, according to Marsh (1996). Became operational in 1979, and only a few states have had access to its acquisition; The T-59 tank, which has been the base of armored vehicles even in our armed force, although made operational in the 1950s and 1960s, has appeared on the battlefield in recent years, or the B1 Spirit strategic bomber produced in 1974 (Rockwell B-1 Lancer 2025, October 12) it will be operational at least until 2030, etc. This combat technique, like other missile or missile defense systems, is accompanied by a staggering cost both in terms of production and in terms of maintenance or even training of the relevant personnel. If we analyze today’s technological developments, we believe that the first impact would be a significant decrease in operational time, and the construction of systems against them would be very efficient and at a cost many times smaller.

The equireements, technical specifications and standards required by the AF to produce technology have already increased the group of stakeholders. Like the developments in the military industry, as well as those of

other contractors, make it possible for many commissioned designs to be in demand in fields outside the armed forces. Mutually, if the civil industry presents a particular technological advancement, the first supporter of its advancement must be the armed forces. This is also based on the already known fact of the corresponding expenses allocated to the AF, as specified in the annual report for the year 2024 of the Secretary General of NATO. The growing financial resources of the AF will enable it to be more at the forefront than other institutions or organizations in terms of technological development. Moreover, in some cases, the armed forces have the exclusivity of using advanced technologies, even when they have unaffordable financial values compared to other sectors, because, as Smith points out (2025, September 16), protection is more critical than wealth. It is enough to bring as a case one of the last conflicts, Israel-Iran, where it cost only Israel a daily cost of approximately $725 million. In the early days this cost is thought to have been $1.45 billion per day. This means that investments in future technology must be highly flexible, allowing them to pursue innovation or quickly adapt to other models.

Conclusions

Technology determines the attitude towards war and the method for doctrinal solutions being an essential factor in military matters. It has led to evolutions to and from revolutions on such issues, and usually the present will bring about one. War technology in different periods of industrial development was a precursor, and in not a few cases, they progressed further than fighting methods. Elements of doctrine and tactics remained undetected, further influencing the basic elements of tactical organization. Innovations in technology make possible a military evolution, but the real revolution occurs in the birth and development of new operational concepts and in the creation of new military structures, where technological advances are applied, a long process that takes a long time to happen.

Doctrine as well as other documents have a profound impact on technological research, where the basis is the increase in strength efficiency as well as the decrease in the degree of danger of living strength. Innovations or technological developments can be tangible in terms of tools or weapons, but if the relevant doctrine does not support these, this technology loses effectiveness. The application of technologies requires a resilient doctrine that can be compiled in such a way that the innovative impact of technology on the doctrine is reduced, if not eliminated. A technological approach based on doctrine will guide technological progress within the ranks of the armed forces and at the same time would be attractive to other sectors as well. Creating opportunities for more efficient coordination between the military and civilian sectors is a practical approach to final and sustainable solutions. The requirements, technical specifications and standards required by the AF to produce technology have already increased the group of stakeholders. Like the developments of the military industry, as well as those of other contractors, they make it possible for this technology to be applied in areas outside the armed forces. This requires an even deeper interaction with many different actors in this field, focusing on or using the relevant financial values dedicated to this direction more effectively.

The numerous changes in weaponry and technology result in heterogeneous training of the AF. From the

perspective of the armed force's current functioning, we can expect equally significant turbulence in doctrine, training, organization, and personnel structure. Judging by the increase in the degree of operationality of units or departments on the one hand, as well as of the various forces that may be part of an operation, we think that we should be cautious, as continuous technological changes will also lead to a decrease in the degree of cohesion. The coordination of forces and weapons is vastly different, and the reality of operational development requires Proactive initiatives. In terms of building or rebuilding the military industry, innovation is required not only in technology but also in forecasting. This means that investments in future technology must be highly flexible, allowing them to pursue innovation or quickly adapt to other models.

The application of technologies requires a resilient doctrine that can be compiled in such a way that the innovative impact of technology on the doctrine is reduced, if not eliminated. In future conflicts, conventional superiority can be challenged by effective management of innovation and technological development during the conflict, thereby bringing about changes on the battlefield.

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Lexicon Enhanced Transformer Bi-LSTM Model for Detecting Cyberbullying in Kazakh Textual Data

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Abstract: Cyberbullying detection in low-resource languages remains a major challenge due to limited annotated data and complex linguistic structures. This study introduces a Transformer-enhanced Bidirectional Long Short-Term Memory (Bi-LSTM) model specifically designed for detecting cyberbullying in Kazakh-language social media texts. The proposed architecture leverages the sequential processing capabilities of Bi-LSTM to capture bidirectional contextual dependencies, while the Transformer layer with Multi-Head Attention refines the representation by modeling global semantic relationships between words. The model was trained on a custom-built Kazakh-language dataset collected through automated social media parsing. Preprocessing steps included data cleaning, tokenization, and embedding generation using pre-trained multilingual transformer embeddings. Experimental results demonstrate that integrating the Transformer component into the Bi-LSTM backbone significantly improves detection accuracy, precision, recall, and F1-score compared to standalone Bi-LSTM or CNN-based approaches.

Keywords: Cyberbullying, NLP, Neural Networks, Deep Learning, Artificial Intelligence.

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Introduction

In today's rapidly evolving digital era, the proliferation of social media and online communication platforms has dramatically transformed how individuals interact, share information, and connect between each other.

However, this digital transformation has also given the rise to new challenges, one of the most pervasive being cyberbullying. Unlike traditional bullying, cyberbullying transcends physical boundaries, allowing harmful behavior to occur anywhere and at any time, leaving victims vulnerable to persistent psychological and emotional distress [1]. With the exponential growth of user-generated content, the manual monitoring of online abuse has become nearly impossible. Consequently, the development of artificial intelligence (AI)-based algorithms has emerged as a vital solution to automatically detect and mitigate cyberbullying behaviors in real time [2]. These intelligent systems leverage natural language processing (NLP), machine learning, and deep learning techniques to analyze linguistic patterns, contextual semantics, and emotional tones within digital communications.

Especially, it is a vital problem for Kazakhstan due to the rapid growth of digital literacy and the increasing penetration of mobile technologies among young people. As internet access expands even to remote regions, social media platforms have become the primary means of communication and self-expression for adolescents and young adults. Unfortunately, this expansion has also intensified instances of online harassment, hate speech, and cyberbullying, often exacerbated by the lack of effective monitoring and awareness mechanisms [3].

Related Works

Research on automated cyberbullying detection has grown rapidly alongside advances in natural language processing (NLP) and deep learning. Recent surveys and benchmarks consolidate methods ranging from classical machine-learning pipelines (e.g., TF-IDF + SVM) to transformer-based architectures, and they highlight persistent challenges such as data imbalance, domain shift, and bias in toxicity labels across platforms and languages [4]. These works also emphasize that evaluation should consider not only accuracy/F1 but latency and deployment constraints for real-time moderation.

For low-resource and morphologically rich languages like Kazakh, model transfer and adaptation remain central. Studies note that agglutinative morphology, sparse lexical coverage, and colloquial orthography can degrade off-the-shelf performance, motivating morphology-aware tokenization, subword modeling, and targeted data curation. In the Kazakh context specifically, recent work underlines the need to tailor feature extraction and model training to handle inflectional richness and code-switching.

Kazakhstan-focused research has begun to address these gaps. Altayeva et al. propose a hybrid LSTM-CNN model for cyberbullying detection and report improvements over traditional classifiers on social-media text using standard metrics [5]. Toktarova et al. systematically compare machine-learning and deep-learning approaches for hate speech/cyberbullying, offering a methodological baseline for local datasets [6]. Complementary Kazakh-affiliated work in IJACSA frames offensive-language detection a regional priority, with multi-institutional participation from universities in Almaty, Turkistan, and Shymkent.

Parallel efforts focus on building or characterizing Kazakh corpora and problem settings. Preprint and published

studies on “destructive content” like extremism, racism, cyberbullying in Kazakh social media highlight data collection/annotation protocols and the limits of generic NLP pipelines without language-specific adaptation [6]. Emerging dataset papers for Kazakh hate speech aim to make labeled resources available, while linguistic analyses of Russian borrowings in Kazakh social media underscore the prevalence of code-mixing—an important confounder for toxicity models trained on monolingual data [7-8].

In the table below Table 1 comparative analysis of related works is given. This table describes each author’s domain of the work, the task of work, best proposed solution, and shows achieved results by each author. Using these data we can propose own model by analyzing which approach fits the aim of our work best.

Table 1. Comparative analysis of related works

Authors	Language / domain	Task	Proposed model	Results
[3]	Social-media text (cyberbullying)	Classification	LSTM + CNN	Acc: 0.9752 Prec: 0.9687 Rec: 0.9896 F1 score: 0.9828
[4]	Kazakh	Offensive language identification	Bi-LSTM (Transferred learning)	AUC-ROC plots show BiLSTM dominates from earliest epochs
[5]	Social-media text (generic)	Cyberbullying detection	Hybrid CNN - LSTM	Accuracy = 0.957
[6]	English	Toxic/ offensive detection	BERT variants	Accuracy = 0.8963
[7]	Kazakh	Detection of destructive content	ML vs DL	Deep Learning approaches’ superiority

Across studies, sequence-aware deep models (BiLSTM / CNN-LSTM / BERT) consistently outperform classical ML for abusive/cyberbullying detection; the only paper with a full metric table reports F1≈0.983 and AUC≈0.987 for a CNN-LSTM hybrid. For Kazakh, available works either (a) show BiLSTM superiority in AUC-ROC without publishing exact numbers, or (b) demonstrate BERT-family gains with preprocessing, aligning with broader low-resource trends [9]. A benchmark-style number you can cite externally is BERT accuracy ≈ 0.896 on SemEval Toxic Spans (English), indicative of transformer-level performance on toxicity tasks.

In the regional literature on abusive language and cyberbullying, Altayeva et al. report that a hybrid LSTM–CNN model decisively outperforms shallow baselines, achieving the highest accuracy, F1, and AUC-ROC; the

gains are attributed to combining local n-gram cues with sequential context modeling. Toktarova et al. likewise find BiLSTM variants to be consistently superior in AUC-ROC and confusion-matrix analyses, underscoring the value of sequence modeling for subtle hate speech and recommending balanced precision–recall targets for moderation. A subsequent Altayeva et al. study confirms strong hybrid CNN–LSTM performance on social-media text but cautions about overfitting and stresses regularization and generalization, alongside ethical deployment concerns (bias, privacy). Namazbayev's BERT-based case study on toxic-span detection shows that explicit insults are captured reliably whereas implicit toxicity, sarcasm, and micro-aggressions remain challenging; it also highlights that span-level detection is inherently harder than post-level classification [10]. For Kazakh as an agglutinative, low-resource language, Bolatbek et al. demonstrate measurable benefits from language-aware preprocessing for both classical ML and BERT-family models, emphasizing the need for morphology-sensitive pipelines. Complementing these findings, Sultan et al. benchmark shallow vs deep approaches across multiple corpora and conclude that BiLSTM delivers the best accuracy and recall for cyberbullying detection. Collectively, these results indicate that sequence-aware deep architectures dominate shallow baselines; however, robust performance in the Kazakh context depends on curated datasets, morphology-aware preprocessing, careful regularization, and a practical balance between accuracy and inference efficiency [11-12].

Materials and Methods

This section outlines the end-to-end methodology used to build and evaluate a transformer-enhanced Bi-LSTM model for detecting cyberbullying in Kazakh-language text. We first describe a Kazakh-focused data acquisition workflow that aggregates social-media content under clear moderation criteria. Next, we detail preprocessing tailored to Kazakh's agglutinative morphology, sub word tokenization, and optional morphology-aware segmentation. Our experimental protocol specifies stratified k-fold splits, low-resource data augmentation. Finally, we document all implementation details—software/library versions, random seeds, and GPU specifications — to ensure full reproducibility. Together, these components provide a transparent, replicable template for robust Kazakh-language cyberbullying detection suitable for deployment on digital platforms. The whole processes from

Data Mining

Kazakh is a low-resource language in NLP, which makes building robust AI models particularly challenging. Publicly available, well-annotated datasets for toxicity and cyberbullying are scarce, fragmented, and often inconsistent in label schemas, hindering reproducible benchmarking. The situation is compounded by Kazakh's both of which increase vocabulary sparsity and degrade off-the-shelf tokenizers and embeddings. Collecting new data is non-trivial: platform terms of service, privacy constraints, and the need for expert, culturally aware annotation raise costs and slow dataset growth. Domain drift across platforms (e.g., Instagram vs. TikTok vs. forums) further reduces the portability of small corpora.

To achieve this aim and collect relevant data, we built an in-house web parser that gathers publicly available Kazakh-language content from open sources. The system respects platform terms of service, adheres to robots.txt, applies conservative rate limiting, and collects only data that is publicly accessible without authentication. Our pipeline focuses on sources where cyberbullying is most prevalent (public social-media posts, comments, forums), prioritizing Kazakh text that are common in local discourse. The process of parsing and collecting data from open ended resources scheme is given in the image below.

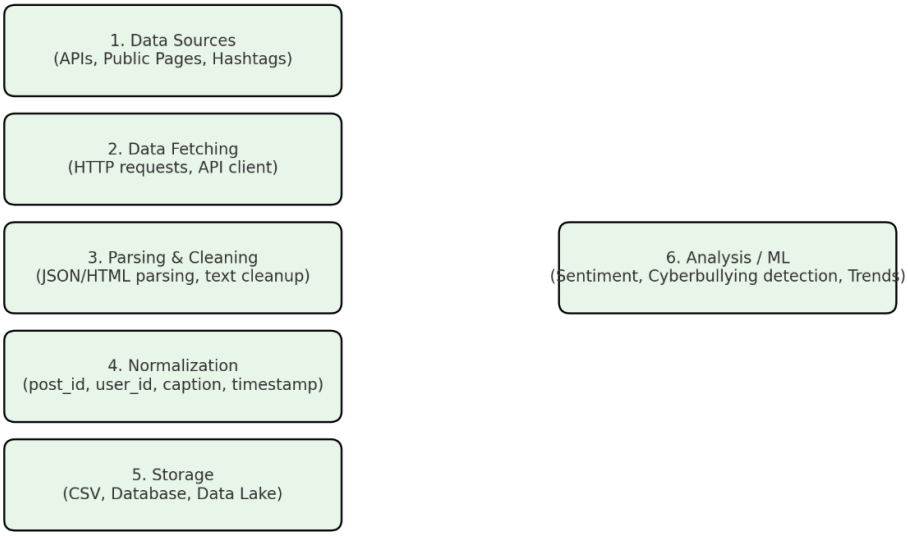

Figure 1. Data Collecting Logic

Data Preprocessing

Once our data is collected, the next step to prepare them for AI algorithms is data preprocessing. This stage involves cleaning, normalizing, and structuring the raw data to ensure consistency and quality. During preprocessing, duplicate or irrelevant records are removed, text is tokenized, and features are standardized — enabling the AI models to learn effectively and produce accurate results.

Data Cleaning

This step focuses on identifying and correcting errors or inconsistencies within the dataset. Missing values are filled or removed, irrelevant features are discarded, and incorrect entries (such as malformed dates or mislabeled samples) are corrected. The goal is to eliminate inaccuracies that could mislead the learning algorithm and to maintain overall data integrity [13].

Noise and Duplicate Reduction

Noise refers to random or irrelevant variations in the data — for example, spam content, typos, or background

information unrelated to the main topic. Duplicates arise when identical or nearly identical entries are collected multiple times. Both can distort model performance [14]. Noise reduction uses filtering or rule-based heuristics, while duplicates are typically detected through similarity measures (e.g., cosine similarity, hash matching).

Data Sampling

When datasets are extremely large or unbalanced, sampling helps create a representative and manageable subset of data. It can be random sampling (selecting examples uniformly) or stratified sampling (preserving class distribution). Sampling improves computational efficiency, reduces overfitting, and allows fair model evaluation by ensuring the training data reflects the true population structure.

Tokenization

In Natural Language Processing (NLP), tokenization is the process of splitting text into smaller, meaningful units called tokens — typically words, phrases, or subword segments. For instance, the sentence “Cyberbullying detection in Kazakh language” becomes tokens like [Cyberbullying] [detection] [in] [Kazakh] [language]. Proper tokenization is crucial because it defines how models interpret textual data, directly influencing accuracy in downstream tasks like classification or sentiment analysis.

Feature Extraction

Once the data have been cleaned, deduplicated, sampled, and tokenized, the next essential stage is Feature Extraction. This process transforms preprocessed raw data into numerical or categorical representations that can be effectively understood and utilized by machine learning algorithms. Feature extraction bridges the gap between raw textual or multimedia inputs and computational models by capturing the most informative aspects of the data — such as linguistic, semantic, or statistical patterns — while reducing dimensionality and noise. To do so we choose two tools of feature extraction: Word Embeddings and Sentence embeddings.

Word Embeddings

Word embeddings are dense vector representations of words in a continuous vector space where semantically similar words are positioned closer to each other. Unlike one-hot encoding (which treats each word as independent), embeddings capture semantic and syntactic relationships between words based on their context of use. For instance, In a trained embedding space, vectors for words like ["king", "queen", "man", "woman"] might satisfy the famous relation: vector("king") - vector("man") + vector("woman") ≈ vector("queen") [15].

Sentence Embeddings

Sentence embeddings extend the same concept from words to entire sentences or documents. They represent the

overall semantic meaning of a text, allowing models to compare, cluster, or classify sentences based on meaning rather than individual word overlap. For instance, let's take two sentences: "A child is playing football." and "A kid kicks a ball on the field." Even though they use different words, their meanings are nearly identical. Sentence embedding models like BERT or RoBERTa will place both sentences close together in the embedding space because they express similar concepts. It helps us focus on the meaning of whole sentence while word embedding shows the relationships just between words [16].

Proposed Model

To effectively capture both the sequential dependencies and contextual relationships present in Kazakh social media text, we propose a Transformer-enhanced Bidirectional Long Short-Term Memory (Bi-LSTM) model. This hybrid architecture leverages the strengths of both transformer-based attention mechanisms and recurrent neural networks, ensuring a more comprehensive understanding of linguistic nuances and semantic patterns. Traditional deep learning models, such as standalone LSTM or CNN architectures, often struggle to balance contextual depth with long-range dependency modeling, especially in morphologically rich and low-resource languages like Kazakh. By integrating transformer layers with Bi-LSTM units, our model not only captures bidirectional temporal dependencies but also dynamically attends to the most relevant tokens within each sequence. This model architecture was selected because in Kazakh language meaning relationship between words is distributed from the end of sentence. That is why simple LSTM or CNN cannot capture or lose important relationships.

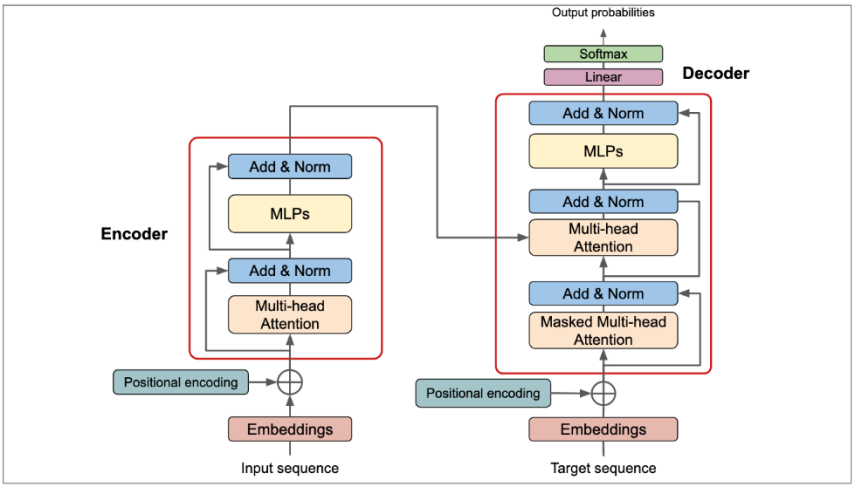

Figure 2. Transformer Layer Structure.

This image shows the classic transformer architecture, which is the foundation of modern language models like GPT. It consists of two main parts: encoder and decoder.

Encoder's responsibilities:

Input: a sequence of tokens (words) converted into embeddings.

Positional Encoding adds information about the order of tokens (since attention has no inherent sense of

position).

Each encoder layer includes:

Multi-Head Attention: lets every token attend to every other token in the sequence (to learn contextual relationships).

Add & Norm: residual connection followed by layer normalization.

MLPs (Feed-Forward Network): apply nonlinear transformations to the features.

Another Add & Norm to stabilize training.

Decoder's responsibilities:

Takes as input both the previously generated tokens (target sequence) and the encoder's outputs.

Each decoder layer includes:

Masked Multi-Head Attention: allows attention only to earlier tokens (so the model can't "peek" ahead).

Multi-Head Attention: attends to the encoder's output (linking input and output sequences).

MLPs and Add & Norm, same as in the encoder.

After the decoder stack, the result goes through a Linear layer and a Softmax, producing probabilities for the next token. After passing through all the decoder layers, each position in the output sequence (e.g., each word being generated) is represented by a vector — often called a hidden state or context vector.

Next step is combining this layer with Bi-LSTM architecture to provide continuous dependency which can walk through the sentence in both directions (begin -> end, end -> begin). Unlike simple LSTM which keeps relational information only in forward direction Bi-LSTM is built from two LSTMs that process the same sequence in opposite directions:

The forward LSTM reads from the first token to the last.

The backward LSTM reads from the last token to the first.

At each position in the sequence, the outputs from both directions are concatenated (or sometimes summed). This gives each step information from past and future context — a full view of the sequence around it. Inside each direction (forward or backward), every LSTM cell has three gates that control the information flow [17]:

Forget gate (f_t): decides what to forget from previous memory

$$ft=\sigma(Wf[ht-1,xt]+bf) \quad (1)$$

Input gate (i_t): decides what new information to store

$$it =\sigma(Wi[ht-1,xt]+bi) \quad (2)$$

Candidate memory ($\hat{c}_t$): creates new candidate information

$$ct = \tanh(Wc[ht-1,xt]+bc) \quad (3)$$

Cell state update: combines previous memory and new input

$$ct=ft*ct-1+it*ct \quad (4)$$

Output gate (o_t): decides what to output at this step

$$ot = \sigma(Wo[ht-1,xt]+bo) \quad (5)$$

$ht = ot * \tanh(ct)$ (6)

The image representation of single Bi-LSTM cell is given in the figure below. This figure shows how Bi-LSTM processes input sequences in two directions simultaneously, merges both contextual outputs at every step, and produces context-rich representations that are ideal for text classification, sentiment analysis, and cyberbullying detection.

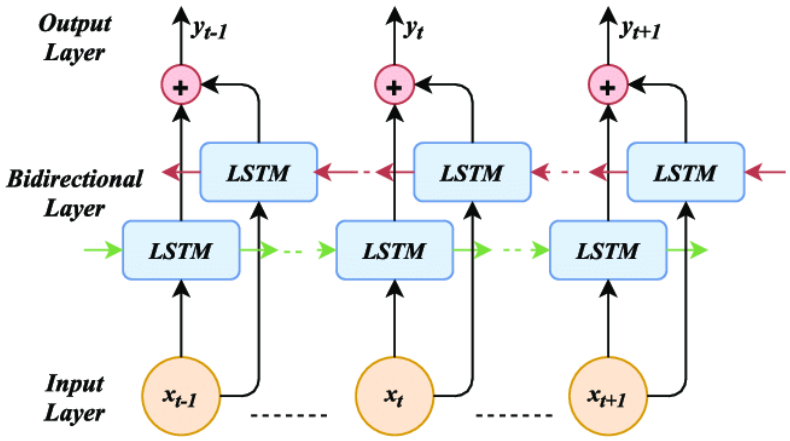

Figure 3. Bi-LSTM single cell structure

Summing up, we can say that Bi-LSTM operates by reading a sequence in both directions and learning long-term dependencies through its gated memory mechanism. It outputs a context-aware representation for each element, containing information from both the past and the future of the sequence.

Two Architectures Combination

Mentioned two architectures combined, they form a hybrid architecture capable of capturing both global contextual relationships and local sequential dependencies, which is particularly beneficial for low-resource languages, Kazakh language in our case. Together, they produce a comprehensive representation of text — globally attentive and locally coherent — enabling more accurate detection of cyberbullying expressions, which often rely on nuanced combinations of words, tone, and context. Namely, transformer's global attention mechanism helps the model understand semantic meaning and word-to-word relationships and Bi-LSTM's architecture enables the network to encode the full context around each token, making it highly effective in understanding morphological variations and word order. The overall formula of proposed model is given in the figure below. We need to remember that Bi-LSTM and Transformer architectures consist of their own formulas, presented previously.

$$\hat{y} = \text{softmax}\left(\frac{1}{T}\sum_{t=1}^{T}\left[\text{BiLSTM}(\text{Transformer}(X))\right]_t W_c + b_c\right)$$

Figure 4. Proposed model total formula.

Evaluation and Results

In evaluating the performance of a classification model for cyberbullying detection, standard quantitative metrics are employed to capture complementary dimensions of model behavior. These metrics not only assess the model's correctness in predicting class labels but also its ability to generalize, handle data imbalance, and mitigate false predictions. To understand next given formulas, we need to understand confusion matrix results, which are represented in the figure below.

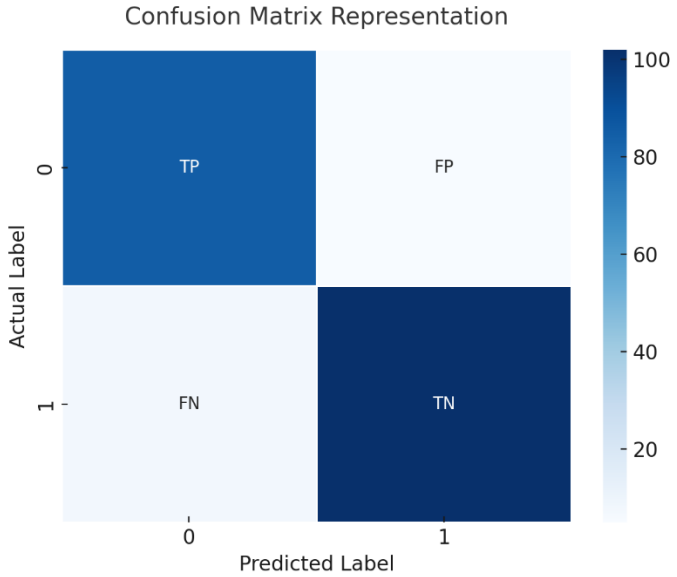

Figure 5. Confusion matrix representation

Where:

TP — correctly predicted positive samples

FP — non-bullying posts wrongly labeled as cyberbullying

FN — bullying samples missed by the model

TN — correctly predicted non-bullying samples

Accuracy

Accuracy is one of the most fundamental metrics in evaluating classification models. It quantifies the overall correctness of the model's predictions by measuring the ratio of correctly predicted instances (both positive and negative) to the total number of predictions made [18]. Formally, it is expressed as:

$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN} \quad (7)$$

Precision

Precision is a metric that evaluates the accuracy of the model's positive predictions. It measures how many of the instances predicted as positive (cyberbullying) are positive [19]. A model with low precision tends to

produce numerous false alarms, wrongly identifying benign comments as harmful. Formally, it is defined as:

$$Precision = \frac{TP}{TP+FP} \quad (8)$$

Recall

Recall, also known as Sensitivity or True Positive Rate, measures the model's ability to correctly identify all actual positive instances [20]. In the context of cyberbullying detection as classification task, it quantifies how effectively the model detects all bullying samples among those that truly contain harmful content.

$$Recall = \frac{TP}{TP+FN} \quad (9)$$

F1-Score

The F1-Score is a harmonic ratio of Precision and Recall, designed to provide a single, balanced metric that considers both the accuracy of positive predictions and the completeness of detection [21-22]. It is particularly valuable when dealing with imbalanced datasets, such as in cyberbullying detection, where harmful posts (positives) are far fewer than neutral ones.

$$F1_{Score} = 2 * \frac{Precision * Recall}{Precision + Recall} \quad (10)$$

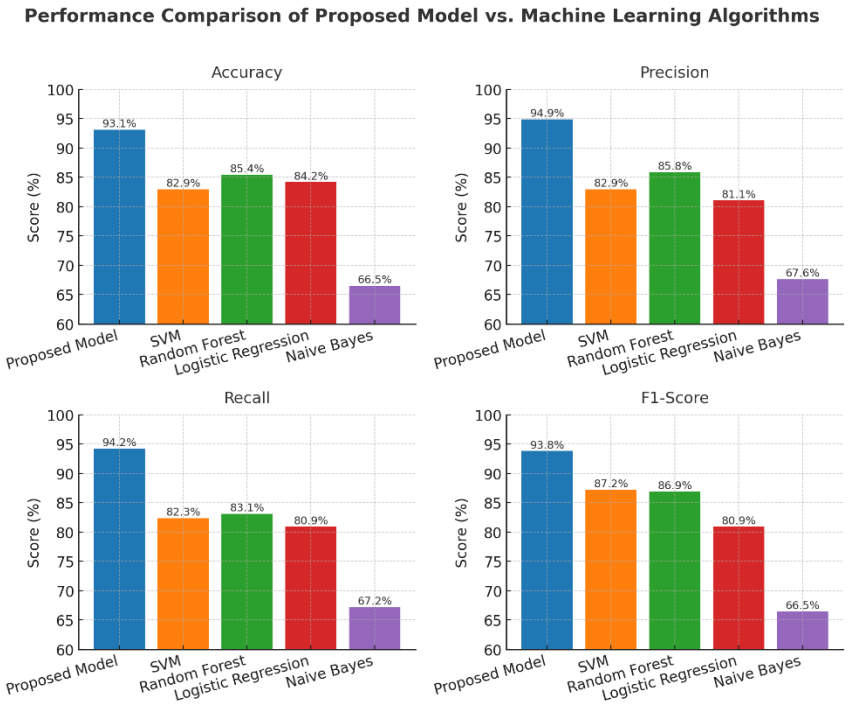

Figure 6. Proposed Model vs ML Algorithms Metrics Comparison

The image above presents a comparative performance analysis between the Proposed Model and traditional machine learning algorithms across four core evaluation metrics: Accuracy, Precision, Recall, and F1-Score.

Proposed Model achieves consistently superior results across all four metrics, scoring between 93% and 95%. This uniform performance indicates both high precision and strong recall which says about balanced and robust model. These results prove our idea to develop Transformer based Bi-LSTM model can perfectly fill the gaps in the process of analyzing texts in complex languages, like Kazakh.

Discussion

The proposed Transformer-enhanced Bi-LSTM model demonstrates significant superiority over traditional machine learning classifiers and earlier deep learning architectures in the domain of cyberbullying detection for Kazakh-language text. By integrating the global attention mechanism of the Transformer with the bidirectional contextual learning capacity of the Bi-LSTM, the hybrid framework effectively captures both long-range semantic dependencies and fine-grained sequential nuances that are essential for understanding complex linguistic phenomena in agglutinative, low-resource languages such as Kazakh.

Empirical results reveal that this hybrid approach consistently outperforms conventional models — including standalone CNNs, LSTMs, and Transformer baselines — in all major evaluation metrics (Accuracy, Precision, Recall, and F1-Score). The self-attention component enables the model to weigh the importance of words across the entire sentence, thereby identifying latent semantic cues indicative of cyberbullying, while the Bi-LSTM component preserves the word-order information and syntactic dependencies that are often critical for contextual disambiguation. This dual encoding of information allows the model to distinguish subtle differences between neutral and harmful expressions, a common challenge in Kazakh text where meaning is highly context dependent.

From a practical standpoint, the Transformer-enhanced Bi-LSTM model provides a scalable and efficient solution for integration into content moderation systems across social media platforms, online forums, and digital news outlets. Its capability to process text in real time supports automated detection of cyberbullying, reducing the psychological and operational burden on human moderators while significantly enhancing the speed and accuracy of harmful content identification. Moreover, this system can facilitate regulatory compliance with emerging digital safety standards in Kazakhstan and other Turkic-language regions, where automated moderation tools remain underdeveloped.

Conclusion

This study presented a Transformer-enhanced Bi-LSTM deep learning model designed to detect cyberbullying in Kazakh language text, addressing the linguistic challenges inherent to low-resource languages. By combining multi-head self-attention in Bidirectional LSTM and Transformer architecture, the model effectively captures both contextual and syntactic dependencies within text, resulting in a more comprehensive linguistic representation compared to traditional architecture.

Experimental evaluation demonstrated that the proposed model outperformed classical machine learning algorithms. Specifically, it achieved higher values across all major evaluation metrics: accuracy, precision, recall, and F1-score, indicating superior generalization, improved contextual understanding, and robustness against noisy real-world data. In future studies we aim to expand the dataset, optimize computational efficiency, and adapt the model for multilingual and cross-cultural cyberbullying detection, ensuring scalability and applicability across diverse linguistic and social contexts. Overall, this research not only strengthens the technological capacity to combat cyberbullying in Kazakhstan but also contributes meaningfully to the broader development of ethical, language-inclusive artificial intelligence systems.

Acknowledgements

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Development of A Low-Latency and Secure Order Processing Engine for Cryptocurrency Trading

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Abstract: Cryptocurrency markets are much more dynamic than traditional markets due to high volatility, 24/7 trading, and sudden volume fluctuations, and high-frequency users need ultra-low latency order processing engines that require execution times in milliseconds. For these engines to work quickly and accurately, their order processing algorithms must be optimized and supported by balanced tree and hash-based data structures. Furthermore, the security and scalability of systems are critical; robust encryption protocols, anti-cyberattack measures, and horizontal/vertical scalability are imperative to ensure user trust and handle heavy transaction volumes. For these needs, an order processing engine platform that is fully compatible with centralized and decentralized exchanges, operates with low latency and can handle high transaction volumes has been developed in this study. The platform architecture has been designed with Command Query Responsibility Segregation (CQRS) and Event Driven Architecture (EDA) approaches. The Red-Black Tree data structure has been used while developing the order processing engine. The STRIDE methodology has been applied to ensure the security of the system and precautions against attacks have been developed in this context. The platform performance has been evaluated by comparing it to conventional matching engines and analyzing their latency and throughput measures. The results obtained revealed that the developed engine increases operating efficiency and provides horizontal scalability by keeping the average latency below 1 millisecond in a high volatility data

load scenario. Additionally, the delay distribution and coherence (Jitter) of the platform in the high volatility load scenario have been examined and it has been confirmed that the platform has a predictable performance.

Keywords: Order processing, Low-Latency Order Matching, High-Frequency Trading, Cryptocurrency

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Introduction

In today's financial environment, cryptocurrency markets are among the fastest-growing sectors. Because of their characteristics, they operate far more dynamically than traditional markets. This dynamism is due to the seamless 24/7 and high volatility of crypto trading, coupled with sudden volume fluctuations. An order describes the buying and selling transactions of investors. Order processing is gaining great importance today as the system executes the buy or sell order given by an investor to the cryptocurrency exchange. Users who engage in high-frequency trading aim to take advantage of even the smallest price fluctuations in the market to get the most out of this dynamic structure, so it is critical that transaction times last milliseconds. The high latency and slow order processing offered by existing solutions negatively impact trading performance. Therefore, it creates the need for an order processing engine that operates with ultra-low latency and can handle even the heaviest transaction volumes. Furthermore, the optimization of advanced order-matching algorithms is a fundamental requirement to meet the needs of users engaged in high-frequency trading in cryptocurrency markets. Because trading users send many orders within milliseconds, and it is of great importance that the system works both quickly and accurately. Algorithms such as First-In-First-Out (FIFO), Pro-Rata and Price-Time Priority should be optimized to respond to user demands in the fastest and most accurate way. In addition, as the order book grows, these algorithms must be supported by balanced tree structures and hash-based data structures to handle the transaction load.

Security is another critical requirement. Users who trade on centralized and decentralized exchanges want to be sure of the security of their funds and data. Providing effective protection against threats such as Distributed Denial of Service (DDoS) attacks and data breaches increases user trust. Robust encryption protocols and safeguards against cyberattacks are imperative for securely managing order books to ensure user trust and gain a competitive edge. On the other hand, the constant fluctuations in the trading volume of cryptocurrency markets make the scalability of systems essential. During periods of sudden rise or fall in the markets, systems must have horizontal and vertical scalability to respond to transaction demands.

This study aims to provide high-speed, low-latency, scalable, and reliable order processing for cryptocurrency markets. For this purpose, a platform has been developed that is fully compatible with centralized and

decentralized exchanges, operates with ultra-low latency, and can handle high transaction volumes.
This study is organized as follows: Section 2 includes relevant literature. Details of the platform are presented in Section 3. Platform testing process is presented in Section 4. Results of the study are given in Section 5. Section 6 concludes the paper.

Literature Review

Elisa Beraudo and Yurii Oliinyk (2024) designed an automated trading bot that addresses critical issues such as latency, risk management, scalability, and reliability in real market conditions. In this context, a new scalping method has been developed, software architecture has been created, and pseudocode has been prepared for the decision-making process using technical indicators such as The Volume Weighted Average Price and the Exponential Moving Average. Modules such as exchange integration, data management, strategy analysis, transaction execution, and historical data storage have been created in the system, supported by PostgreSQL, Redis, WebSocket, and Python libraries. In experiments conducted on the BTC/USDT pair, the bot closed 13 out of 15 trades with a profit in a 2-hour trading period, resulting in a total gain of 120 USDT, proving its effectiveness with low latency and balanced resource utilization.

(Robert Henker et al., 2024) explained the design and implementation of Athena, a system that automatically splits orders across multiple exchanges to minimize implicit costs in cryptocurrency spot trading. In the developed system, order books have been aggregated from several centralized crypto exchanges and combined into an internal unified order book. In addition, the inputs in the unified order book have been enriched with information about the stock market. According to the evaluations made on the system, it has been seen that the use of the order routing algorithm provides savings in costs.

(Xiaoqing Wen et al., 2024) introduced a new system called MERCURY, enabling secure and efficient trading without the need for an online client. For this purpose, Trusted Execution Environment (TEE) technology has been used to protect against malicious behavior and eliminate the need for trusted intermediaries. In addition, the reliability problems of TEEs have been solved with the query-answer mechanism and lightweight verification methods working on smart contracts. Test results showed that the developed system reduces costs by 45% to 68% compared to XClaim, ZK-bridge, and Tesseract systems.

(James Lovejoy et al., 2023) introduced a high-speed, low-latency, reliable, and flexible processor system for central bank digital currency, which is called Hamilton. Hamilton offered different programmability options and allowed for the definition of various roles for financial intermediaries. The system separated the transaction verification steps, ensuring that only the verification layer sees the transaction details, and allows for efficient implementation of status updates in parallel by designing the transaction format with a simple "two-step confirmation protocol". Evaluations have revealed that Hamilton can process 1.7 million transactions per second, even in geographically dispersed environments.

(Matheus V. X. Ferreira and David C. Parkes, 2023) proposed an approach called "verifiable ordering rules" that alter the interaction between miners and users. With this framework of rules, miners have been obliged to make the order of transactions according to certain and verifiable rules when choosing block content. Findings of study showed that situations where miners can earn risk-free profits are inevitable in every ranking rule, but the proposed rule prevents miners from profiting from this situation by guaranteeing a fair price to user transactions. (Yihao Guo et al., 2023) introduced an off-chain channel to support cross-chain services, which is named “Cross-Channel” to ensure scalability, fairness, and atomicity of cross-chain interactions. Additionally, strong security and practicality issues have been demonstrated by avoiding high latency in asynchronous networks. After all, it has been shown that Cross-Channel is well-suited for processing cross-chain transactions in high-frequency and large-scale scenarios and brings a significantly enhanced throughput with minimal gas and delay overhead, through deployment of 50-instances on AliCloud.

(Ivan Jericevich, et al., 2022) introduced an open-source, low-latency, and high-throughput matching engine called CoinTossX. The system has been designed to be usable by sending orders in Julia and Python languages. The viability of the system has been demonstrated through small-scale desktop testing, local large-scale usage, and cloud deployment scenarios on Microsoft Azure. Orders have been transmitted over User Datagram Protocol in binary format in the Java-enhanced system. Aeron Media Driver has been used for low-latency communication. In the study, order generation and simulation environments have been separated from order matching and data flow, allowing for more realistic modeling of market dynamics and it has been recommended that Julia be preferred for order sending with simulation.

(Fan Fang et al., 2022) examined 146 research studies on cryptocurrency trading, providing a comprehensive compilation. Topics included trading systems, bubble and extreme situations, volatility and return forecasting, crypto asset portfolio building, technical analysis, and other topics. Additionally, some promising opportunities in cryptocurrency trading that are still open have been discussed by analyzing data sets, research trends, and the distribution of technology and content.

(Carsten Baum et al., 2021) presented an efficient exchange protocol that protects private information and has been decentralized as a precaution against front-run attacks. In this protocol, a group of servers conduct cross-chain order-matching transactions in a private and confidential manner and are financially incentivized to act honestly. Users can exchange assets across multiple blockchains as long as they have access to a public ledger that supports standard smart contracts. When parties act honestly, the system's on-chain complexity remains on par with the cost of transactions on a centralized exchange. If malicious behavior has been detected, users have been automatically protected from harm at a low cost, and the offensive servers have been compensated. Servers, the majority of which are actively corrupted, can only perform a DDOS attack; in this case, the servers are publicly identified and penalized, while honest users do not lose their funds. The study also gave the experimental results of the multi-party computing component and showed that the method is efficient enough to be used in practice.

(Moritz Platt et al., 2020) introduced a protocol that addresses key shortcomings in the decentralized exchange process. This protocol maintains the order book using a distributed ledger, monitors order statuses in real-time, and provides participants' performance scores and accurate exchange rate information. It also demonstrates how performance scores can reduce opportunity costs and how a continuous benchmark rate generated on verifiable transactions can be used to ensure a reliable exchange rate between cryptocurrencies. It has been stated that future research will be focusing on formally validating the suggested technical processes.

Details of the Platform

Architecture

The platform's architecture has been built on two key design patterns proven in high-frequency financial systems: CQRS and EDA. In the CQRS approach, write operations such as placing and canceling orders are completely separated from reading operations such as viewing the order book and querying the transaction history. This separation allows the platform to handle tens of thousands of read and write requests simultaneously without slowing each other down. In the EDA, every state change in the platform (e.g. a new order, cancellation, a match) has been recorded as an "event". In the study, these events have been stored on Apache Kafka in an immutable way. This paradigm gives the platform exceptional durability, auditability, and fault tolerance.

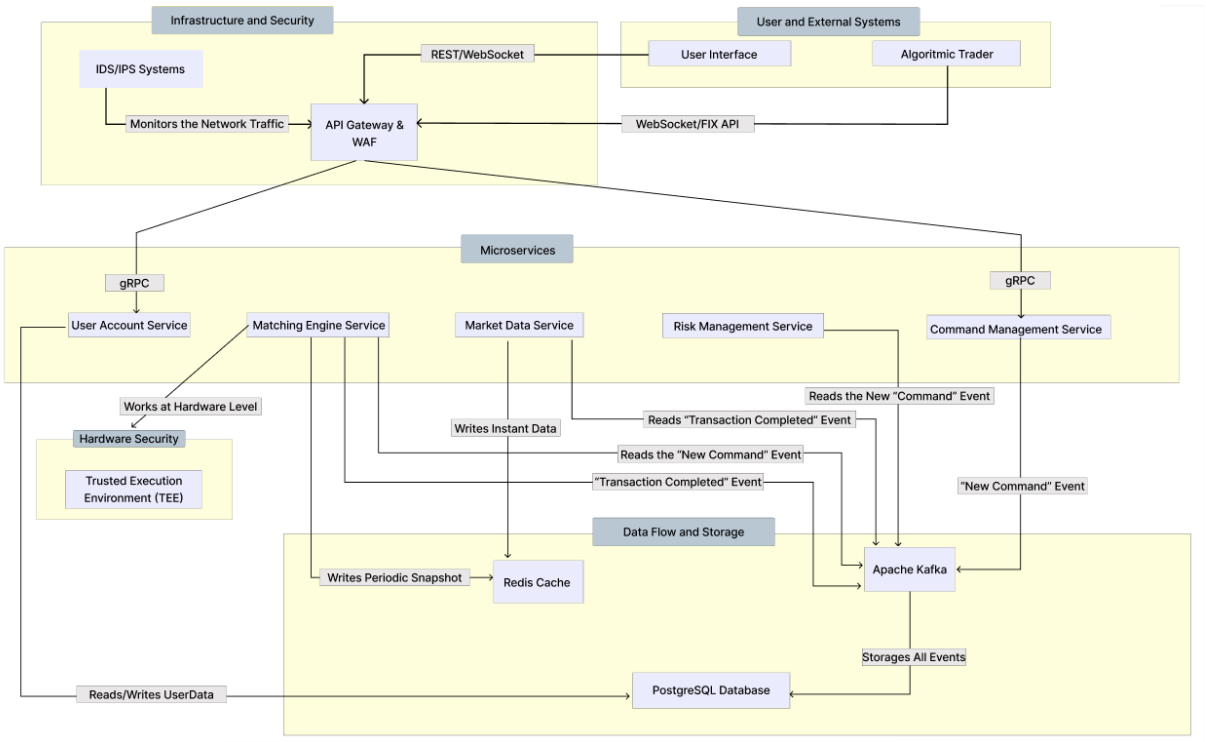

Figure 1. The platform architecture flow

There are various components in the layers of the platform such as infrastructure, security, and microservice.

These components have been described below. The Application Programming Interface (API) Gateway & Web Application Firewall (WAF) component, located in the infrastructure and security layer of the platform, is the single-entry point for all requests that come from the outside world. It forms the first layer of defense against attacks such as authentication, rate limiting, and DDoS. The Order Management Service component is a service that performs pre-validations of incoming orders and has the function of writing them as an "event" to Apache Kafka in a standard format. The Matching Engine Service reads orders from Kafka and matches the orders in the in-memory order book and writes the transactions to Kafka as a "Transaction Completed" event. Critical code blocks for this service run in a TEE for hardware-level isolation. The Market Data Service listens to " Transaction Completed" events in Kafka to generate data such as current price, volume, and order book depth. The Risk Management Service monitors the flow of orders, detects abnormal activity, and implements adaptive limit controls. Figure 1 presents the diagram of platform architecture.

Matching Engine

The matching engine is built on a series of deliberate engineering decisions aimed at reducing the platform's performance and latency from microseconds to nanoseconds. These decisions are based on three main pillars: data structure selection, in-memory computation architecture, and lock-free concurrency model. These foundations have been detailed later in the text.

An order book basically consists of two main structures: Buy offers (Bids) and sell offers (Asks). Both of these structures should be sequential according to their price levels. New orders are constantly being added and removed from the order book, and hence there is a constant change in the book. This dynamic structure would lead to very slow insertion/deletion operations, with a time complexity of O(n) according to Big O notation, in an ordered array. For this reason, self-balancing binary search trees that offer sequential insertion, deletion and search operations in logarithmic time, with the complexity of O(logn), has been seen as the most appropriate solution and the Red-Black Tree algorithm has been applied accordingly. In this structure, the order book consists of Red-Black Trees designed separately for the buy (Bid) and sell (Ask) sides. Each node represents a specific price level; For example, all orders at $50,000 have been aggregated under a single node. However, since more than one order can be placed at the same price, orders at that price level have been in a two-way linked list. Thanks to this list, orders can be easily added and deleted, and the "time" part of the Price-Time Priority algorithm, i.e. the first order to arrive at the same price level, which is named FIFO, is guaranteed in O(1) complexity. Thus, the platform can perform quick searches by prices and process orders at the same price level in the correct order. With this hybrid structure, finding the best offer (going to the rightmost or leftmost leaf of the tree) takes place in O(log n) complexity, while executing the oldest order at that price is done in O(1) complexity, i.e. fixed time.

Since the latency budget in high-frequency trading has been measured in microseconds, operations that take milliseconds, such as disk Input/Output (I/O), are unacceptable and therefore the matching engine should not have any contact with the disk. Due to this requirement, all active order books on the market are kept in the

server's main memory, which is named Random Access Memory (RAM), and all matching logic runs directly on this memory area, which is close to the Central Processing Unit (CPU) cache, without disk or network latency.

A two-layer resiliency and recovery mechanism has been implemented to prevent the risk of data loss in the event of power outages or crashes, which are vulnerabilities of the in-memory architecture. In the first layer, every order to the platform has been written to Apache Kafka as an "event" in an immutable form, and the matching engine processes these events to create its in-memory state; when the engine has been restarted in the event of a crash, it reads the events in Kafka from the beginning and reconstructs its state in seconds without error. In the second layer, to further shorten the recovery time, the engine writes a snapshot of the order book to Redis asynchronously at regular intervals; thus, crash recovery begins with the installation of the latest snapshot from Redis and only the events from that moment onwards are read from Kafka, thus reducing the system reboot time from hours to seconds.

In traditional multi-threaded systems, shared data structures like the order book have been protected by locking mechanisms like mutex or semaphore, but this approach leads to performance loss and unpredictable delays under high contention. To eliminate this problem, a model inspired by the LMAX Disruptor architecture has been adopted, and the basic logic of the matching engine has been designed to run on a single thread fixed to a single CPU core. Thus, the order book has been authorized to write only to this thread, eliminating the need for locking, resulting in a low-latency, deterministic pipeline.
Separate I/O threads have been assigned to receive orders from the network and send the processed results; Instead of passing orders directly to the core logic, these threads write to a ring buffer that does not require a lock, and the core thread reads and processes the orders from this buffer very quickly, and then passes the results back to the I/O threads via the ring buffer. Thus, slowdowns in the network have been prevented from affecting the core logic.

For high availability, the matching engine works with an active-passive replication model; In addition to the main server, there is a backup server that stays synchronized by listening to the entire order flow, and when an error occurs on the active server, Kubernetes directs the traffic to the passive server within milliseconds, ensuring uninterrupted service. Additionally, Apache Kafka replicates data across multiple servers, to ensure that even if any Kafka server goes down, no order or transaction data is get lost for ensuring data integrity. In short, active-passive replication model provides service continuity and Kafka replication ensures data integrity.

Security Architecture and Defense Model

The security architecture of the platform is based on the principle of "defense-in-depth"; that is, instead of relying on a single layer of security, multiple independent and layered defense mechanisms have been used. Potential threats have been modeled using the industry-standard STRIDE methodology; in this context, specific countermeasures have been developed for threat categories such as Spoofing, Tampering, Repudiation,

Information Disclosure, DDOS and Elevation of Privilege.

Spoofing

A spoofing attack occurs when an attacker impersonates a legitimate user, which can be individual or algorithmic, to send fraudulent orders to the platform or access sensitive information. Authentication measures have been put in place against such attacks. Authentication has been ensured using OAuth 2.0 and JSON Web Token (JWT) in user interfaces. After users authenticate through a standard identity provider, they receive an ephemeral JWT. Every request to the API Gateway has been signed and authenticated with this token, ensuring that a stolen password is useless on its own and that sessions are securely managed. For users engaged in algorithmic trading, an API key/secret mechanism has been employed. In this platform, API keys have been used to sign the body (payload) of each request with Hash-Based Message Authentication Code – Secure Hash Algorithm 256-bit encryption algorithm. The nonce and timestamp sent with the request make replay attacks impossible. The server follows the same signing procedure, verifying the integrity and origin of the request.

Tampering

Tampering occurs when an order has been changed on the network or within the platform, falsifying the price or quantity, deleting the record of an executed transaction, or disrupting the state of the order book. One of the strongest defenses against such threats is the TEE. The C++ code where the matching engine runs and the memory area that holds the order book has been isolated at the CPU level with TEE technologies such as Intel SGX. Thus, even an attacker with root access to the server or a malicious system administrator has been prevented by hardware from tampering with the memory of the running engine or changing its logic; process integrity has been guaranteed at the hardware level, not the software. In addition, immutability has been achieved with the event sourcing method. Every order and transaction event written to Apache Kafka has been stored in an append-only log. This log acts as an immutable registry where it is not possible to update a row in the database. Thus, any attempt to falsify any data can be detected immediately as it will disrupt the integrity of the event chain. Additionally, communication security has been ensured by end-to-end encryption. Communication between the user and the API Gateway, as well as between all microservices, has been encrypted with TLS 1.3, preventing Man-in-the-Middle attacks.

Repudiation

Repudiation is a threat defined as a user denying a transaction, especially after placing a large order that manipulates the market. Precautions have been taken against such situations by using an immutable audit trail. The event log stored in Apache Kafka is irrefutable retrospective evidence by showing which user gave what order from which Internet Protocol (IP) address and in what nanosecond. In case of any dispute, these event records can be used as conclusive evidence. Additionally, for high-volume enterprise customers, each API request can be required to be digitally signed with the customer's private key. This method creates cryptographic

proof that the placed order has been indeed sent by the respective customer.

Information Disclosure

Information disclosure is when an attacker compromises other users' open orders, trading strategies, balances, or API keys. Access to such data can make the transaction process susceptible to attacks such as Front Running. To mitigate this risk, API Gateway and role-based access control have been implemented at each microservice level. Thus, a user's JWT or API key only authorizes access to their account data. In addition, security has been enhanced by encryption at rest of data. All sensitive information stored in the PostgreSQL database, such as API keys and email addresses, has been encrypted with the AES-256 algorithm at the application layer. This way, even if database files are stolen, the data remains meaningless. Finally, the principle of inter-microservice isolation has been applied. Thanks to this structure, which has been designed according to the "Principle of Least Authorization", for example, the Market Data Service does not have access to the database of the User Account Service. Thus, the blast radius of the data leakage that may occur in the event of a service compromise has been limited.

Distributed Denial of Service (DDOS)

Denial of service is an attack defined as preventing legitimate users from receiving service by an attacker by consuming the platform’s resources or saturating its network. As a precaution against such attacks, a layered rate limiting solution has been implemented. API Gateway sets complex rate-limiting rules based on user identifier, IP address, and order type, preventing simple spam attacks from reaching the core system. In addition, Horizontal Pod Autoscaler (HPA) mechanisms come into play. The Kubernetes HPA mechanism monitors the CPU and memory usage of services in real-time, and in the event of a legitimate traffic spike or a sophisticated attack that exceeds the WAF, Kubernetes starts new copies of the service in seconds to handle the increased load, thus preventing platform slowdown. In addition, Kafka acts as a buffer in the architecture as a strong DDoS defense. Even if the API layer encounters a flood of orders that are too high, these orders are written to Kafka, which holds these orders like a massive buffer, ensuring that the matching engine continues to run at its maximum capacity without crashing. Thus, instead of causing a system crash, an attack has been limited to only a temporary latency spike.

Elevation of Privilege

Elevation of Privilege is a situation where a low-privileged user or a compromised service gains access to administrator privileges by exploiting vulnerability in the platform. To reduce this risk, each microservice has been run in its own isolated container. With this Docker-based isolation, it has been made difficult for a vulnerability in one service to spread to other services on the same server or to the main operating system. In addition, the passwords and tokens that services use to communicate with each other or with infrastructure components such as databases have been protected by ephemeral credentials. These credentials, which are

dynamically generated by a secrets management system such as HashiCorp Vault, are only valid for a very short period of time (e.g. 5 minutes). Thus, even if a credential has been compromised, it becomes invalid in a short time, minimizing the risk of attack. The screenshots of the developed platform have been presented in Figure 2 and 3.

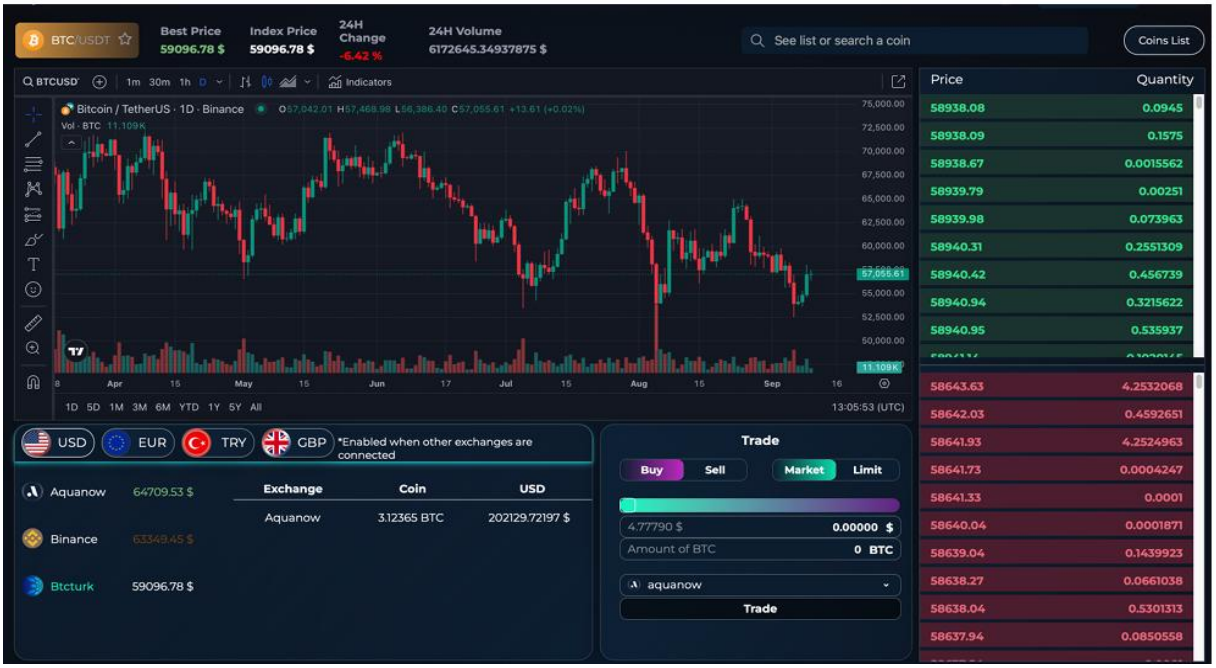

Figure 2. The screenshot of the platform

On the screen shown in Figure 2, exchange, coin, USD values can be followed, and graphs can be displayed.

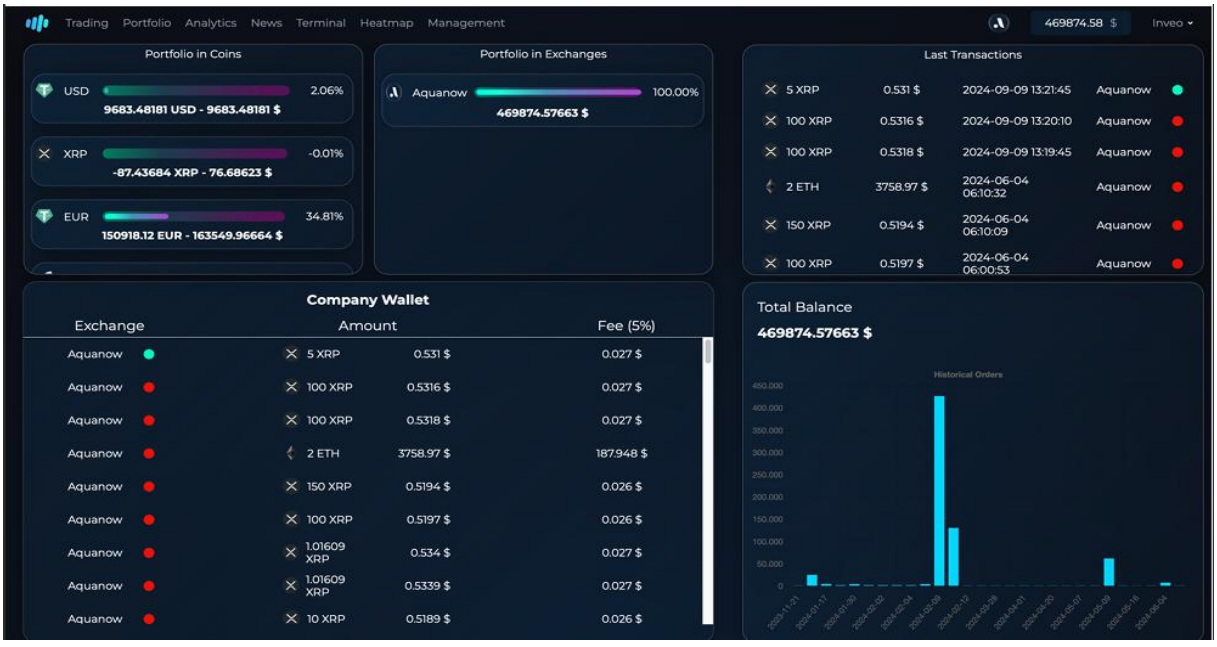

Figure 3. The screenshot of the platform

On the screen shown in Figure 3, exchange, amount, fee values can be followed, and portfolio in coins and portfolio in exchanges can be observed.

Testing Process of The Platform

Performance tests have been conducted on c5n.4xlarge, which is a compute-intensive virtual servers running on AWS with 16 vCPUs and 64 GB of RAM designed to minimize network latency. To simulate real market conditions, a historical data set containing the entire one-day order flow (tick-by-tick data) of a major cryptocurrency exchange has been used. This data set has been presented to the platform in three different scenarios: real-time market flow with a specially developed market replay tool, 10x accelerated data flow simulating moments of high volatility, and 100x accelerated data flow simulating extreme situations such as market crashes. Latency and Throughput Key Performance Indicators have been used for evaluation. Latency refers to the time in microseconds between the moment an order enters the API Gateway and the time the match result has been generated. Throughput refers to the average number of orders that the platform can process in one second.

The performance of the developed order processing engine has been directly compared with that of a traditional database-based virtual exchange engine by applying three different load scenarios. The comparison results have been given in Table 1.

Table 1. Comparative Performance Test Results of Order Processing Engines

Load Scenario	Metric	Conventional Engine	Proposed Engine	Performance Flow
Normal Market (1x)	Latency (µs)	8.500	120	~ 70 times
	Throughput	15.000	250.000	~ 16 times
High Volatility (10x)	Latency (µs)	25.000	280	~ 89 times
	Throughput	12.000	650.000	~ 54 times
Market Crash (100x)	Latency (µs)	150.000	850	~ 176 times
	Throughput	4.000	1.200.000	~ 300 times

According to the results obtained in Table 1, the conventional engine has been shown to experience severe performance degradation as the load increases; Switching from 1x to 100x load increased latency by ~17 times, while processing capacity decreased by 73%. This is thought to be a typical result of database bottlenecks and synchronous transaction limitations. It has been observed that the engine developed within the scope of the study achieved the "ultra-low latency" target of the study by keeping the average latency below 1 millisecond (850 µs) in the high volatility scenario. In addition, as the load increased, the transaction volume increased and exceeded 1.2 million orders per second, showing that the working efficiency and horizontal scalability of the platform's event-driven and asynchronous structure have been successful.

Table 2. Latency Distribution and Jitter Analysis

Metrik	Conventional Engine	Developed Engine
Latency (µs)	25.000	280
99.9 Persentil Tail Latency (µs)	210.000	950
Jitter(µs)	12.500	85

According to the results obtained in Table 2, the 99.9 percentile represents worst-case scenarios. While the slowest 0.1% of the conventional engine completes the operations in 210,000 microseconds, the developed engine's 99.9 percentile Tail Latency value remained below 1 millisecond. This value indicates that predictable performance has been achieved, which is vital for algorithmic strategies. The Jitter value of the developed engine is 85 microseconds, while the conventional engine has a jitter value of 12,500 microseconds. The low Jitter value of the developed engine is thought to be a direct result of the lock-free design and single-threaded core logic in the architecture. The high Jitter value obtained with the conventional engine reveals that the engine's performance is chaotic and unpredictable.

Summary of the Study Results

With the developed platform,
An order processing engine has been developed that overcomes the limitations of existing systems by increasing transaction speed and reliability in cryptocurrency markets.
An innovative platform offering low latency and high transaction volume capacity has been provided.
Transaction costs have been reduced, and trading processes have been optimized.
A system fully compatible with centralized and decentralized exchanges has been developed, allowing users to easily trade across different platforms.
Its broad integration capabilities have enabled investors and traders to achieve greater flexibility and accessibility in the cryptocurrency markets.
Security solutions supported by blockchain-based registry systems and TEE technology ensure the secure storage of user data and transaction history.
Adaptive risk management mechanisms and machine learning-based data analytics have protected users against market volatility and enabled them to make more informed investment decisions.

Conclusion

The dynamic nature of cryptocurrency markets is driving the need for systems with low latency, high scalability, and secure transaction processes. For users engaged in high-frequency trading and traders developing algorithmic trading strategies, processing times in milliseconds are critical. When trading on centralized and decentralized exchanges, strong encryption protocols and security measures must be ensured to ensure the security of funds and data. For this purpose, a high-performance order processing engine platform has been developed in this study. A comparison has been made with a conventional matching engine to test the

performance of the developed engine. The conventional matching engine experienced a serious decrease in performance as the data load increases; latency increased nearly 17 times and processing capacity decreased by 73%. In contrast, the developed engine kept the average latency below 1 millisecond in a high volatility scenario, processing 1.2 million orders per second, ensuring high throughput and horizontal scalability. In addition, the Tail Latency and Jitter values of the engine developed within the scope of the study offer predictable and stable performance with 1 millisecond and 85 μs, respectively, while the high values of the conventional engine showed that the performance is chaotic and unpredictable.

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The Role of Higher Education and Scientific Research in the Revitalization and Innovation of the Military Industry

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Abstract: In an era of rapid technological transformations and emerging geopolitical challenges, the military industry requires sustainable and advanced approaches to revitalize itself and enhance innovation. Today, the military industry must be regarded and valued not only as a component of national security, but also as an economic opportunity. Albania, in its effort to position itself as a small yet ambitious actor in the global defense industry, has initiated a gradual but determined process to revive its military industry. Academic and research institutions hold a crucial role in advancing the modernization of the Armed Forces, as well as in fostering technological development and innovation. Higher education and scientific research provide the foundation upon which the modern military industry is built and renewed. In an era where technology determines strategic superiority, higher education and scientific research serve as indispensable instruments for development, independence and national security. Through sustainable investments and structured cooperation between academia, industry and the state, innovative solutions can be generated that not only strengthen military capabilities, but also promote the overall technological and economic development of a country. This process requires close cooperation among higher education institutions, research centers and the defense industry. High-quality education in science, technology, engineering and mathematics (STEM), combined with the promotion of defense-oriented scientific research, is essential for the development of new military technologies, intelligent command and control systems, as well as advanced defense materials. This paper aims to analyze how education and scientific research contribute to strengthening the innovative capacities of the military industry, providing concrete examples from different countries while identifying development opportunities in the Albanian context. It highlights the need for reforms in university curricula, the establishment of specialized programs in defense technology, and the creation of effective bridges of cooperation between the Armed Forces Academy and the military-industrial sector.

Keywords: military industry, innovation, higher education, scientific research, defense technology, education-industry cooperation.

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Introduction

The modernization of the Armed Forces is a complex process, which includes fundamental changes in material

capacities to meet strategic objectives. The Armed Forces aim to increase qualitative levels by transforming them into a professional, well-trained force, equipped with modern technical and weapons systems, modern and interoperable means, and capable of carrying out a wide range of operations. The modernization process in the Armed Forces is designed to serve this purpose. Following the 1990s, the Albanian military industry, once built on a spirit of self-sufficiency and entirely oriented towards national capacities, fell into complete collapse. Factories like those in Poliçan, Gramsh or Mjekës, which once produced light weapons, ammunition and explosives, were left neglected, serving more for the process of disarmament and dismantling than for production development. After decades of abandonment, during which the military-industrial heritage of the communist period remained in oblivion and was degraded, Albania is now seeking to rebuild this sector as a vital component of both national defense and development. To advance national security and defense capacities through innovative projects and the integration of modern technologies, the Albanian Government has set a clear objective that by 2030 it will produce weapons and equipment bearing the "Made in Albania" label, capable of being used by the Albanian army and for potential export to international markets.

To achieve this objective, the Albanian Government and the Ministry of Defense have taken successive, concrete steps, starting with the adoption of a special law that paves the way for the revitalization of the military industry. "The new law paves the way for the modernization and revitalization of inherited capacities and established a new state structure for the military industry" (Pirro Vengu, statement during the visit to the Medical Factory, Ministry of Defense , August 2024). Subsequent measures include completing and approving the full legal framework, rebuilding and upgrading infrastructure by constructing the necessary factory facilities, legally defining the principal responsibilities of entities tasked with restoring a defunct industry, as well as establishing cooperation in this field with actors at the global level for the production of military technologies and systems. "We are negotiating with major allies… part of these investments is expected to support the production of military vehicles… intelligent drones… the production base… will give us the opportunity to produce for ourselves and export" (Edi Rama, quote from the conference in Rubik about the weapons factory, *Shqiptarja.com* , July 2024).

Today, in a world marked with new conflicts, hybrid aggressions, and unforeseen threats, the reconstruction of military-industrial structures is viewed not merely as an economic ambition, but as a strategic necessity for national security. Undoubtedly, the military industry constitutes a critical component of the national security and strategic development in any country. In the case of Albania, the revitalization of this industry has come to the fore as a necessity, not only to strengthen the country's defense capacities, but also to create a sustainable economic and technological base that contributes to regional peace and stability.

Within a broader geopolitical context, NATO has increasingly called upon its member states to contribute more to the field of defense, including building domestic production capacities, identifying it as one of the driving factors. As an international military alliance, NATO has consistently emphasized the importance of the defense industry, considering it as one of the main pillars for maintaining collective security. “Strong defense industries across the Alliance are essential for our security” (NATO, " Speech by NATO Secretary General Jens

Stoltenberg at the Defence Industry Forum", Brussels, 19 April 2023. https://www.nato.int/cps/en/natohq/opinions_213123.htm Eisenhower, DD, 1961, January 17. Farewell Address. The American Presidency Project. https://www.presidency.ucsb.edu/documents/farewell-address-president-dwight-d-eisenhower). The military industry provides the armed forces with the means, technologies and equipment needed to fulfill the Alliance's common missions and obligations.

In this view, NATO relies on the military industry to ensure that member countries have equivalent or interoperable capabilities, meaning the production of equipment that is standardized and suitable for joint operations. Without a strong, coordinated, and cooperative industry, the effectiveness of military interventions would be significantly impaired. "Only an alert and knowledgeable citizenry can ensure the proper integration of the vast industrial and military machinery of defense with our peaceful methods and goals"(Eisenhower, DD, 1961, January 17. Farewell Address . The American Presidency Project. https://www.presidency.ucsb.edu/documents/farewell-address-president-dwight-d-eisenhower). This quote emphasizes the crucial role of an educational system that produces conscientious and knowledgeable citizens who can help guide the ethical and strategic direction of military development. Higher education creates the right personnel to formulate defense policies and lead technological research.

By promoting the military industry, innovation and technological development, NATO ensures that the military arsenal of its member states remain aligned with modern security challenges, such as cyber-attacks, hybrid warfare and threats from sophisticated weapons. Investments in the defense industrial base are therefore not only a matter of physical strength, but also of strategic foresight. "We must invest in our defense industrial base not only for today, but to prepare for the challenges of tomorrow" (US Department of Defense. " Remarks by Secretary of Defense Lloyd Austin at the Reagan National Defense Forum, California", December 3, 2022. https://www.defense.gov). NATO also views the defense industry as an integral part of national economies, where by promoting cooperation between the public and private sectors for the development of defense technologies it helps not only to increase military capacities, but also to strengthen the economic sustainability of member countries. In this context, for Albania, in order to take concrete steps in this direction, instead of continuously importing high-cost military equipment, it should rebuild and put into operation the domestic production chain, as a long-term solution for increasing defense independence. "Transatlantic security relies on sustainable supply chains and a strong defense industrial base" (US Department of State. " Secretary Antony Blinken's Remarks at the NATO Public Forum", Vilnius, July 11, 2023. https://www.state.gov). In these circumstances, the revitalization of the Albanian military industry is no longer an option, but rather a strategic, economic and political necessity. As a NATO member and a stabilizing factor in the Balkans, Albania needs to build its military production capacities, guaranteeing higher security and offering a new potential for development and international cooperation.

It is certain that, at present, this effort may appear more as an industrial initiative with strategic and symbolic significance than as an immediate source of revenue. However, in a rapidly evolving context where security in Europe is once again called into question and countries are seeking greater diversification of supply sources,

Albania secures a place in this emerging market landscape, if it brings the projects it has started to completion. In conclusion, we can state that the military industry is a key element for the functioning of NATO and Euro-Atlantic security. “Europe’s security also depends on a competitive and innovative defense industry” (European Commission. " Ursula von der Leyen's State of the Union Address" , Brussels, 15 September 2021. https://ec.europa.eu). The defense sector is not merely an instrument of war, it is a strategic factor for the peace, security and technological development of the alliance and its member states.

The revitalization of the military industry in a world of rapid technological development cannot be conceived without the support of academic and research institutions. This article examines how higher education and scientific research serve as engines of innovation in the defense sector, with a particular focus on the development of new technologies, increasing human capacities and building a scientific infrastructure in the service of national security. “Scientific research is essential for military power, but it must be balanced with civilian progress” (Bush, V. (1945). Science: The Endless Frontier . United States Government Printing Office. https://www.nsf.gov/od/lpa/nsf50/vbush1945.htm). The link between science and defense presents a balancing need, as universities and research institutes are key sources of technology with dual civilian and military uses.Through the analysis of international models and the examination of local challenges, this article proposes concrete ways for strengthening the connection between education, research and the military industry in the Albanian context.

The military industry is inevitably closely linked to the technological development and intellectual capabilities of a country. In this context, the role of universities and research institutes becomes essential. Applied research, the training of specialists in strategic fields and the building of innovative capacities are key elements for the revitalization and modernization of the defense industry.

Higher Education as a Basis for Military Innovation

In an increasingly complex world of security challenges and conflicts of various kinds, the military industry is no longer just a field of production of equipment and armaments, but a complex sector that requires advanced knowledge, high technology and close cooperation with academic institutions. Higher education and scientific research are the foundation of international competitiveness, including in the field of the military industry. Investing in universities strengthens the technological capacities of a country. "Nations that surpass us in education today will surpass us in competitiveness tomorrow" (Obama, B. (2011, January 25). State of the Union Address . The White House Archives. https://obamawhitehouse.archives.gov/the-press-office/2011/01/25/remarks-president-state-union-address).

In this context, higher education and scientific research play a fundamental role in the revitalization and modernization of the military industry, acting as the main engine of innovation, the development of technological capacities and the formation of qualified human resources. As Confucius stated “Education breeds confidence, confidence breeds stability, stability brings strengt” (Li, C. (2000). The Confucian Philosophy of

Harmony . Cambridge University Press.). While philosophical in nature, this quote underscores the link between education and state strength, highlighting that a robust educational system supports political stability and sustainable development, including in the defense sector.

Higher education prepares specialists in disciplines such as engineering, information technology, electronics, cybernetics, artificial intelligence, etc., which are vital for the development of modern military equipment and systems. Without a strong academic foundation, the military industry cannot produce or maintain advanced technologies. Another aspect of the role of universities in revitalizing the industry is through scientific research.
Higher education and scientific research, particularly when conducted in collaboration with universities and research centers, generate new ideas and technologies, making discoveries that can be applied to intelligent weapons and ammunition, automated defense systems, drones and combat robots, communications and military cybersecurity. Scientific research, supported by universities and research institutes, is the basis of every advance in the modern military industry. Technologies that were once distant, such as artificial intelligence, autonomous systems, hypersonic weapons or quantum technologies, are today a reality through sustained investment in scientific research. Cooperation between universities and military research centers has brought significant advances in areas such as cyber defense, electronic warfare, command and control systems, as well as in the field of biotechnology for defense purposes. Through structured collaboration among academia, industry, and the military, scientific research outcomes are transformed into tangible military products. This encourages the creation of new enterprises (start-ups) oriented towards defense technology.

In this regard, the development of national policies and strategies is of great importance, where academic institutions, especially the Armed Forces Academy (AFA) and research centers such as the Institute of Military Scientific Research (IKSHU), as well as other research centers, should play a central role in the drafting of defense policies and military industry development strategies, by providing expertise in the fields of international relations, security and conflict analysis. Reviewing and updating study programs at all levels, in accordance with vital defense and security needs, remains a permanent challenge.
Specifically, the Armed Forces Academy should ensure that:

Bachelor's programs are carefully reviewed, oriented and focused on the engineering-technical and professional training of officers and specialists in fields such as military engineering, information and communication technologies, cybersecurity, economics-finance, as well as in the production of defense equipment. “Scientists study the world as it is, engineers create the world that never existed” (V on Kármán, T. (1967). The Wind and Beyond . Little, Brown and Company). Higher education in engineering fields is essential for innovation in military technologies, as military engineers are the ones who develop drones, missiles, defense systems and artificial intelligence in defense.

Master's programs focus on deepening aspects of defense systems management, cybersecurity, computer science and artificial intelligence, risk analysis and innovation in defense technologies, collaborating with industrial actors and other research centers. Doctoral programs, through research projects, focus on advanced scientific

research, in areas such as artificial intelligence in defense, military robotics, autonomous systems, modeling and simulation of conflict scenarios, as well as the development of innovative prototypes for military use. Enhancing the quality of teaching should continue through digitalization and the use of virtual simulations and interactive training, as another necessary step, by integrating online learning platforms and artificial intelligence tools.

Internationalization should be developed through the Armed Forces Academy serving as the key institution in its strategic role by establishing partnerships with homologous institutions at home and abroad. It is crucial to recognize that investments in education and research can significantly reduce dependence on imported weapons and technologies. This is particularly important for countries striving to maintain strategic autonomy and strengthen national defense capacities.

Human capital development. Universities contribute to human capital development in various ways, through a sustainable, comprehensive and quality-oriented approach. Higher education is not only a source of theoretical knowledge, but also a ground where professionals are formed who will lead and improve the military industry, who will later engage in the development of defense technologies, such as artificial intelligence, robotics, cybernetics, materials engineering and communication systems. Improving the quality of education for students, through the development of modern and labor market-related curricula, strengthening practical skills, as well as laboratory work, professional practices, project-based learning, as well as mentoring and academic advising to support the personal and professional development of students.

In this context, the Armed Forces Academy (AFA) plays a key role in the development of the country's defense and security capacities, through the training and education of future officers. In the times we live in, the development of human capital is not only an institutional need, but a strategic necessity for building a professional, modern military force capable of facing complex security challenges in an increasingly dynamic geopolitical environment. One of the fundamental steps in the development of human capital is the continuous improvement of the academic curriculum and military professionalism. This means harmonizing military education with national and Euro-Atlantic standards, especially those of NATO, including advanced knowledge in the fields of security management, strategic direction, military technology and multinational operations. Education should not be limited to the theoretical aspect alone, but be closely combined with practical training, strategic simulations and international exercises, which enhance the operational and decision-making competencies of cadets and young officers. Comprehensive training of students and cadets integrates theoretical, practical and physical training to develop strategic and tactical skills, leadership and decision-making under pressure, while fostering discipline and social responsibility. Additionally, foreign language courses (e.g., English, French, etc.) facilitate participation in international missions, as well as it builds "soft" skills (like communication, cooperation and ethics skills) through extracurricular activities and military simulations.

The development of human capital at the AFA should not be limited to military students, but starts with the academic staff themselves. Lectures and instructors should be involved in continuous professional training and international exchange programs to adopt modern teaching methodologies and to remain updated with the latest

developments in the field of security and defense. Supporting scientific research and participation in international academic projects are effective ways to increase the quality of teaching and create a sustainable climate for professional development. To build a human capital adaptable to change, the AFA should invest in the use of technology and in the digitalization of teaching and training processes, through e-learning platforms, tactical and strategic simulation systems, as well as artificial intelligence for military data analysis, creating an advanced learning environment. This not only increases the efficiency of education, but also strengthens the ability of personnel to operate in a modern battlefield, which is increasingly influenced by technology.

In a globalized world and with common international security challenges, cooperation between public and private HEIs, with foreign military academies and international organizations is essential. Involvement in programs such as Erasmus+, student exchanges and training in allied countries helps to build a broad strategic culture and significantly increases the quality of military human capital. National and international partnerships, cooperation with NATO military academies for student and staff exchanges, participation in peacekeeping missions or joint exercises, which increase real-world experience and intercultural interaction, as well as engagement with civilian academic institutions for modules that are not specifically military, but useful for intellectual development.

In addition to technical and military skills, the AFA should also focus on developing soft skills such as effective communication, conflict management, critical thinking and ethics in leadership. A good officer is not just an executor of orders, but a leader who inspires, organizes and makes decisions in complex situations. In this regard, education on military ethics and a culture of responsibility is essential to ensure the integrity and professionalism of the armed forces.

In conclusion, the development of human capital at the Armed Forces Academy is not simply a matter of professional preparation of future officers, but a national strategy for strengthening defense and security. Only through a comprehensive approach, which includes curriculum improvement, professional development of staff, digitalization, cultivation of soft skills and international cooperation, can the Academy build a strong, resilient and prepared human capital to face the challenges of the future. In this way, the Academy is not just an educational institution, but a strategic factory that forms tomorrow's leaders of the country's security and defense.

Armed Forces Academy-Industry Interaction. Developing partnerships with industry and the wider community, through cooperation programs with businesses and public organizations for professional practices, joint projects, or curriculum development. Commitment to community service that helps students develop social sensitivity and civic capacities.

In this context, structured cooperation programs should be established with public and private enterprises operating in the field of defense, where students can develop professional practices, joint projects and be included in the innovation and production cycle, as well as academic-industrial councils should be created,

where industry representatives contribute to the design of curricula and the definition of research priorities. “Military innovation does not happen in isolation. It requires cooperation between academia, industry and government” (Petraeus, DH (2012, May 21). Remarks at RUSSIA on Strategic Innovation . Royal United Services Institute.). This statement reinforces the importance of an integrated ecosystem where higher education plays a key role as a catalyst for research and a partner in defense and security projects.

The revitalization of the military industry requires a well-coordinated ecosystem where higher education and scientific research are key links. The creation of strategic partnerships between universities, academia and military industry companies and state defense institutions enables the effective transfer of knowledge into practice. This interconnection is essential to ensure that public investments in research and development turn into concrete products that increase a country's defense capacity.

When discussing the development of human capacities at the Armed Forces Academy, it is essential to recognize the unique context of this institution, which serves not only as an educational center but also as a formative environment for military leadership, discipline, and public service. The university-industry partnership highlights the importance of deepening collaboration between the Armed Forces Academy and universities and research institutes, both domestically and internationally, particularly with the Polytechnic University and the Faculties of Natural Sciences. These institutions provide expertise in electronics, communication systems and energy, which are applicable in defense technologies. The Armed Forces Academy should also increase cooperation with the Military Industry. Development of teaching practices with students, training of technical specialists for the Armed Forces, who work in the maintenance and modernization sector of military equipment. AFA, in cooperation with UPT or the Faculty of Information Technology, can develop prototypes for surveillance drones or encrypted communication systems. AFA, through its expertise, can assist in the modernization of military depots and ammunition renewal, the safe handling and renewal of ammunition or the development of military recycling technologies, etc.

Albania is currently at a crucial stage in revitalizing its military industry, and the success of this process depends largely on structured and long-term cooperation between universities, the Armed Forces Academy, and the military industry sector. Through investments in education, scientific research, and innovation, the country can build a modern, sustainable, and independent military industry. Academia-industry interaction, as well as the creation of collaborative bridges between universities and the military sector, helps translate theoretical ideas into applicable defense products. Successful models include technology incubators, centers of excellence, and joint research practices.

The revitalization of the military industry through cooperation with the academic sector generates new jobs for engineers, researchers, and technicians, having a positive effect not only on security, but also on national economic development. In conclusion, we can say that higher education and scientific research are not simply supporters of the military industry, they are the foundation on which a modern, efficient and strategically independent industry is built. Investing in these two sectors is a necessity for any state that aims to have a strong

and advanced defense.

The Role of Scientific Research in the Revitalization of Military Industries

In this regard, the role of Scientific Research in the Revitalization of the Military Industry, as well as technological innovation in the defense function, takes on a very great importance. Scientific research constitutes the basis of every military innovation, starting from advanced drones to cyber security systems, most innovations are born in scientific laboratories, often in collaboration with academia.

Through applied and interdisciplinary research, the military industry can gain significant benefits, as fields such as computer science, psychology, engineering, and even molecular biology converge to create innovative defense solutions. “The best way to predict the future is to invent it” (Kay, A. (1987). The best way to predict the future is to invent it. Stanford Engineering Lectures.). niversities serve as centers of innovation where ideas shaping the technologies of the future are conceived, and when these ideas are channeled into the military industry, strategic advantages are created.

One of the weaknesses of the military academic environment in Albania remains the weak connection between scientific research and real industry, so importance and attention should be paid to the strengthening of Applied Scientific Research. To improve this aspect, it is necessary to include the following:

- Revitalization of the Military Scientific Research Institute and other research units within the AFA specialized in priority defense areas, in cooperation with technical universities and international partner defense institutions.
- Budgetary support through the financing of applicable research projects, where academy personnel, as well as Master's and Doctoral level students, are directly engaged in the production of solutions for the operational needs of the Armed Forces. Encouraging publications in military scientific journals, as well as international scientific journals, with the aim of disseminating knowledge and increasing the academic reputation of the institution.

International Models and Practices

Cooperation between universities and the defense and security sector is a consolidated practice in many countries around the world. This collaboration is implemented through diverse institutional, legal, and technological frameworks, all aimed at linking academic and scientific capabilities with the strategic security needs of the state.

There are numerous international models of cooperation. One of the main models of cooperation is the establishment of joint research centers between defense ministries in partnership with public universities or scientific institutes. As a positive example, we can mention NATO Centers of Excellence (COEs) - the Center in

Tallinn (Estonia) for Cyber Defense is a collaboration between universities, NATO and the defense sector.

Joint doctoral and research programs represent another effective model, where universities provide research opportunities focused on defense technologies, often funded by the state. A notable example is the Defense Advanced Research Projects Agency (DARPA) in the USA, which cooperates closely with universities such as MIT, Stanford, Georgia Tech, etc., for the development of advanced military technologies. Defense technology incubators are another key approach. These structures support startups that develop dual-use (civilian-military) technologies, often in partnership with governments and universities. For instance, in Israel, the Innovation Authority collaborates with universities like Technion to foster startups in cybersecurity and drone technologies. Another aspect of University-Defense Sector cooperation is through the construction of joint civil-military education policies.

The development of university courses and training and training for military officers and civilian students on the same academic platform. A positive example of this approach is Germany's Bundeswehr University, which provides higher education to both military and civilian personnel in fields such as engineering, information technology, and national security. This model is increasingly being adopted by defense academies and universities worldwide. A notable regional example can be found in the Balkan countries, including Albania. In Albania, the Armed Forces Academy (AFA) collaborates with public universities to train officers and develop academic programs at the bachelor's and master's levels, including institutions such as AM University (Durrës) and IQ University (Vlorë). The Academy has also reintroduced doctoral programs in fields such as Security and Defense and Security and International Politics. Additionally, the Polytechnic University of Tirana maintains partnerships with the Ministry of Defense for research and development in engineering and communication technologies.

Other countries in the region also have strong developments in cooperation between universities and the relevant ministries of defense. Serbia has a strong collaboration between the University of Belgrade and the Ministry of Defense for the development of military production technologies and smart weapons, and also has research centers within armament factories, supported by the academic community.

In Croatia, the Faculty of Electrical and Computer Engineering (FER) at the University of Zagreb, is one of the institutions conducting research in defense technologies, including cooperation with NATO, focusing on projects with drones, robotics and cyber defense systems. Similarly, North Macedonia has also initiated cooperation programs between the Military Academy and civilian universities for the development of academic modules in security and defense and is benefiting from cooperation with NATO member states after joining the alliance.

In this context, we assess and recommend that international models and regional practices show that successful cooperation requires political will and financial support, appropriate legislation and joint research and training platforms, and finally international networking (e.g. through NATO, the EU, or Erasmus).

Challenges and Opportunities of Military Higher Education and Scientific Research in the Albanian Context

The existing challenges are mainly related to the lack of research infrastructure in the defense function, as well as the low level of cooperation between the Academy and the Armed Forces. In this regard, the drafting of national policies for military scientific research, the financing of cooperation programs between the Academy of the Armed Forces, universities and defense institutions, as well as the involvement of the Armed Forces in the process of drafting technology curricula, constitute the main step of a successful cooperation between HEIs and the military industry.

In the Albanian context, cooperation among universities, the defense sector and the military industry is an area with great development potential, but at the same time faces significant challenges. In the period of revitalization of the Albanian military industry, this cooperation takes on strategic importance for increasing the country's technological, research and operational capacities. The challenges in the Albanian context in terms of cooperation between universities and the defense sector are numerous.

Albania lacks a strong tradition of systematic and institutionalized cooperation between universities and the defense sector. In fact, there has been an absence of a long-term national strategy that links education, scientific research and defense needs. Scientific research has generally not been prioritized, and the country has had limited research and technological capacities. Public universities, including the Armed Forces Academy (AFA), have limited resources for research oriented towards the fields of defense and security. There is a lack of advanced laboratory infrastructure for military technology, robotics, simulations or intelligent weapons.

In Albania, the long-term isolation of the military industry from the academic world, where former military industry (e.g. former factories producing ammunition, weapons or military repairs) did not operate for decades, has resulted in minimal cooperation with universities. The lack of transparency and limited data exchange has negatively affected cooperation. Another influential aspect of this lack of cooperation was the inadequate or long-absent legal framework, which prevented university-industrial cooperation in the field of defense and security, as is common in EU or NATO countries.

The opportunities and potential in the reorganization of the Albanian military industry in recent years, including the renewal of ammunition production, repair of military equipment and research into defense technologies, is creating new ground for the involvement of universities, in particular in areas such as: Armament Engineering, Electronics, Cybersecurity, Artificial Intelligence and Communication Technologies. In the conditions of an ever-changing security environment and the increasing needs for a functional and sustainable military industry, the Armed Forces Academy (AFA) has an essential role to play in the preparation of personnel, in the development of scientific research and in the connection of knowledge with military production and technology. A continual challenge remains: the review and improvement of study programs at all levels, Bachelor, Master

and Doctorate, as a strategic necessity to increase the real impact of higher education in the development and revitalization of the national military industry. The adaptation of Study Programs must be done in accordance with the strategic needs of the country's defense and security. To truly contribute to the revitalization of the military industry, academic programs must directly reflect the current and long-term needs of the Armed Forces and the defense sector in general.

Conclusions and Recommendations

The lack of structured cooperation between universities, research institutes and the military industry sector has been an obstacle to technological development and innovation in this field in Albania. The country has sufficient human and academic potential, but it is not adequately directed or stimulated toward technological developments applicable to national defense and security.

Revitalization of the military industry requires a new approach in which higher education and scientific research play a key role in creating technical capacities, developing new products, and adopting modern technologies. Innovation in the military industry cannot be achieved without a strong academic and research foundation, and in this regard, Albania must create sustainable policies that link higher education with national defense and security priorities. In an increasingly tense global climate, where states aim to reduce dependence on foreign technologies, especially in the defense sector, higher education and scientific research directly contribute to building technological independence, through the development of domestic research capacities and the education of new generations of scientists.

Key recommendations include:

- Creating specialized university and research programs in fields such as military engineering, defense technologies, and artificial intelligence with applications in security, to prepare qualified personnel.
- Promoting strategic partnerships between the Ministry of Defense, universities and the private sector, to develop joint research projects that support the modernization of the military industry.
- Use of European funds and international grants for scientific research and innovation in defense technologies, with the aim of strengthening domestic capacities and increasing competitiveness.
- Raising awareness about the role of scientific research in developing the country's defense capabilities.

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Development of a Large Language Model Supported Low-Code/No-Code Workflow Engine Platform

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Abstract: Small Medium Enterprises (SMEs) make significant contributions to employment, innovation and regional development. To ensure the sustainability of them and increase their competitiveness, it is crucial to create customer-centric strategies in customer relations. Customer Relationship Management (CRM) or Customer Experience Management (CEM) platforms are used to manage customer relationship activities and create relevant business rules. The limited technical knowledge of SME employees makes it difficult to use CRM softwares. In this regard, the emergence of Low-Code/No-Code (LCNC) platforms have been a promising solution for this issue. Although LCNC solutions facilitate workflow creation, it is thought that performing these processes directly through natural language prompts will significantly speed up the processes. The aim of the study is to accelerate the processes of creating workflows on CRM platforms for SMEs and to reduce the need for technical knowledge. For this purpose, ROBOSME Workflows, a Large Language Model (LLM)-powered LCNC, customer relationship workflow automation system, has been developed. This platform has enabled SME employees to create workflows using natural language without requiring technical knowledge. Thus, with fast workflow creation processes, both times have been saved, and the automation of these processes could be facilitated.

Keywords: Low-Code/No-Code, Workflow Automation, Large Language Models

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Introduction

SMEs are enterprises that operate below the annual balance limit and the number of employees determined by the regulations. SMEs increase the economic development level of nations by increasing job employment, regional development and added value production, forming an important part of the economic structure. One of the important business lines that directly affects the sustainability and competitiveness of this critical economic role is customer relations. By collecting and processing various data of customers, important strategies are developed at sales and marketing points. Customer satisfaction is increased by making business decisions in line with customer needs and demands. Thus, customer loyalty is ensured, the reliability of businesses is increased, and their sustainability is secured.

CRM or CEM platforms are used to control customer relationship operations, collecting and easily managing customer data. An effective CRM platform ensures healthy communication with customers and helps SMEs to make customer-oriented decisions by providing an overview of the company's target audience. For this reason, it might increase the company's reputation by ensuring customer satisfaction. However, the limited capital structures and lack of technical expertise of SMEs make it difficult to use traditional and inflexible CRM softwares. Therefore, the need for the necessary solutions to accelerate the workflow creation activities of SMEs and to facilitate their technical processes becomes even more evident. In this regard, the emergence of LCNC platforms stands out as an effective solution for these problems experienced by SMEs. With LCNC solutions, it is possible to create the automations they need, in a short time, without the need of advanced code and architecture knowledge. These platforms utilize drag-and-drop interfaces and visual flows, enabling users to create customized solutions tailored to their needs.

Although LCNC solutions make it easier to create workflows, they cannot reach their full potential in terms of speed due to their use by adapting to visual tools with low flexibility. At this point, supporting LCNC platforms with LLM and performing workflow creation processes directly through prompts using natural language greatly speed up the processes. LLMs are important language models that stand out today for their numerous capabilities. They are used to analyze historical task data and text content with low error rates, accurately classify tasks according to priority, and assign tasks to appropriate personnel within this classification, thus optimizing workload balance to maximize efficiency. In this context, LLMs reduce technical dependencies and increase operational efficiency.

The aim of this study is to facilitate and accelerate the processes of creating workflows on CRM platforms for SMEs. In this direction, an OpenAI's LLM-supported LCNC, customer relationship workflow automation

platform which is named “ROBOSME Worklows” has been developed that enables the creation of workflows with the explanations that the user will send to the system via a chatbot and the transformation of the created flows into draggable and changeable visual elements for customization and editing. This study is organized as follows: The relevant literature is presented below. After that, thedetails of the system are provided. Following this, the result of the study has been given. And finally, the conclusion of the study is included.

Literature Review

Introduced an LLM-based mechanizm, called Action Engine, that can create and automate Function as a Service (FaaS) workflows using user queries in natural language (Akiharu Esashi et al., 2025). Action Engine has been developed in a modular structure to determine the relevant functions in the FaaS repository and manage the data relationships between them, when the developer sends a request for processing and resolution. Evaluations have shown that the developed engine works independently from the platform or language, thus minimizing the dependence on the provider in workflow creation. With the developed engine, it has been demonstrated that, FaaS workflows can be created for cloud-based platforms without technical knowledge about cloud services, and development processes can be carried out faster.

Aimed to present the architecture, deployment approaches, and practical applications of Small Language Models (SLMs) for business workflow automations in SMEs (Nagaraju Gaddigopula, 2025). For this purpose, a comprehensive analysis of implementation approaches, such as model architecture, domain adaptation techniques, and strategic deployment options has been provided. Challenges such as data scarcity, integration complexity, and stakeholder expectations have been addressed, through case studies. In the study, it has been stated that SLMs would benefit automation and development processes with advanced natural language processing features in business environments.

Presented a cloud-based low-code platform called Dandelion+, designed to build domain-specific Low-Code Development Platforms (LCDPs) applications to overcome the rigid code creation processes of existing LCDPs that limit flexibility and hinder interoperability (Francisco Martínez-Lasaca et al., 2025). Dandelion+ has been able to perform functions such as defining models, metamodels, users, and roles for low-code platforms, and creating applications. The applications have been supported by PlatFlow, a workflow language creation. Case studies have been conducted to evaluate the developed platform. In this context, Dandelion+ has been compared with other LCDP platforms, and the benefits of Dandelion+ have been analyzed in the industrial context of a software company called UGROUND, which uses low-code in its projects.

Aimed to overcome the insufficiency of the existing single LLM agent-based methods in complex problems that require specialized knowledge (Hanchao Liu et al., 2025). For this, he proposed a multi-mediated approach consisting of a supervisor, a regulator, and a filler tool. The "WorkTeam" model with a workflow creation framework from natural language instructions has been developed. In addition, a dataset named HW-NL2Workflow has been created for model training. The results obtained in the study revealed that the proposed

approach enhances the workflow generation performance of LLMs.

Introduced the “MASFlow”, a phased multi-agent collaboration framework for creating an automated service workflow model (Rui Zhu et al., 2025). In the proposed approach, using agents with various job descriptions, the modeling process has been divided into three stages: configuration, editing and re-viewing. Experimental results have shown that MASFlow reduces the phenomenon of hallucination, which is a common belief about LLMs. The model provided significant advantages over existing neural network architecture techniques and solutions, by providing an Accuracy rate of 93%.

Addressed how LLMs can be used to perform business process management tasks (Michael Grohs et al., 2024). Using textual descriptions, test cases have been created for the mining of process models, mining of declarative process models, and consideration the compliance of automation for robotic processes. The results obtained in the study revealed that LLMs performed better than existing solutions without configuration or prompt engineering.

Aimed to minimize human effort in workflow creation and automate the workflow processes (Jiayi Zhang et al., 2024). For this purpose, workflows have been represented as code, and each step of these flows, such as LLM call and tool usage, have been modelled as nodes, considering them as code snippets. The connections between these nodes, such as data flow, control flow, etc., have been shown as edges. By designing such an approach, the only thing that needs to be done is to search for the best flow on this node-network structure. Monte Carlo Tree Search has been used for this search step. This developed approach mentioned above has been called AFlow. Based on evaluations of six benchmark data, AFlow showed that smaller models outperformed GPT-4o on certain tasks and had a 5.7% performance increase over state-of-the-art baselines.

Aimed to solve the shortcomings of existing workflow processing approaches, such as limited scenario coverage, simple workflow structures, and weak evaluation mechanisms (Shuofei Qiao et al., 2024). To this end, WorfBench has been recommended as a benchmark for creating a unified workflow that can handle versatile scenarios and create complex workflow structures. Additionally, the VorfEval protocol has been introduced, utilizing subarray and subgraph matching algorithms for a comprehensive evaluation of the LLM agent's workflow generation performance. With this protocol, the distinct gaps between the sequence planning capabilities of LLM agents and their graph planning capabilities are exposed. Additionally, two open-source models have been trained to test their generalization capabilities on long duration tasks. Results from the proposed approach showed that the generated workflows have been able to enhance downstream tasks and spend less time inference.

Proposed a data-centric approach, which is called WorkflowLLM, to enhance the capability of LLMs to make workflows (Shengda Fan et al., 2024). In the first step of the study, “WorkflowBench” dataset has been created, using 106,763 examples spanning 1,503 Application Programming Interfaces (APIs) from 83 applications across 28 categories. The dataset has been created with real-time business data, cathered from Apple Shortcuts

and RoutineHub, and converted into Python-style code. Subsequently, more business queries have been generated using ChatGPT, increasing the diversity of the dataset. Finally, an annotation model trained on the collected data has been leveraged to create workflows for the synthesized queries. By combining the synthesized data with the actual data, Llama-3.1-8B has been fine-tuned. Evaluation experiments on the study showed that WorkflowLlama performed well in orchestrating complex workflows, as well as achieving remarkable generalization performance on previously unseen APIs (Jia Xu et al., 2024) addressed the use of LLMs for building workflow automation models. In this context, LLM4Workflow, an LLM-based automated workflow generation model, has been proposed. In this model, workflow definitions have been used as inputs. Based on these inputs, LLM has created manageable workflow models that can automatically populate relevant API information. The effectiveness of the proposed model has been validated by simulation tests on a real workflow system.

Presented a generic prompt recipe for a lecture that has been developed, ensuring that the logical reasoning of the LLM has been guided based on reliable APIs (Zhen Zeng et al., 2023). Thus, both the one-to-one interaction between LLMs and confidential data has been eliminated and hallucinations, which might likely to be seen frequently in LLMs, have been significantly reduced. The system simplified user interaction by providing descriptions of automated workflows, allowing users to provide feedback. In addition, the NCEN-QA dataset, which is a financial dataset and created for question-and-answer tasks, has been also presented in the study. With this dataset, FlowMind has been tested. The results obtained proved the importance of each component in the proposed lecture recipe and effectiveness of FlowMind.

Details of the Platform

The .NET Core framework has been used for the backend of the platform. PostgreSQL database has been chosen for data management, and Event Stream Processing has been used to collect and process data continuously and in real-time. The platform has been designed as a cloud-based Software as a Service solution for SME's sales, marketing, and service operations. The cloud-based nature of the platform ensures high availability, scalability, and security. The platform includes 7 modules such as FollowUpSME, SaleSME, MarketSME, ServiSME, SetSME, Customer Analytics, SocialSME. FollowUpSME provides task and activity tracking. The SaleSME module is used for sales channel and contract management. MarketSME provides campaign execution. The ServiSME module is used for service operations. The SetSME module is used for configuration and engagement. The Customer Analytics module is used for segmentation and performance insights. Social media integration is provided by SocialSME.

The platform's LLM-powered workflow engine provides three key functions. First, users can simply and clearly define the tasks to be converted into workflows by the platform. Workflows can be created to be reconfigured to respond to changing markets and demands. Furthermore, sales, marketing, and service workflows can be automated with contextual intelligence. In Figure 1, the LLM chatbot is called with the "Ai button" in the upper right corner of the platform interface.

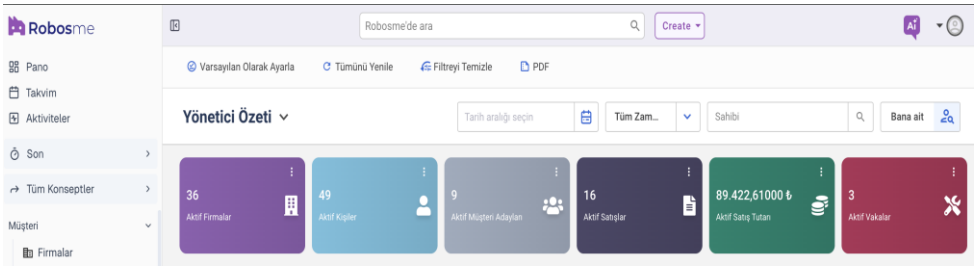

Figure 1. Calling the LLM

After the LLM is called, a chat section that opens and a written command is entered by the user. Figure 2 shows the step of entering the user command.

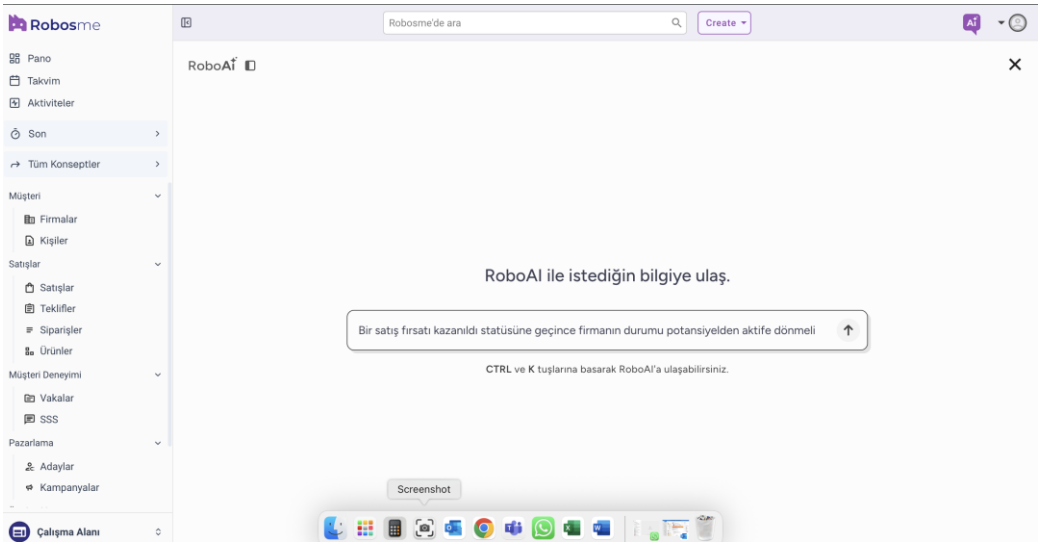

Figure 2. Entering the User Command

Once the workflows are created, they can be viewed on the "Workflows" page. Figure 3 shows the workflows page.

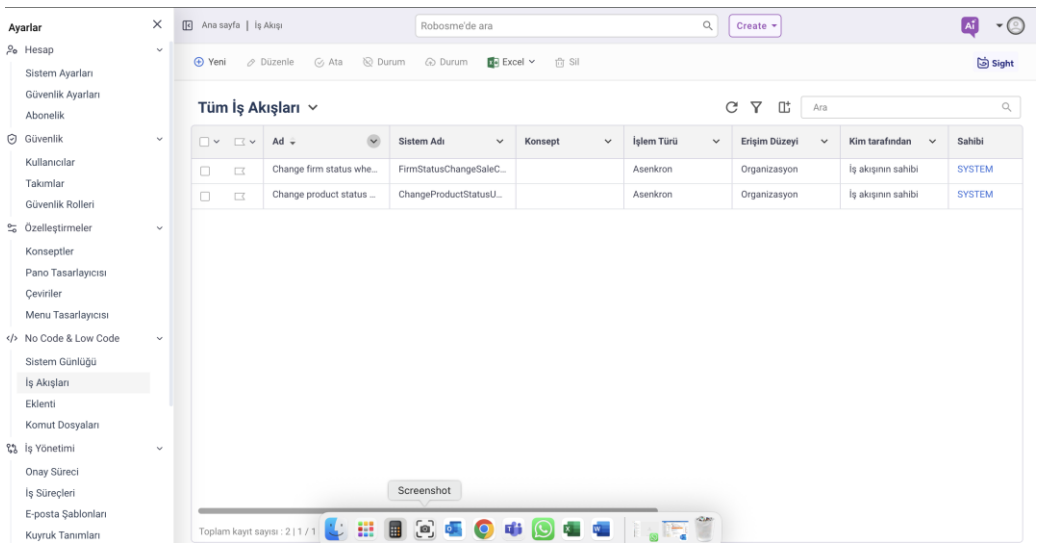

Figure 3. "Workflows" Page

Operations such as editing or determining the details of workflows are done through the "Detail Definition Page" as in Figure 4.

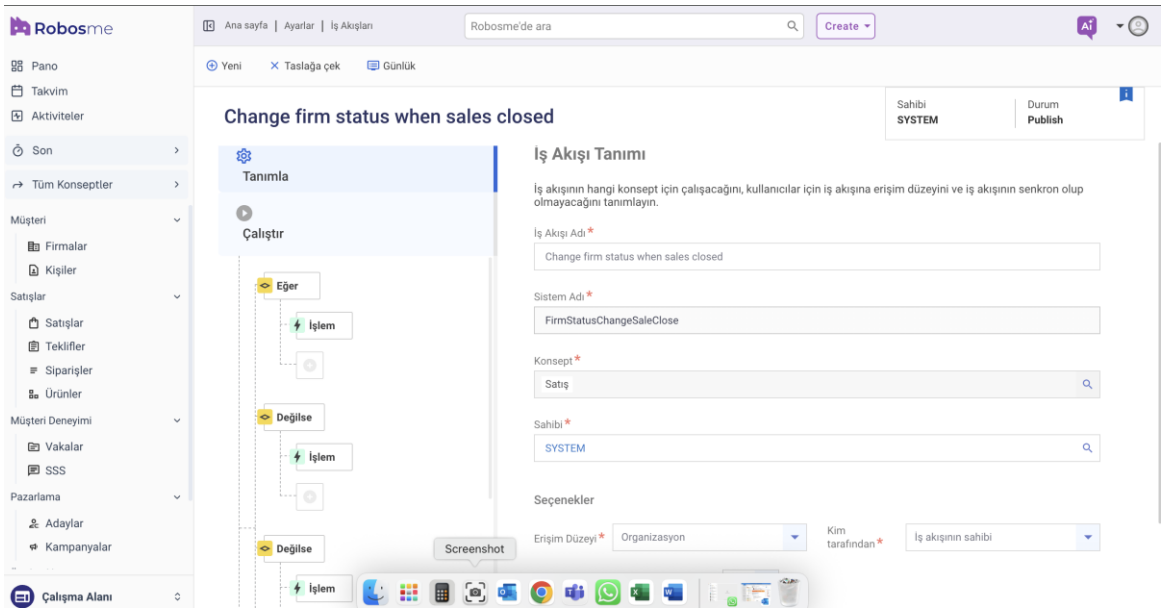

Figure 4. Detail Definition Page

Summary

With the developed platform:

SMEs had access to advanced CRM/CEM functionality that has been previously only available to large enterprises.

Operation time has been reduced, and time has been saved as a result of workflow automation performed by entering direct commands.

CRM processes have been made agile by providing real-time adaptation of workflows.

Non-technical personnels' scope of work has been diversified, and organizational innovation has been achieved by ensuring that they are directly involved in workflow automation processes.

Conclusion

Customer relations are of critical importance for SMEs to increase their competitiveness and ensure the sustainability of their economic contribution. In this context, the need for CRM and CEM platforms used for CRM to be accessible to SME employees without having to learn detailed technical knowledge has increased. While LCNC platforms have streamlined the CRM workflow creation process, they are still not flexible and fast enough. To overcome this problem, OpenAI's LLM supported, LCNC, CRM workflow creation system has been developed. In this way, SMEs have also been provided with access to advanced CRM/CEM functions that have

been previously only accessible to large enterprises. Workflows have been created by entering direct commands, and as a result, time has been saved. Non-technical personnel have been included in the workflow automation process, and their variety of tasks has been increased.

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Comparison between Sydney and ACR/Eular Classification Criteria in the Diagnosis of Antiphospholipid Syndrome

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Abstract: The classification criteria of Antiphospholipid Syndrome (APS) have changed over the years. The APS classification criteria, first published in 1999 known as Sapporo criteria and revised as Sydney criteria in 2006, require at least one clinical and one laboratory criterion to classify as APS. In 2023 American College and Rheumatology (ACR) and European Alliance of Associations for Rheumatology (EULAR), initiated a multidisciplinary effort to develop new APS classification criteria with high specificity and sensitivity. In this paper we will compare Syndey criteria with those of the ACR/EULAR in a diagnosed patient with antiphospholipid syndrome. According Syndey criteria this patient is classified as APS, due to pulmonary thromboembolism as clinical criterion and positivity of anti-cardiolipin IgG, antiβ-2glucoprotein IgG and LAC as laboratory criteria. Using the new ACR/EULAR classification, also classified this patient as APS, because there were at least 3 points from clinical domain and more than 3 points from the laboratory one, according the classification rule. What happens in other clinical and laboratory situations? Are new classification criteria useful for diagnosis?

Keywords: antiphospholipid syndrome, Sapporo criteria, ACR/EULAR criteria, anticardiolipin, anti β-2 glycoprotein antibodies, lupus anticoagulant etc.

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Introduction

Antiphospholipid Syndrome (APS) is an autoimmune disorder defined by thrombotic events or obstetrical morbidity in presence of persistent antiphospholipid antibodies, such as lupus anticoagulant (LAC), anticardiolipin (aCL) and ß2-glucoprotein (ß2-GPI) (Garcia & Erkan, 2018; Miyakis et al., 2006). Classification criteria for APS are proposed for the first time in 1987, by Haris. He emphasized the coexistence of typical clinical complications (arterial thromboses, thrombocytopenia, and obstetrical complications) and laboratory test abnormalities, among them he listed the presence of LAC and anticardiolipin. These criteria were slightly modified during the conference in Sapporo in 1999 (Swadźba et al., 2007). Sapporo criteria were the first formal attempt to standardize the classification of APS. These criteria combined clinical and laboratory domains to classify antiphospholipid syndrome. Sapporo criteria required at least one clinical event like thrombosis or pregnancy morbidity and persistent presence of antiphospholipid antibodies (aPL) such LAC or aCL IgG/IgM as laboratory criterion, detected on two ore more occasions at least six weeks apart, (Miyakis et al., 2006; Wilson et al., 1999). Over time the Sapporo classification criteria demonstrated several limitations, that highlighted the necessity for revision to improve diagnostic accuracy.

In 2006, in Sydney, Australia an international consensus group revised Sapporo criteria, keeping the fundamental requirement for APS: at least one clinical and one laboratory criteria, but they introduced some modifications in order to ensure accuracy and standardization in diagnosis. Clinical criteria included vascular thrombosis and pregnancy morbidity, while the laboratory criterion included for the first time anti-ß2-GPI, extended testing interval of antibodies persistence from 6 to 12 weeks and established antibody positivity by setting cut-off values (Kaul et al., 2007).

Lack of strict definition and limitations of Sapporo criteria, initiated a multidisciplinary effort from American college and Rheumatology and European Alliance of Associations for Rheumatology (EULAR), to develop new APS classification criteria with high specificity and sensitivity (Erkan, 2024 & Barbhaiya et al., 2023). New criteria ACR/EULAR differ from the Sapporo criteria in several aspects. The “entry” criteria, was first introduced and had to be fulfilled for the patient to be classified as APS. Clinical symptoms and laboratory criteria are hierarchically clustered in domains and each of them is weighted with score-points. A patient is classified as APS if he meets the entry criteria and accumulates at least 3 points from clinical domain and 3 points from laboratory domain (Toska et al., 2024). In this paper we will compare Sydney and ACR/EULAR classification criteria in a diagnosed patient with APS and will see how applicable are new criteria for diagnosis in other situations APS related.

Material and Methods

Realization of this comparison required both classification criteria for APS, Sydney and ACR/EULAR. Sydney classification standard as clinical criteria include vascular thrombosis and pregnancy morbidity: One or more

clinical episodes of arterial, venous or small vessel thrombosis confirmed by imaging or histopathology. One or more unexplained deaths of a morphologically normal fetus at or beyond the 10th week of gestation, with normal fetal morphology documented by ultrasound or by direct examination of the fetus.

One or more premature births of a morphologically normal neonate before the 34th week of gestation because of 1) eclampsia or severe pre-eclampsia, 2) recognized features of placental insufficiency.

Three or more unexplained consecutive spontaneous abortions before the 10th week of gestation, with maternal anatomic or hormonal abnormalities and paternal and maternal chromosomal causes excluded (Antovic et al., 2018; Peng et al., 2023; Gao & Qin, 2024).

Laboratory criteria according Sydney Classification includes:

Lupus Anticoagulant (LAC) present in plasma, on two or more occasions at least 12 weeks apart;

aCL-IgG/IgM in serum or plasma, present in medium or high titer, on two or more occasions, at least 12 weeks apart, measured by a standardized ELISA;

aβ2GPI-IgG/IgM in serum or plasma (in titer >99th percentile), present on two or more occasions, at least 12 weeks apart, measured by a standardized ELISA (Antovic et al., 2018; Peng et al., 2023; Gao & Qin, 2024).

New antiphospholipid syndrome classification criteria are published in 2023, according the standardized EULAR methodology. “The entry criteria” was first presented and required the presence at least one clinical criterion and one laboratory criterion within 3 years. The clinical and laboratory criteria are differentially weighted and organized in hierarchical domains. The goal of this new classification is to classify patients having APS, with high specificity and sensitivity for research purposes (Musial, 2023; Barbhaiya et al., 2023; Erkan 2024).

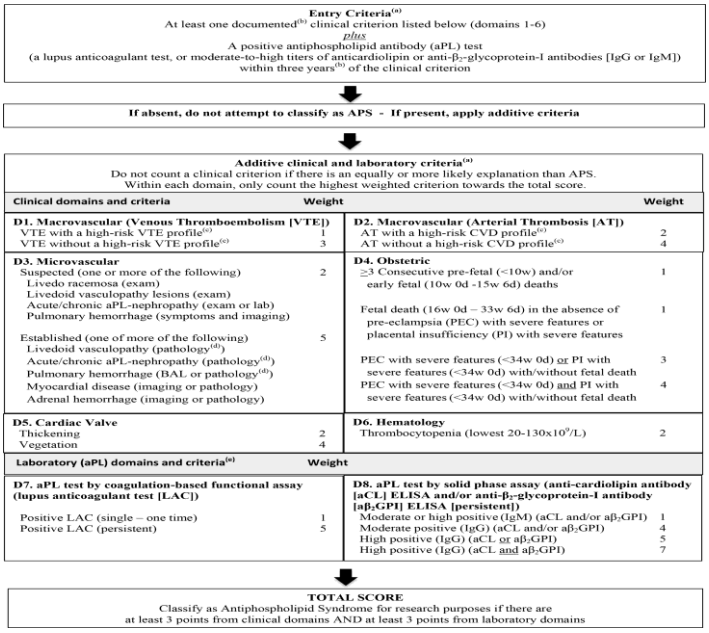

Figure 1. ACR/EULAR classification criteria

Source: The 2023 ACR/EULAR Antiphospholipid Syndrome Classification Criteria," by M. Barbhaiya, S. Zuily, R. Naden, A. Hendry, F. Manneville, M. C. Amigo, ... ACR/EULAR APS Classification Criteria Collaborators, 2023, Arthritis & Rheumatology, 75(10), 1687–1702. https://doi.org/10.1002/art.42624

Results

The patient diagnosed with APS is a 28 -year- old young lady, with her first thrombotic event at age of 14 (fourteen): a deep vein thrombosis in the right leg. Being suspect for APS she underwent several laboratory examinations for LAC, aCL and anti-ß2GPI. Results of laboratory examinations were positive for LAC, aCL IgM and IgG. These tests are repeated even after 12 weeks to confirm antibodies persistence. The diagnosis for this patient was APS with aCL IgM/IgG positive, with thrombotic events. Two years later she experienced another thrombotic event, bilateral pulmonary thromboembolism (PE) and persistence of LAC and aCL antibodies IgM/ IgG was still present.
Speaking in term of Sydney classification criteria this patient experienced one clinical criterion; deep vein thrombosis (and PE later) and laboratory criteria was fulfilled as well with persistent positivity for LAC and aCL IgG and IgM.

New ACR/EULAR classification, first of all needs to be fulfilled "entry" criteria. This patient has continuous thrombotic events and persistent aPL within 3 years, so we can apply additive criteria. First thrombotic event, deep vein thrombosis and PE belong to the first macrovascular domain and is assessed with 3 points as VTE (venous thromboembolism) without high risk. Lupus anticoagulant remains persistent from initial diagnosis until now (2025) and is scored with 5 points. Antiphospholipid antibodies in the last check realized in 2025 for this young lady resulted positive for aCL and ß2-GPI IgG and they are evaluated with 7 points. According new ACR/EULAR criteria we classify as APS if there are at least 3 points from clinical domain and 3 points from laboratory one. In this case we have 3 points from clinical domain and 12 points from laboratory one, leading in a case classified as APS.

Discussion

Despite new ACR/EULAR are classification criteria for research purposes, in prescribed case functioned as well even for diagnostic purpose. If another patient refers recurrent miscarriages, as one of the most common forms of APS, the clinical criteria is evaluated only with 1 point, not meeting the 3 points required to be classified. It has been early (1975) known the association of recurrent miscarriage with LAC and from epidemiologic studies it is, one of the most common causes of APS (Garcia & Erkan, 2018; Antovic & Sennström 2018), but not meet required criteria for ACR/EULAR classification. In this way, a patient who may actually have APS, is incorrectly excluded both for research or diagnostic purposes. This remains an important matter for experts to assess.

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Seroepidemiology of Cytomegalovirus Infection in Albania

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Abstract: Infections with cytomegalovirus are widespread among populations. This study presents a analyse of cytomegalovirus (CMV) serological testing in Albania. During an eight-year period (2017-2025) 38,216 serum samples collected in a private laboratory were tested for the presence of CMV IgG and CMV IgM antibodies using Roche, Electrochemiluminescence method. The purpose of the analysis was to assess the distribution of CMV immunity through the presence of IgG and IgM antibodies, with further breakdown by gender and age. Starting from 1599 samples in 2017, the number of tests has increased significantly, and precisely 5288 samples analysed in 2024. The high positivity rate for IgG (97,1%) indicates widespread past exposure or immunity to CMV among the population tested. In contrast, IgM positivity which indicates recent or acute infection was relatively low (135). The highest number of tests was conducted in the 31-40 age group (20,072 individuals), followed by the 21-30 group (13,568). These age groups represent the prime reproductive years, suggesting a focus on prenatal screening or fertility related testing. It was observed that females had a consistently higher number of tested, likely due to CMV screening in pregnancy.

Keywords: Cytomegalovirus, Seroprevalence, ECLIA, Albania

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Introduction

Human cytomegalovirus (HCMV; also known as human herpesvirus 5) is the prototype member of the Betaherpesvirinae family. Like all herpesviruses, it establishes latency and persists for the life of the individual. Infection with HCMV is common throughout the globe (Zuhair et al., 2019). Cytomegalovirus establishes a lifelong latent infection following primary infection that can periodically reactivate with shedding of infectious virus (Pembrey et al., 2013). Primary infection occurs when an individual with no immunity against this virus becomes infected for the first time. Afterwards, the virus establishes latency from which it may reactivate (second type of infection). The third type of infection is called reinfection when contact with an infectious individual results in superinfection of someone who has already been infected, despite their possession of natural immunity (Atabani et al., 2012).

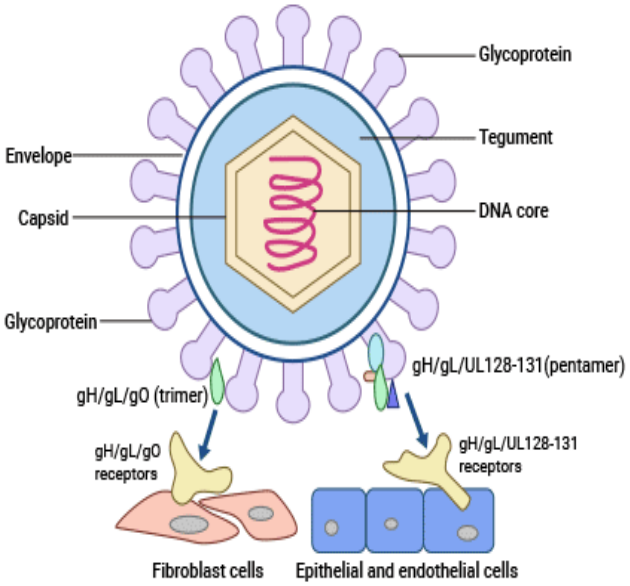

Figure 1. The structure of HCMV (Jahu Chen et al. 2022)

Primary infection, reactivation and reinfection during pregnancy can all lead to in utero transmission to the developing fetus. CMV infection is relatively common, but CMV is not spread very easily through simple contact. It can be spread through close contact with bodily fluids, such as saliva, urine, and breast milk, and can also be transmitted through blood transfusions, organ transplants, and sexual contact. (Cheeran et al., 2009). CMV can be secreted in body fluids for months, even throughout life, in people with weak immunity, such as those with HIV, without causing any symptoms. CMV transmission can also occur during pregnancy through the placenta from the mother's blood or from vaginal secretions during childbirth. This can cause congenital CMV infection in the newborn. The risk of congenital CMV is greatest when the mother is infected with primary infection during pregnancy. (Cheeran et al., 2009; Nassikas & Tsaples,2013).

Method

A total of 38,216 serum samples were collected and CMV tested in eight years from 2017 till June 2025. All of them were tested for cytomegalovirus IgG/IgM, regarding their clinical manifestations. Blood was collected by VACUETTE® TUBE 7 ml CAT Serum Separator Clot Activator 16x100 red cap-yellow ring, non-ridged, double gel, and then centrifuged 4000 rpm speed for 10 minutes. The age of tested people varied from 1 to 90 years, and no exclusion criteria were applied for sampling.

Testing for CMV IgG and CMV IgM is accomplished with test ECLIA (Roche, Electrochemiluminescence; Elecsys CMV IgG and CMV IgM). This method represents a reaction with the total duration of assay of 18 minutes. In the 1st incubation, 12 µL of sample, biotinylated recombinant CMV specific antigens, and CMV specific recombinant antigens labelled with a ruthenium complex) form a sandwich complex, while in the 2nd

incubation, after addition of streptavidin-coated microparticles, the complex becomes bound to the solid phase via interaction of biotin and streptavidin. Next, the reaction mixture is aspirated into the measuring cell where the microparticles are magnetically captured onto the surface of the electrode. Unbound substances are then removed. Application of a voltage to the electrode then induces chemiluminescent emission which is measured by a photomultiplier.

Results are determined automatically by comparing the electrochemiluminescence signal obtained from the reaction product of the sample with the signal of the cutoff value previously obtained by a calibration curve. Results obtained with the Elecsys CMV IgG assay can be interpreted as follows: Non-reactive: < 0.5U/ml, Reactive: ≥ 1.0 U/ml. Also results obtained with the Elecsys CMV IgM assay can be interpreted as follows: Non-reactive: < 0.7 COI, Reactive: ≥ 1.0 COI. Samples with a cutoff index < 1.0 are non-reactive in the Elecsys CMV IgG/IgM assay. These samples are considered negative for CMV IgG/IgM specific antibodies and do not need further testing. Samples with a cutoff index ≥ 1.0 are considered reactive in the Elecsys CMV IgG/IgM assay. The samples should be retested. If the result is still in the grey zone, a second sample should be tested within the next 2-3 weeks.

Results

In this study 38,216 serums were analysed for the presence or absence of specific IgG and IgM antibodies, serum testing was performed through the most efficient immunological methods: CMV IgG, CMV IgM via ECL method. This table summarizes the annual distribution of IgG and IgM antibody result among males and female subjects between 2017 and June 2025. Over these year's 38,216 individuals were examined, revealing consistently high IgG seropositivity and very low IgM reactivity across both sexes. While female positivity remained slightly higher (97% and 98%) the proportion of IgG positive males ranged from 86% to 95% throughout the study years. This sustained high level of IgG antibodies indicates widespread prior exposure and long-term immunity within the examined population.

On the other hand, the presence of IgM antibodies was low in all these years, ranging from 0 to 9% in females. The consistently low IgM positivity suggests that new infections were infrequent during the observation period.

Table 1. Overall and overview of all patient samples analysed

Year	TOTAL	IgG Total Males	IgG Positive Males	Positive % IgG Males	IgM Total Males	IgM Positive Males	Positive % IgM Males	IgG Total Females	IgG Positive Females	Positive % Female IgG	IgM Total Females	IgM Positive Females	Positive % IgM Females
2017	1599	44	40	91%	45	5	11%	585	576	98%	925	13	1%
2018	3784	99	93	94%	111	9	8%	1520	1486	98%	2054	35	2%
2019	4880	94	91	97%	98	4	4%	2032	1984	98%	2656	3	0%

Year	TOTAL	IgG Total Males	IgG Positive Males	Positive % IgG Males	IgM Total Males	IgM Positive Males	Positive % IgM Males	IgG Total Females	IgG Positive Females	Positive % Female IgG	IgM Total Females	IgM Positive Females	Positive % IgM Females
2020	4744	69	65	94%	75	1	1%	2045	1986	97%	2555	9	0%
2021	5184	90	84	93%	93	1	1%	2164	2108	97%	2837	0	0%
2022	4906	93	81	87%	108	3	3%	2036	1981	97%	2669	5	0%
2023	5108	106	92	87%	96	1	1%	2104	2034	97%	2802	13	0%
2024	5288	86	74	86%	101	2	2%	2144	2062	96%	2597	56	2%
06. 2025	2723	44	40	91%	49	3	6%	1141	1116	98%	1489	19	1%

The total number of tested samples increased steadily from 1599 in 2017 to 5281 in 2024, indicating expanded screening coverage and improved diagnostic surveillance.

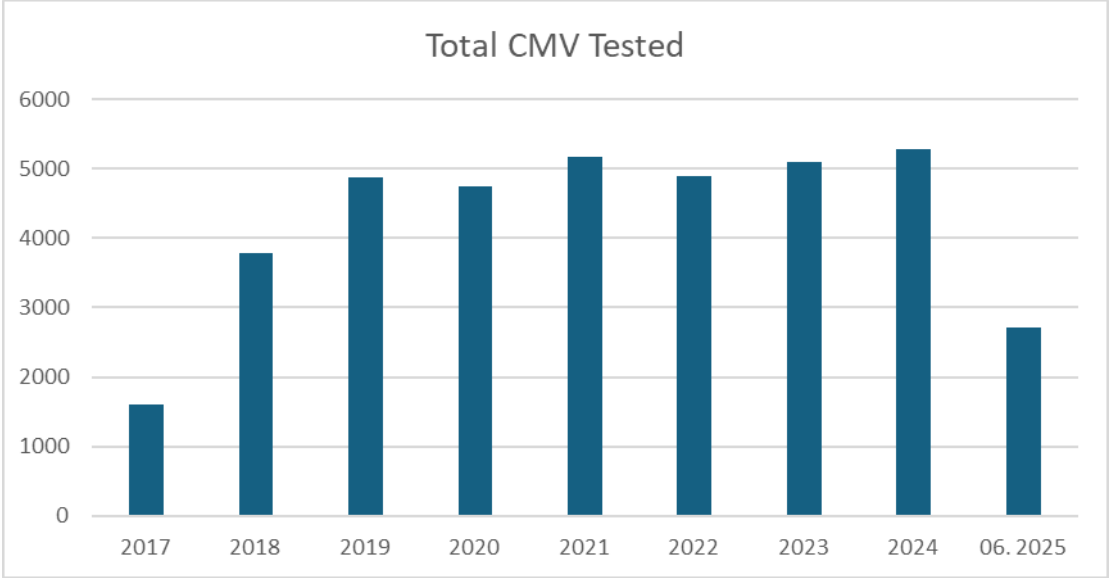

Figure 1. Distribution of total CMV tests from 2017-2025

Above it is shown the distribution of cytomegalovirus tests conducted from 2017 through June 2025. A clear upward trend is observed over this period. The number of tests increased markedly from approximately 1.500 in 2017 to nearly 5000 in 2019, followed by a sustained high level of testing between 2020 and 2024 (exactly from 5000 to 5500 tests).For the first half of 2025, approximately 3000 tests have already been performed suggesting that the total for the year may approach the levels observed in the preceding years if the same testing rate continues. This progressive rise in CMV testing over time may be attributed to sever factors such as the growing awareness of CMV infection. Also, the routine of CMV screening in the pregnant women may also increase the number of tested patients.

A total of 38.216 individuals were tested, comprising 1504 males (3.93%) and 36.712 females (96.06%). Patients were stratified into nine age groups. The highest number of tests was conducted in the 31-40 age group

(20,072 individuals), followed by the 21-30 group (13,568). Similar trends have been reported in Parma (Italy) were among 19,043 persons, prevalence increased from ~28% in early childhood to ~95.7% in age 45–54 (Natali et al.,2020). In Germany seroprevalence was 51% in men and 62.3% in females. A systematic literature review found for Europe shows IgG seroprevalence among women of reproductive age ranged approximately from 45.6%-95.7% (Lachmann et al.,2018). In national France the survey of people aged 15-49 years seroprevalence was 39.3% in men and 45.6% in women (Antona & Lepoutre et al., 2017). Among men data are more limited, one study in France had 39.3%. This predominance of female testing reflects the inclusion of CMV serology as part of infection screening protocols in women during pregnancy. The higher number of females is consistent with the clinical relevance of CMV infection in pregnancy, where maternal primary infection poses risk for congenital transmission and potentially fatal complications (Adler, 2011). CMV testing in males is less frequently, because it is generally performed in specific clinical context, such as infertility problems, transplant donor, or immunocompromised patients.

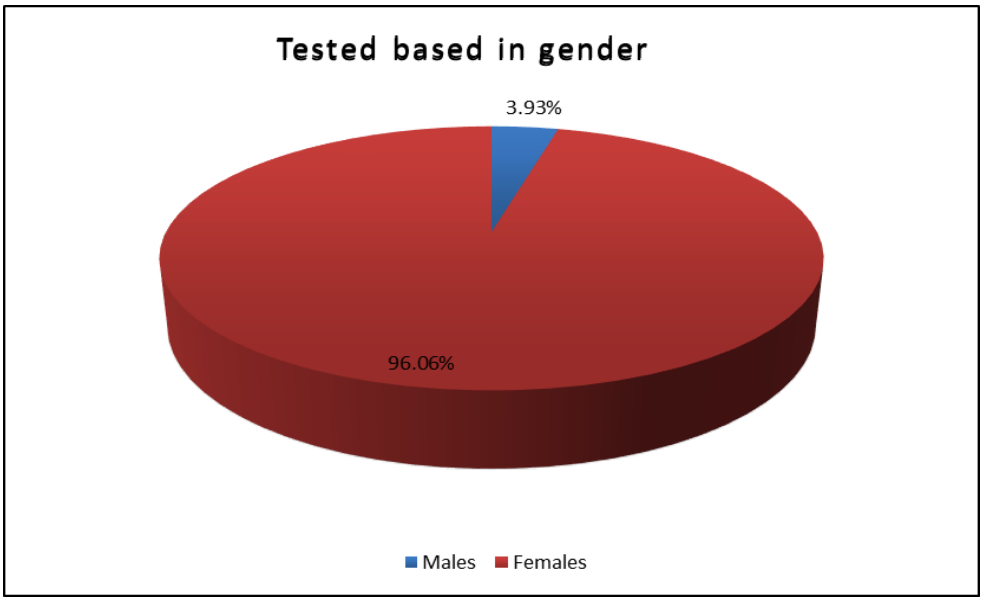

Figure 2. Distribution of CMV Ig based on gender

Figure 4 presents the distribution of cytomegalovirus antibodies among males over the period 2017 to 2025. The analysis includes both IgG and IgM antibodies profiles. A gradual increase in the total number of CMV antibody tests is observed throughout the study period, with notable rise in 2021onwards. This trend may be attributed to the expansion of CMV serological screening protocols, and the broader implementation of preventive measures in the general population. The prevalence of IgG positive males remained consistently high across all examined years that indicates a stable pattern of past CMV exposure. On the other hand, IgM positivity rates remained low and relatively constant suggesting that primary or recent CMV infections were infrequent during the study period. From 2024 until the June of 2025 the highest number of total IgG and IgM tests was recorded, reflecting the possible consolidation of CMV antibody testing as a part of routine clinical or epidemiological surveillance programs. From a public health perspective, these findings emphasize the importance of continues CMV surveillance to identify trends in reactivation and transmission especially in high-

risk groups.

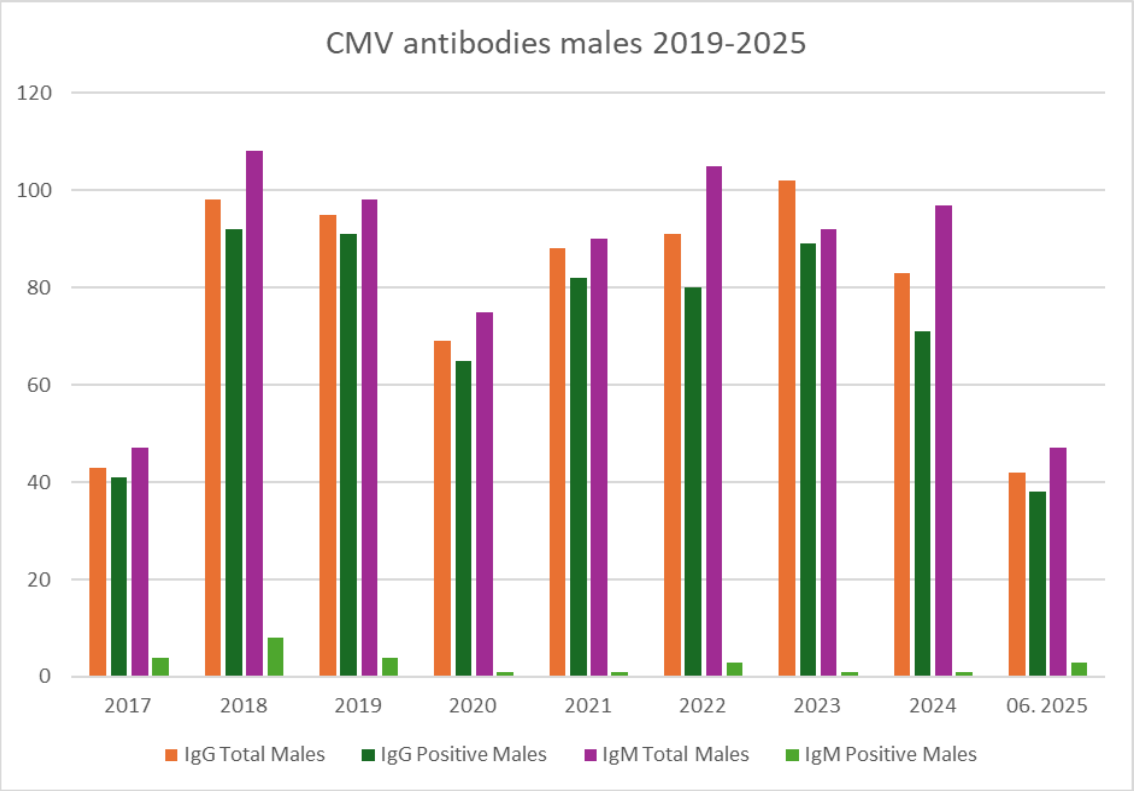

Figure 3. Distribution of CMV antibodies in males

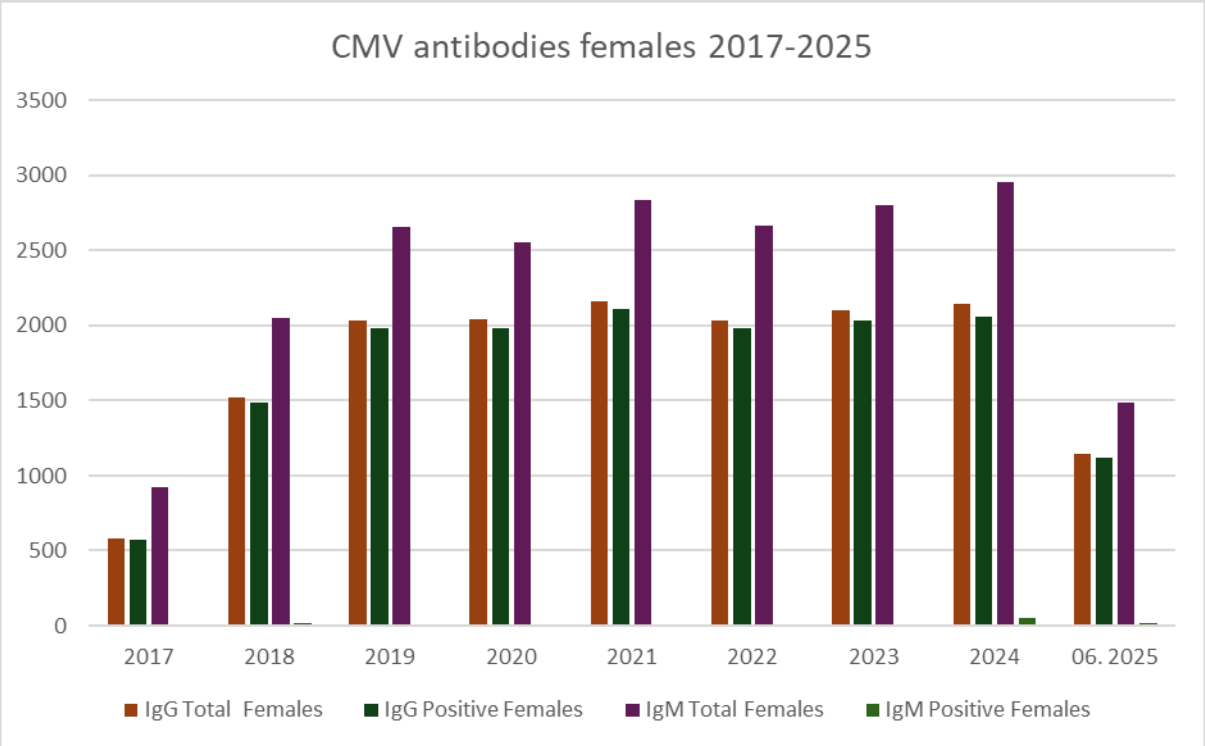

Figure 4. Distribution of CMV antibodies in females.

The analyses of CMV antibodies results among females between 2017 and June 2025 demonstrates a progressive increase in both testing. A steady increase is observed in the total number of CMV tests and IgG positive results over the years. From less than 1000 in 2017 to over 2500 in 2024 indicates a continues rise in CMV seroprevalence within the tested population. This consistently high proportion of IgG positive results reflects a substantial level of prior CMV exposure and long-term immunity among women of reproductive age. A large retrospective study of women aged 16-45 years in Croatia found CMV IgG seroprevalence of 70.6% in 2015-2024 (Vilibić-Čavlek et al., 2025). While study in Romania among pregnant women, between 2013-2016 the IgG seroprevalence was 93.6% (Radoi et al.,2024). Also, in Bulgaria during 2003-2015 the seroprevalence was 78.45% (Stoykova et al., 2017). In contrast the number of IgM positive cases that represent recent or primary infection remained relatively low throughout the study period. This suggests that most infections identified during pregnancy or reproductive screening are latent rather than newly acquired.

Conclusion

These findings highlight a largely immune population with limited evidence of ongoing transmission during the studied period, underscoring the effectiveness of current preventive measures and the importance of continued surveillance to detect potential shifts in infections dynamics.The markedly higher number of female participants reflects the greater focus on CMV screening among women of reproductive age, consistent with public health priorities aimed at preventing congenital CMV infection.

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Trends and Effectiveness of Moodle in Interactive Learning: A Systematic Review

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Abstract: Technological advancements have driven the adoption of digital platforms to foster interactive and flexible learning experiences. Moodle, as an open-source Learning Management System (LMS), has emerged as a primary choice across diverse educational contexts. This study aims to investigate the main research focuses, effectiveness, and developmental potential of Moodle through a Systematic Literature Review (SLR) guided by the PRISMA protocol. Data were retrieved from the Scopus database using the keyword 'Moodle,' and 16 articles meeting the inclusion criteria, published between 2018 and 2023, were analyzed. The findings reveal that Moodle facilitates the development of higher-order thinking skills (HOTS), supports inquiry-based learning, and enhances the personalization of learning processes through its interactive features. Furthermore, Moodle has demonstrated greater effectiveness than alternative platforms, such as Facebook and Google Classroom, in improving learning outcomes and student engagement, attributed to its flexibility and open- source design. The study also highlights potential avenues for development, including the integration of advanced technologies such as augmented reality (AR) and artificial intelligence (AI), the enhancement of features for students with special needs, and cultural adaptations to improve user acceptance in various regions. The study concludes that Moodle is an innovative and effective platform with significant potential to support technology-driven learning. However, its success hinges on the availability of robust infrastructure, comprehensive educator training, and tailored adaptations to meet regional needs. Further research is recommended to solidify Moodle's role as an inclusive, adaptive, and technology-based learning platform.

Keywords: Moodle, Interactive learning, effectiveness

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Introduction

Technological advancements have catalyzed a rapid transformation in the educational landscape. Alongside the progression of science, technology plays a pivotal role in reshaping how education is delivered and accessed to align with contemporary needs (Daryanes et al., 2023). Education, as a means to develop individual potential,

represents a fundamental human necessity. Consequently, integrating technology into education has become indispensable. Among the platforms supporting this shift is Moodle, an open-source Learning Management System (LMS) designed to facilitate interactive, flexible, and collaborative learning experiences. Moodle is extensively utilized across diverse educational levels and contexts, ranging from primary schools to higher education and professional training programs (Anggraeni & Sole, 2018a, 2018b; Teo et al., 2019).

Moodle, short for Modular Object-Oriented Dynamic Learning Environment, is one of the most widely adopted e-learning platforms globally, particularly in educational institutions (Anggraeni & Sole, 2018a; Marcen et al., 2022; Teo et al., 2019; Zhang et al., 2020). It is purposefully designed to support collaborative and self-directed learning, featuring tools particularly suited for physics education (Gamage et al., 2019; Teo et al., 2019). As an e-learning platform, Moodle provides robust interactive features, enabling dynamic teacher-student interactions while integrating various educational resources. The teaching and learning process facilitated by Moodle can occur through formal instruction or alternative approaches recognized by communities (Munfaridah et al., 2022; Lestaran et al., 2023). Its implementation aims to equip students with the adaptability and positive behaviors necessary for personal growth and societal change. For example, research by Alkholy (2015) demonstrated that a Moodle-based LMS significantly enhances critical thinking skills. Similarly, a study by Ardianti et al. (2020) found that Moodle- based e-learning platforms promote student autonomy and collaboration. Further, Saefullah et al. (2023) explored a Moodle-based learning model integrated with the Problem- Based Learning (PBL) approach to improve critical thinking skills. PBL engages students in solving real-world problems, fostering critical thinking and problem-solving abilities (Ali et al., 2024; Ørngreen et al., 2021). The study revealed that Moodle effectively facilitates digital access to learning resources and enhances students' critical thinking skills. In the digital era, integrating technology into education has become an unavoidable necessity.

Moodle, as an open-source LMS, supports this transformation by delivering interactive, flexible, and collaborative learning environments (Amin et al., 2023; Marcen et al., 2022; Mustafa & Ali, 2023; Rivers, 2021; Zhang et al., 2020). It has been widely adopted across educational and professional training contexts, from primary to tertiary education. As technology and the demand for distance learning evolve, research on Moodle's utilization has grown significantly (Zhang et al., 2020). Moodle serves not only as a learning management platform but also as a tool for enabling more interactive, technology-driven education (Anggraeni & Sole, 2018b; Fernando, 2020; Setiaji et al., 2022; Teo et al., 2019; Zhang et al., 2020). However, its adaptation depends on institutional needs, curriculum design, and avaiable technological infrastructure. Between 2018 and 2023, research trends on Moodle have expanded, focusing on its effectiveness, innovative features, and adaptability to specific aeducational needs. Systematic research is crucial to understand how Moodle is utilized across diverse contexts and how it compares to other platforms in supporting technology- enhanced learning. This study addresses there primary research questions:

What are the main research focuses related to Moodle's use in interactive learning at secondary and tertiary education levels between 2018 and 2023?
How effective has Moodle been during this period?

What are the most promising research topics for future exploration?

This analysis aims to provide a comprehensive understanding of Moodle's potential, challenges, and future directions as a leading e-learning platform.

Method

This study uses a systematic literature review research method. The stages of this literature study were carried out systematically by following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines. The articles used in this study were taken from the Scopus database using the keywords: ("Moodle").

The exclusion criteria used in this literature study are as follows: (1) research related to Physics and Astronomy Learning, computer science and engineering, (2) articles other than in English, (3) articles that are not published in the range between 2018-2023. (4) The sample is students and high school level.

Of the total 96 published articles that have been identified through a keyword search in the Scopus database, 16 articles that meet the inclusion and exclusion criteria and research objectives are included in this literature review. Furthermore, article filtering is assisted using the Mendeley application.

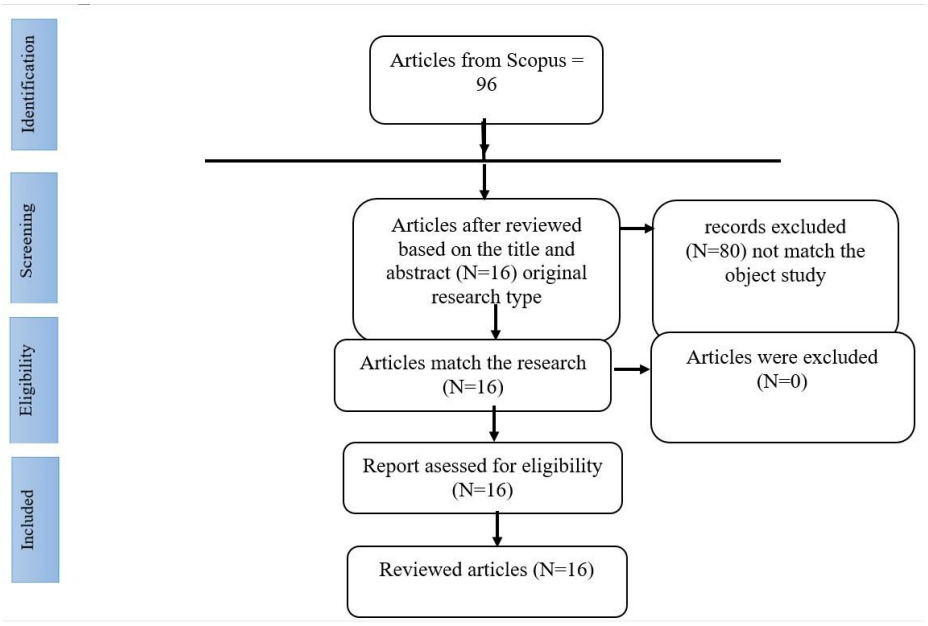

Figure 1. Prisma Chart

Findings

The main focus of this literature review is to identify the use of Moodle in interactive learning at the high school and college levels, the effectiveness of Moodle use during the period, and the most potential research topics to

be developed in the future. Several studies of the use of Moodle in interactive learning at the high school and college levels, the effectiveness of Moodle use from various literatures that have been identified are as follows.

Table 1. Systematic Review of Moodle Research Articles

Title	Author	Research Design	Finding
Quizzes Via Augmented Reality On Learning Management System: A Case Study Of Moodle	(Rodríguez et al., 2023)	Descriptive Quantitative	The results of the study show that it has been successfully proven that agreeableness and conscientiousness have a direct positive influence on online academic self-efficacy, which further contributes to increasing acceptance of Moodle as a learning platform.
The role of personality traits and online academic self-efficacy in acceptance, actual use and achievement in Moodle	(Rivers, 2021)	Non-experimental Quantitative using Structural Equation Modeling (SEM) approach for path analysis	The results of the study showed that it was successfully explained that the research model was able to predict 14% of the variance in course achievement, with a significant relationship between personality, online academic self-efficacy, Moodle acceptance, and learning outcomes. Personality traits, especially agreeableness and conscientiousness, were shown to have an important role in supporting academic self-efficacy and acceptance of learning technologies such as Moodle, which overall influenced the success of online learning.
The Development of the HOTS Test of Physics Based on Modern Test Theory: Question Modeling through E- learning of Moodle LMS	(Widyanings ih et al., 2021)	research and development using the ADDIE model	Valid instruments according to expert assessment based on Aiken's V formula. Analysis of the characteristics of the questions shows: The mean and standard deviation of the INFIT MNSQ were 1.0 and 0.0, indicating that the item conforms to the 1-PL Rasch Model. The item reliability value is 0.66. The case reliability value is 0.85.
The development of moodle based e-	(H Permana et al., 2021)	Research and Development (R&D)	The results of the study indicate that Moodle-based learning media for Newton's Law

Title	Author	Research Design	Finding
learning for newtons' laws in high school physics		with the ADDIE approach (The focus of the design is the development of Moodle-based e-learning media for Newton's law material at the high school level	material at the high school level using the ADDIE approach has been successfully developed. This media is designed with interactive features that support student learning activities, so that it is in accordance with the needs of physics learning. Based on the assessment by media experts, material experts, and physics teachers using a Likert scale questionnaire instrument, this e-learning is declared feasible and meets the criteria for use as a learning aid. The implementation of this e-learning is also considered effective as an alternative physics learning media in high schools .
Development of web-based learning media for physics materials using Moodle in high school	(A Afrilia, et al., 2020)	This study uses a Research and Development (R&D) design with the ADDIE model approach. The process of developing Moodle-based physics learning media involves a validation stage by material experts, media experts, and physics teachers as practitioners. The effectiveness of the media was tested using a one group pre-test and post-test design .	The results of the study indicate that Moodle-based physics learning media developed using the ADDIE model is considered valid by material and media experts and practical by physics teachers for use in learning. The effectiveness test of the media with a one-group pre-test and post-test design showed an increase in student learning motivation with an N-gain value of 0.80, which is included in the high category. These findings provide insight for physics teachers on how to design technology-based learning to increase student motivation in learning physics.
Implementation of adaptive learning at higher education institutions by	(N Morze et al., 2021)	This research uses a Research and Development (R&D) design with the	The results of the study showed that the e-learning for Newton's Law developed focused on student activities, such as fill-in-the-blank questions, multiple-choice exercises, and

Title	Author	Research Design	Finding
means of Moodle LMS		ADDIE model approach.	course presentation-based learning, which were designed to encourage active student participation. If students answered the questions correctly, they could continue learning, while if they answered incorrectly, they were asked to repeat the material. Based on validation by media experts with a score of 92.5%, material experts with a score of 96.67%, and physics teachers with a score of 93.75%, this product was declared very feasible to use. Therefore, this e-learning is very suitable to be applied in physics learning at the high school level .
Development of e-Teaching Material Based on Moodle Web	(Ramadhani Putri Lestari S et al., 2021)	This research uses the R&D (Research and Development) method with the ADDIE model.	This study shows that Moodle-based e-learning integration can support the chemistry learning process effectively and in accordance with national education standards.
A Personalized Learning Service Compatible with Moodle E- Learning	(Yi-Chun Chang et al., 2022)	Quantitative (quantitative)	This study shows that the personalized Moodle e-learning platform, designed to customize the learning process, materials, and learning paths to suit individual needs, significantly improves learning efficiency. The
Management System			average post-test results of students after using the platform were higher than those in the pre-test, indicating improved learning achievement. In addition, the gap in learning outcomes between students in the post-test was also reduced compared to the pre-test, reflecting the platform's ability to create a more equitable learning experience. These results confirm that the personalized Moodle e-learning platform provides significant benefits in supporting effective and equitable learning.
The role of personality traits	(Rivers, 2021)	Non-experimental Quantitative using	The adjusted research model successfully explained 14% of the variance in learning

Title	Author	Research Design	Finding
and online academic self-efficacy in acceptance, actual use and achievement in Moodle		Structural Equation Modeling (SEM) approach for path analysis	achievement, indicating a significant relationship between personality, online academic self-efficacy, Moodle acceptance, and learning outcomes. Personality traits, especially agreeableness and conscientiousness , play a crucial role in supporting academic self-efficacy and acceptance of learning technologies such as Moodle, which ultimately influence online learning success.
Design and Development of Interactive Moodle-Based E-Learning Platform for Competency Training	(Shida et al., 2023)	development research or development research, with a design -based approach , which includes the development of e-learning systems and evaluation of their effectiveness using a six-step inquiry-based learning approach	This study successfully developed an online learning design using the Moodle Learning Management System (LMS) integrated with the H5P engine. This platform is designed to overcome the limitations in online teaching and learning, using the scientific inquiry learning model. This interactive Moodle-based e-learning platform has been proven to improve student competence and provide a more interactive student learning experience.
Examining User Experience Of Moodle E- Learning System		This study uses a mixed-method approach with qualitative and quantitative data collection. The instruments used are semi-structured interviews and questionnaires.	The results of the study indicate that the Moodle e-learning system used in one of the universities in Malaysia provides a positive user experience (UX) from the perspective of students. Students were satisfied with most of the evaluated metrics, including teaching and learning, usability, and hedonic aspects. However, students also identified several challenges they faced while interacting with the system, indicating areas for improvement to further enhance the user experience and maximize the benefits of a well-designed e-learning system.
Impact of E-Learning Orientation, Moodle	(Saori Aida., 2023)	descriptive-analytical	-E-learning orientation does not have a significant influence on learning outcomes.

Title	Author	Research Design	Finding
Usage, and Learning Planning on Learning Outcomes in On-Demand Lectures			-The use of Moodle (with higher levels of interaction and utilization of learning features) significantly improves learning outcomes. -Effective learning planning (adherence to schedules and timely submission of assignments) positively influences learning outcomes. The success of online learning cannot be attributed to just one single factor, but involves a combination of factors, such as the use of Moodle and good learning planning.
Moodle-Based Online Learning Management in Higher Education	(Imam Makruf et al, 2021)	Quantitative approach and descriptive analysis	-The use of Moodle-based e-learning at IAIN Surakarta is still less than optimal, especially in the implementation and evaluation of learning. -Recommendation: Improving the quality of Moodle applications, supporting facilities, and user capabilities is essential for optimizing learning.
Optimizing Moodle quizzes for online assessments	(Gamage et al., 2019)	The research design used is quantitative descriptive design. This study aims to evaluate the effectiveness of Moodle quizzes as a learning and assessment tool using quantitative statistical data to analyze the level of student engagement, knowledge, and satisfaction. Data were collected through	-Student Engagement: Students demonstrated high engagement in formative assessments, with 65% of students attempting all formative questions and watching the interactive video 2–6 times. -Quiz Effectiveness: The FI index indicates the student's pass rate for summative questions, while the DI indicates the level of difficulty that can differentiate the student's knowledge level. -Impact on Assessment: The combination of FI and DI helps redesign quiz questions to improve assessment quality. 1. Increased Assessment Autonomy: Moodle statistics provide easily accessible data to help academics revise and improve the

Title	Author	Research Design	Finding
		Moodle-based statistical analysis, namely the Facility Index (FI) and Discrimination Index (DI) , to measure the level of difficulty and effectiveness of the quiz in distinguishing the level of student knowledge.	effectiveness of quizzes without the need for manual assessment. Thus, the use of Moodle quizzes has proven to be effective in increasing student engagement and assessing knowledge efficiently in civil engineering courses.
The effectiveness of Moodle among engineering education college students in Indonesia	(Amin et al., 2023)	The research design used was a quasi-experiment with a one-group pretest-posttest design.	The results of the study showed that the use of Moodle significantly improved the performance of Indonesian students in learning research methodology. Students responded enthusiastically to Moodle because of its simplicity, ease of use, and accessibility. This study also confirmed the reliability of Moodle as an effective online learning platform to be applied in various contexts. In addition, this study recommends further exploring the effectiveness of Moodle in other learning contexts to expand its use.
A Novel Two-Factor Authentication Scheme for Increased Security in Accessing the Moodle E- Learning Platform	(Vasile Bane et al,. 2023)	This research uses a technology development method with a technical case study design and a mixed approach (quantitative-qualitative).	The results of this study show that the implementation of a new authentication scheme based on digital certificates significantly improves security on the Moodle platform, overcoming the weaknesses of traditional authentication methods such as passwords that are vulnerable to hacking. Users feel more confident and satisfied with this new authentication system, with no reports of security breaches during implementation. In addition, this system also improves more efficient account management for IT administrators and offers better data protection by reducing the risk of unauthorized access.

Results and Discussion

What are the main research focuses related to the use of Moodle in interactive learning at various levels of education from 2018 to 2023? Research on the use of Moodle in interactive learning has shown a diverse focus during the period 2018 to 2023. One of the main focuses is the effectiveness of Moodle in supporting HOTS (Higher Order Thinking Skills)-based learning. by Widyaningsih et al. (2020) developed a HOTS-based evaluation instrument through Moodle that can improve students' analytical skills. Another focus is interactive learning design, such as the integration of Moodle with an inquiry learning model that allows students to be active in solving real problems (Muangbangyung & Srisawasdi, 2022). In addition, several studies highlight Moodle as an adaptive learning tool to support students from various educational backgrounds. For example, Saori Aida's (2023) study noted that the use of Moodle's interactive features helped overcome barriers to online learning during the pandemic.

Furthermore, research (H Permana et al., 2021) showed that Moodle-based learning media for Newton's Law material at the high school level using the ADDIE approach had been successfully developed. This media is designed with interactive features that support student learning activities, so that it is in accordance with the needs of physics learning. Based on the assessment by media experts, material experts, and physics teachers using a Likert scale questionnaire instrument, this e-learning is declared feasible and meets the criteria for use as a learning aid. The implementation of this e-learning is also considered effective as an alternative physics learning media in high schools. Research shows the development of Moodle features to enhance the learning experience, such as the integration of gamification-based quizzes, interactive discussions, and learning data analytics. Research by Fernando et al. (2023) indicate that Moodle not only functions as a learning management platform, but also as a tool for creating more personalized and collaborative learning experiences.

How effective was Moodle compared to other learning platforms during the period?

Moodle has a number of advantages over other learning platforms, such as Blackboard or Canvas. One of Moodle's main advantages is its feature flexibility and open-source nature, which allows institutions to customize the platform to their specific needs. For example, Fernando et al. (2023) showed that Moodle's quiz feature was able to increase student engagement by up to 65% compared to other platforms that tend to be less interactive. Research conducted by Afrilia et al. (2020) revealed that Moodle-based physics learning media developed using the ADDIE model was deemed valid by content and media experts and practical by physics teachers for instructional use. The effectiveness test of the media, employing a one-group pre-test and post-test design, demonstrated an improvement in students' learning motivation, with an N-gain score of 0.80, categorized as high. These findings provide valuable insights for physics educators on designing technology-based learning approaches to enhance students' motivation in studying physics. In addition, the global community that supports

Moodle provides various plugins and regular updates that enhance the adaptability of this platform. Compared

to Blackboard, Moodle has the advantage of lower implementation costs, especially for educational institutions in developing countries. Research by Amin et al. (2022) in Indonesia showed that the use of Moodle successfully increased student performance by 25% after being implemented effectively in a blended learning program. However, Moodle's effectiveness still depends on the infrastructure and training of educators. In some contexts, such as countries with technical limitations, other, lighter platforms may be more appropriate. However, Moodle's flexibility and ability to integrate new technologies make it a top choice for technology-based learning.

What research topics have the most potential to be developed in the future?

Literature analysis shows several potential research topics that can be further developed. One of them is the integration of cutting-edge technologies, such as Augmented Reality (AR) and Artificial Intelligence (AI), into the Moodle platform to enhance learning personalization. AR can be used to create interactive simulations, while AI can help personalize the learning experience by analyzing student learning data. Research by Saefullah et al. (2023) noted that this innovation can be more effective in supporting project-based learning (PBL) which emphasizes solving real-world problems. Another important topic to develop is the use of Moodle to support students with special needs. Moodle can be adapted with better accessibility features, such as voice captions, visual aids, or interactive guides for students with physical or cognitive disabilities. This is also relevant to the global trend of emphasizing inclusion in education.

In addition, research on the influence of cultural factors on Moodle acceptance also needs to be expanded. In some contexts, cultural adaptation can increase the acceptance of technology by educators and students. Saori Aida's (2023) research shows that the use of Moodle adapted to the regional context can increase user satisfaction by up to 40%. This shows the importance of regional design in increasing the effectiveness of Moodle implementation.

Conclusion

Based on the results and discussion, it can be concluded that Moodle is a very effective learning platform to support interactive learning at various levels of education. During the period 2018–2023, research shows that Moodle is not only able to improve student learning outcomes through innovative features such as interactive quizzes and HOTS-based learning, but also encourages student engagement in online learning. Moodle's advantages over other learning platforms lie in its flexibility, open-source nature, and strong global community support. This allows educational institutions to customize Moodle to their needs, including the integration of cutting-edge technologies such as AR and AI to create a more personalized and collaborative learning experience. However, the success of Moodle implementation is highly influenced by external factors, such as the availability of technological infrastructure, educator training, and adaptation to regional cultural contexts. These factors must be considered so that Moodle can be optimized to support learning in various educational environments.

Potential future research topics include developing Moodle features to support students with special needs, integrating advanced technologies to personalize learning, and further exploring the influence of cultural factors on the acceptance of these technologies. These studies are expected to strengthen Moodle's role as an inclusive and innovative learning platform in the digital age. This conclusion underlines the importance of a holistic approach in integrating technology in education, where the development of learning platforms such as Moodle does not only focus on technological features, but also takes into account the needs of students, educators, and educational institutions as a whole.

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What Guides the Teacher in an Islamic ELT Classroom? Unveiling Ideological Representations of Islamic Values in English Course Syllabi

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Abstract: In Islamic higher education, English language instruction is expected to serve a dual purpose: to develop students' linguistic and professional competence, and to reflect the religious and ethical values upheld by the institution. Despite this expectation, few studies have examined how Islamic values are embedded, explicitly or implicitly, within formal academic documents such as course syllabi. This research addresses that gap by investigating the ideological representation of Islamic values in English language teaching (ELT) syllabi in an Islamic university context. Employing a Critical Content Analysis (CCA) approach, this study analyzes five Learning Plans drawn from core courses in an English Language and Literature program. The study adopts an analytical framework rooted in UIN Alauddin Makassar's Guidelines for the Integration of Knowledge (2013), which emphasize the incorporation of Islamic values such as adab, tawhid, amanah, and ilmu into academic instruction and curriculum development. Findings reveal that Islamic values are present but largely peripheral, symbolically embedded in learning outcomes or course descriptions, rather than substantively integrated into learning materials, pedagogical strategies, or assessment methods. This suggests a disconnect between the institution's Islamic mission and the actual construction of ELT curricula. The study contributes to ongoing conversations about curriculum ideology and value integration in Islamic education. It calls for a more reflective and intentional approach to curriculum design that aligns pedagogical practices with institutional identity and educational philosophy.

Keywords: English language teaching, Islamic higher education, curriculum ideology, Islamic values, content analysis

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Introduction

The teaching of English in Islamic higher education carries unique expectations, functioning not only as a medium for linguistic and professional competence but also as a platform for the embodiment of Islamic values.

In Indonesia, institutions such as Islamic universities are tasked with reconciling the global status of English with the cultural, spiritual, and ethical foundations of Islamic education (Azra, 2014). This dual mandate requires that English Language Teaching (ELT) should not merely be skill-based, but also ideologically aligned with the institution's mission. In this respect, the curriculum becomes a central site where institutional identity, ideological commitments, and educational goals converge.

In recent years, there has been increasing scholarly interest in the ways that values—religious, ethical, and cultural can be integrated into teaching and learning practices. Several studies demonstrate that the integration of Islamic values in ELT practice often occurs through classroom pedagogy, such as the use of texts with moral themes, the employment of discussion topics that highlight Islamic ethics, or the modeling of teacher–student interaction guided by principles of adab (respect and ethics) (Sirozi, 2010; Rohman, 2018).

These approaches highlight the practical possibilities of value-based teaching. However, while such practices are important, they are often fragmented, relying heavily on the initiative and commitment of individual lecturers. What is less examined is how institutional policies and formal documents, such as syllabi and curriculum guidelines, systematically embed and direct these values into the teaching process.

The role of institutional policy is critical because it represents an official articulation of the educational philosophy and ideological orientation of the university. When values are integrated at the policy level, they become not only optional pedagogical practices but institutional mandates that shape curriculum design, teaching strategies, and assessment methods (Apple, 2004; Barnett & Coate, 2005). Such integration ensures consistency across courses and reduces reliance on individual interpretation. In the case of Islamic higher education in Indonesia, institutions such as UIN Alauddin Makassar explicitly commit to the integration of knowledge (integrasi ilmu), which emphasizes the synthesis of Islamic values such as adab, tawhid, amanah, and ilmu—with academic and professional training (UIN Alauddin, 2013). This commitment places syllabi at the center of ideological representation, since they serve as the formal bridge between institutional philosophy and classroom practice.

Yet, despite the presence of institutional guidelines, the actual translation of values into syllabi often remains symbolic rather than substantive. Previous research in curriculum studies has shown that policies are frequently recontextualized when implemented at the departmental level, resulting in a gap between institutional ideals and practical realities (Ball, 1993; Singh, 2002). In the context of ELT at Islamic universities, this suggests that while values may be mentioned in syllabi, they may not be sufficiently operationalized in terms of pedagogy, materials, and assessment. This symbolic presence raises important questions about the extent to which the ideological mission of the institution is genuinely realized in the learning process. Addressing this issue is particularly important for English departments, where the tension between global linguistic demands and local religious identity is most pronounced.

The case of the English Language and Literature program at UIN Alauddin Makassar provides a relevant

context for this investigation. As one of the leading Islamic universities in Eastern Indonesia, UIN Alauddin Makassar has long been at the forefront of integrating Islamic perspectives into modern academic disciplines. The Department of English Language and Literature is tasked not only with preparing students for careers in teaching, translation, and international communication but also with ensuring that these professional pathways are grounded in the Islamic worldview. In this respect, the curriculum becomes both a technical tool for language acquisition and a moral compass for identity formation. Exploring how Islamic values are represented in syllabi within this department therefore sheds light on how institutional missions are enacted—or perhaps diluted—in formal curriculum design.

From a theoretical standpoint, the integration of values into ELT syllabi aligns with the broader discourse on curriculum ideology. Scholars such as Apple (2004) argue that curricula are never neutral; they reflect power relations, social ideologies, and institutional commitments. In faith-based institutions, curricula must balance the universalistic demands of academic disciplines with the particularistic mission of religious identity. In the case of English, a language often associated with secular, global, and Western orientations (Pennycook, 2017), the challenge becomes even greater. Embedding Islamic values in ELT syllabi is thus not only a pedagogical issue but also a political and ideological act of positioning. It demonstrates how institutions negotiate their place within global academia while safeguarding their spiritual commitments.

Given this background, the current study aims to critically examine how Islamic values are represented in the ELT syllabi of the English Language and Literature program at UIN Alauddin Makassar. Unlike previous studies that have primarily focused on classroom practices, this research situates the analysis at the level of policy and formal documentation. It employs Critical Content Analysis (CCA) to investigate how values such as adab, tawhid, amanah, and ilmu are articulated in course syllabi, and whether these articulations move beyond symbolic presence to substantive pedagogical integration. This approach is academically significant because it emphasizes the role of curriculum documents as sites of ideological negotiation. By doing so, it contributes to broader discussions about the role of policy in shaping value-based education and provides insights into how Islamic universities can better align their curricula with their institutional missions.

In sum, the study is motivated by both practical and theoretical concerns. Practically, it seeks to inform curriculum developers, teacher educators, and policymakers about the strengths and limitations of current approaches to integrating values into ELT syllabi. Theoretically, it engages with critical debates about the ideological nature of curriculum and the possibilities of integrating religious values into a global language.

By focusing on UIN Alauddin Makassar, the research not only addresses a gap in the literature but also offers context-specific insights that may be relevant to other Islamic universities in Indonesia and beyond. Ultimately, the study argues that while many efforts at integration occur at the level of classroom practice, integration at the policy level as embodied in syllabi is a particularly powerful and underexplored avenue for realizing the mission of Islamic higher education.

Method

Research Design

This study employs Critical Content Analysis (CCA) as its primary methodological approach. CCA is widely recognized as a qualitative research method that goes beyond surface-level textual analysis to interrogate the ideological assumptions, cultural values, and power relations encoded within texts (Krippendorff, 2013; Rogers, 2018). Unlike conventional content analysis, which emphasizes frequency counts and categorization, CCA situates the analysis of texts within broader social, political, and institutional contexts, thereby enabling the identification of both explicit and implicit ideological representations (Fairclough, 2010). In this research, CCA is employed to uncover how Islamic values are embedded in course syllabi. It involves coding for key concepts derived from institutional guidelines and interpreting their placement, function, and pedagogical significance in shaping English Language Teaching (ELT) in the context of Islamic higher education.

Research Context and Data

The study was conducted at the Department of English Language and Literature, UIN Alauddin Makassar, an Islamic university in Eastern Indonesia committed to integrating Islamic values with academic disciplines. The department offers a range of courses that cover both linguistic skills and literary studies, making it a rich site for investigating the integration of institutional values into ELT curricula.

Five core courses were purposively selected for this study:

Reading is chosen because it develops critical comprehension skills and provides opportunities for embedding ethical perspectives in text interpretation.

Speaking is selected as a course where values such as adab and amanah can be operationalized through respectful interaction and communicative responsibility.

Essay Writing is important for academic integrity, honesty, and responsibility (amanah), particularly in encouraging original work and ethical citation practices.

English Literature represents cultural and moral dimensions, where Islamic perspectives can interact with Western literary traditions.

American Literature is included because of its strong cultural and ideological underpinnings, making it a critical site for evaluating how Islamic values are positioned vis-à-vis global literary canons.

These courses were chosen as they represent a balance of language skill courses (Reading, Speaking, Essay Writing) and content/literature courses (English Literature, American Literature). Together, they provide a comprehensive view of how values are—or are not—integrated across different domains of English studies within the department.

Analytical Framework

The analysis was guided by the Guidelines for the Integration of Knowledge (UIN Alauddin, 2013), which articulate four key Islamic values:

Adab (Ethics/Respect): Proper conduct, ethical communication, humility, and respectful engagement in the learning process.

Tawhid (Oneness of God): The principle of divine unity, linking academic knowledge to a transcendent Islamic worldview.

Amanah (Responsibility): Accountability and reliability in learning, research, and professional tasks.

Ilmu (Knowledge): Pursuit of knowledge as a religious and moral obligation, integrating spiritual and intellectual development.

These values were used as a priori coding categories in the analysis, serving as the framework for evaluating the representation of Islamic ideology in syllabi.

Data Analysis Procedure

The process of Critical Content Analysis unfolded in four stages:

Textual Identification: Each syllabus was examined to identify sections where Islamic values might be encoded, including course descriptions, learning outcomes, teaching strategies, and assessment components.

Coding: Instances of adab, tawhid, amanah, and ilmu were coded as either symbolic (e.g., mentioned only in general aims) or substantive (e.g., operationalized in tasks, teaching methods, or assessment rubrics).

Contextual Interpretation: The coded data were interpreted in relation to the institutional context and broader ideological goals of UIN Alauddin Makassar. This stage involved examining how values were positioned within the tension between global academic standards and Islamic identity.

Comparative Analysis: Findings across the five syllabi were compared to identify patterns of integration, differences between skill-based and literature-based courses, and areas of disconnect between institutional policy and classroom practice.

Findings

The analysis of the five selected syllabi from the English Language and Literature program at UIN Alauddin Makassar revealed varying degrees of integration of Islamic values within the curriculum. Using the framework of Critical Content Analysis (CCA), the study identified explicit and implicit references to values such as adab (ethical conduct), amanah(trustworthiness and responsibility), and ilmu (knowledge). These values were found to be represented in different ways, ranging from symbolic mentions in program learning outcomes to substantive integration within learning activities and assessment strategies. The comparative findings indicate that language skill courses, such as Reading, Speaking, and Essay Writing, tend to incorporate Islamic values more substantively, while literature-based courses, particularly American Literature, display more symbolic or minimal integration. The following table summarizes the main findings of this analysis across the five courses.

Table 1 provides a comparative overview of how Islamic values are represented across the five syllabi examined. The table shows that the courses vary in both the type and depth of integration. Skills-based courses such as Reading, Speaking, and Essay Writing reflect more substantive representations of Islamic values,

particularly adab (ethical conduct), amanah (responsibility and honesty), and ilmu (knowledge). For example, Essay Writing demonstrates a stronger emphasis on honesty and integrity, while Speaking promotes responsibility and respectful communication. In contrast, the literature courses-English Literature and American Literature-tend to show symbolic representation, where values are mentioned in program outcomes or course-level objectives but not translated into specific teaching content or strategies. Among the five, Essay Writing emerges as the course with the most substantive integration, while American Literature reflects the weakest. The following sections elaborate on the main findings drawn from the table and document analysis.

Table 1. Integration of Islamic Values in Five Courses

Course	Islamic Values Identified	Type of Representation	Example of Implementation	Limitations
Reading	Adab, Amanah	Symbolic → Limited Substantive	Emphasis on reading ethics, academic honesty in interpreting texts	No explicit reference to Islamic sources or perspectives
Speaking	Adab, Amanah	Substantive (ethical communication)	Respectful discussion, valuing different perspectives, responsibility in presenting arguments	Islamic values mentioned implicitly, framed as general ethics
Essay Writing	Adab, Amanah, Ilmu	Substantive	Learning outcomes emphasize responsibility, honesty in writing, academic integrity	Limited integration of Islamic worldview directly into writing tasks
English Literature	Adab, Ilmu, Amanah(academic ethics, religiosity)	Symbolic → Normative Substantive	CPL highlights religiosity, academic ethics, cultural diversity	Values remain normative, not directly connected to literary analysis
American Literature	Minimal (general religiosity in program learning outcomes)	Symbolic	Program outcomes list religiosity and ethics	Islamic values absent in course content; focus remains on Western traditions

Peripheral Representation of Islamic Values

The analysis of the five syllabi shows that Islamic values are indeed present but mostly at a peripheral level.

They appear symbolically in course descriptions, general learning outcomes, or program-level expectations rather than being substantively embedded in the teaching content. For instance, the Critical Reading syllabus states that students should "demonstrate religious attitudes, honesty, responsibility, and discipline in reading activities." Similarly, the Speakingsyllabus highlights that "students are able to communicate ideas responsibly, ethically, and in a respectful manner." These references reflect values of adab and amanah, yet the documents provide little detail on how these values are to be cultivated through classroom practice.

In the Essay Writing course, integration appears more substantive, as students are required to "demonstrate honesty and responsibility in academic writing, avoiding plagiarism and upholding integrity." This learning outcome directly engages with academic ethics, making the value of amanah more operational. However, even here the Islamic worldview is not explicitly incorporated, and values are framed in general ethical terms.

For the literature courses, representation remains even more symbolic. The English Literature syllabus includes outcomes such as: "Students are expected to internalize religiosity, uphold academic ethics, and appreciate cultural diversity through literary analysis." While these reflect values of religiosity, adab, and ilmu, they remain normative statements without clear pedagogical strategies for integration. The American Literature syllabus shows the weakest alignment, as Islamic values appear only in program-level outcomes, such as graduates being expected to "possess religiosity, academic ethics, and social responsibility." These are disconnected from the actual course content, which remains fully centered on Western literary traditions.

Disconnect Between Mission and Practice

This symbolic embedding of Islamic values highlights a gap between the ideological mission of UIN Alauddin Makassar and the actual design of ELT curricula. Although the university's mission emphasizes the integration of Islamic values with disciplinary knowledge, the syllabi tend to prioritize English proficiency framed around employability and global competitiveness. As a result, Islamic values appear as peripheral attributes rather than central guiding principles in pedagogy. For example, while adab and amanah are explicitly mentioned in syllabi, they are not operationalized in teaching strategies, reading selections, or assessment methods. This disconnect limits the realization of the institution's mission in classroom practice.

Implications for Curriculum Development

The findings indicate that curriculum development in Islamic higher education requires more intentional strategies to embed values substantively rather than symbolically. Instead of limiting references to course descriptions or broad learning outcomes, syllabi could integrate Islamic values directly into teaching and assessment practices. For instance, in Speaking, assignments could include structured debates on ethical dilemmas; in Essay Writing, reflective essays could require students to engage with Islamic perspectives on honesty and responsibility; and in literature courses, selected readings could be accompanied by critical discussions connecting literary analysis to Islamic ethical or philosophical frameworks. Such approaches would

move Islamic values from the periphery to the core of ELT practice, ensuring that the ideological mission of the institution is authentically realized.

Discussion

The findings of this study demonstrate that the representation of Islamic values in the syllabi of the English Language and Literature program at UIN Alauddin Makassar is uneven, with most courses positioning these values at a symbolic rather than a substantive level. While values such as adab (ethical conduct), amanah (responsibility and honesty), ilmu(knowledge), and religiosity appear across all five syllabi, they are often confined to general statements in course descriptions, learning outcomes, or program objectives. For example, the Critical Reading syllabus states that students should "demonstrate religious attitudes, honesty, responsibility, and discipline in reading activities," and the Speakingsyllabus requires students to "communicate ideas responsibly, ethically, and in a respectful manner." These formulations resonate with Islamic values but stop short of providing concrete pedagogical strategies or assessment methods that would allow such values to be intentionally cultivated in the classroom.

More substantive integration was observed in skill-based courses, particularly Essay Writing and Speaking, where ethical values are more directly tied to the nature of the subject matter. In Essay Writing, for instance, students are expected to "demonstrate honesty and responsibility in academic writing, avoiding plagiarism and upholding integrity." Such outcomes move closer to operationalizing Islamic values, particularly amanah in the form of academic honesty. This echoes findings from Munif et al. (2025), who argue that task-based pedagogies can serve as effective vehicles for embedding Islamic ethics in ELT classrooms when designed intentionally. Similarly, Soleh et al. (2021) have shown that activities such as structured writing tasks and guided peer review can promote honesty and responsibility in ways that align with Islamic educational values.

By contrast, in literature-oriented courses, integration of Islamic values remains largely symbolic. The English Literature syllabus highlights broad expectations such as "internalizing religiosity, upholding academic ethics, and appreciating cultural diversity through literary analysis," yet these values are not embedded in the analytical frameworks or classroom activities provided by the syllabus. The American Literature course reflects the weakest alignment, as Islamic values are mentioned only in program-level learning outcomes, for instance, expecting graduates to "possess religiosity, academic ethics, and social responsibility," without being connected to the study of Western texts. This gap reveals what Sukirman (2022) describes as a disjuncture between the ideological mission of Islamic higher education institutions and the practical realities of curriculum design, in which values are articulated rhetorically but seldom operationalized in teaching practice.

The symbolic positioning of Islamic values in syllabi highlights an ongoing tension in Islamic higher education between global academic demands and institutional ideological commitments. On the one hand, English proficiency is framed in terms of employability and global competitiveness, a priority reflected in the structure of most syllabi. On the other hand, the ideological mission of UIN Alauddin Makassar, as outlined in its policy

documents, emphasizes the integration of Islamic values into all academic activities. The limited presence of substantive integration indicates that this mission is only partially realized at the curriculum level. As Syuhda et al. (2024) note, many Islamic universities in Indonesia face similar challenges, where teachers and curriculum developers express a strong commitment to values but rely on implicit or ad hoc strategies rather than systematic curricular frameworks.

The implications of these findings point to the need for more intentional and reflective curriculum design. Rather than restricting Islamic values to symbolic mentions in course descriptions, future syllabi could embed them explicitly into pedagogical strategies, learning activities, and assessment. For example, in Speaking, assignments could be designed around ethical dilemmas that require students to engage with concepts of responsibility and respect from an Islamic perspective. In Essay Writing, tasks could include reflective essays linking academic honesty to Islamic principles of amanah. In literature courses, the integration could take the form of critical engagement with texts, drawing comparisons between Western literary traditions and Islamic ethical or philosophical frameworks. This approach would resonate with Irwansyah's (2022) argument that authentic integration requires connecting Islamic epistemology with both content and pedagogy rather than limiting it to broad value statements.

Taken together, these findings suggest that while the institutional mission of Islamic universities emphasizes integration, its current manifestation in ELT curricula remains largely symbolic. The challenge lies in moving from symbolic to substantive integration, ensuring that values such as adab, amanah, and ilmu are not only articulated in official documents but also enacted in classroom practices. Doing so would strengthen the alignment between institutional ideology and pedagogical reality, thereby fulfilling the distinctive role of Islamic higher education in shaping graduates who are both linguistically competent and ethically grounded.

Conclusion

This study highlights the symbolic yet peripheral role of Islamic values in the English Language Teaching (ELT) syllabi of an Islamic university. Although the institutional mission mandates the integration of values such as adab (ethical conduct), tawhid (oneness of God), amanah (responsibility and honesty), and ilmu (knowledge), the findings indicate that such values are predominantly articulated at the level of course descriptions and general learning outcomes rather than embedded within teaching strategies, learning activities, or assessment. This pattern reflects a disconnect between ideological aspirations and pedagogical practices, suggesting that the integration of Islamic values has not yet reached a level of substantive operationalization.

To align ELT curricula more closely with the ideological mission of UIN Alauddin Makassar and similar institutions, curriculum developers and teacher educators must adopt a more intentional and reflective approach. This entails moving beyond symbolic mentions of values to embedding them systematically into learning outcomes, instructional methods, and evaluation tools. For example, speaking activities could incorporate ethical debates, essay writing assignments could link academic honesty to Islamic principles of amanah, and

literature courses could encourage comparative analysis between Western texts and Islamic ethical frameworks. Such practices would not only bridge the gap between mission and practice but also ensure that graduates embody both linguistic competence and ethical integrity.

By foregrounding this issue, the study contributes to broader scholarly discussions on curriculum ideology, value-based education, and the contextualization of English within Islamic higher education. It underscores the importance of curriculum as a site where institutional identity and global academic demands intersect, shaping how values are transmitted to learners. Future research could expand on these findings by examining classroom enactments of syllabi, exploring teacher perspectives on integration, and analyzing student experiences in value-oriented ELT classrooms. Collectively, such efforts would provide a more comprehensive understanding of how Islamic values can be authentically realized in language education and how Islamic higher education can navigate the balance between global academic standards and its distinctive ideological commitments.

Disclosure Statement

The authors claim no conflict of interest.

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Mindfulness Practices as a Tool for Reducing Speaking Anxiety: A Case Study in Indonesian Remote Schools

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Abstract: This study explores the impact of mindfulness practices on reducing speaking anxiety and enhancing classroom participation among high school students learning English as a foreign language. Guided by Kabat-Zinn's (1990) theory of mindfulness, which emphasizes the cultivation of present-moment awareness and emotional regulation, the research aims to assess whether mindfulness techniques can help students manage anxiety during speaking tasks and increase their engagement in language learning activities. A qualitative research design was employed, utilizing structured observations and semi-structured interviews as the primary data collection instruments. Observations were conducted during English speaking activities before and after the introduction of mindfulness techniques, while interviews with students and teachers provided insights into their experiences with the intervention. The study was conducted with 30 students from Banat Senior High School in Timor Tengah Selatan, East Nusa Tenggara, and three English teachers who facilitated the mindfulness sessions. The findings indicate that the mindfulness intervention led to significant reductions in students' speaking anxiety, as evidenced by fewer signs of nervousness and hesitation during speaking tasks. Additionally, there was an increase in classroom participation, with students becoming more active in discussions and group activities. Teachers reported improvements in students' emotional regulation and confidence, suggesting that mindfulness practices fostered a more supportive and engaging classroom environment. This study contributes to the growing body of literature on the role of mindfulness in language education. However, future research could explore the long-term effects of mindfulness on speaking anxiety and language proficiency, and consider individualized mindfulness approaches to better support students with varying levels of anxiety.

Keywords: Mindfulness, English Language Teaching, Speaking Anxiety

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Introduction

In recent years, the integration of mindfulness practices in education has gained increasing attention, particularly for its potential to reduce anxiety and improve emotional well-being among students. Among various emotional challenges that learners face, speaking anxiety is one of the most prevalent, especially for students learning English as a foreign language (EFL). Speaking in front of others often triggers fear and self-doubt, inhibiting students from engaging in classroom activities and hindering their language acquisition process. Research has shown that mindfulness, a practice focused on being fully present and aware of one's thoughts, feelings, and sensations without judgment, can help alleviate anxiety by fostering emotional regulation and self-awareness. In the context of language learning, mindfulness techniques have been recognized as effective tools in reducing speaking anxiety and enhancing students' confidence in expressing themselves.

Mindfulness-based interventions that have demonstrated most significant benefits in various domains, particularly in education has underpinned study in this area. Mindfulness, as defined by Kabat-Zinn (1990), involves bringing attention to the present moment with an attitude of acceptance. This process allows individuals to manage their emotions more effectively, reducing the physiological and psychological symptoms of anxiety, including those experienced during public speaking. For language learners, mindfulness can provide an avenue for overcoming the fear of judgment and making mistakes (two key factors that contribute to speaking anxiety). Studies have shown that mindfulness exercises, such as deep breathing, body scanning, and mindful listening, can help students regain focus, stay grounded, and reduce anxiety when speaking in front of peers or teachers (Khatami et al., 2025; Zarin, 2025).

While the effectiveness of mindfulness in addressing speaking-anxiety has been well-documented in various educational settings, there is a notable gap in research on its application in remote and underserved areas, particularly in Indonesia. Much of the existing research focuses on urban or well-resourced schools where students have access to a range of educational tools and support systems in easily ways. However, students in rural and remote areas often face additional challenges, including limited resources, fewer opportunities for language practice, and a lack of specialized support. These factors can exacerbate feelings of anxiety and make it even more difficult for students to engage in learning, especially when it comes to speaking activities. It is in these under-resourced settings where mindfulness may offer an affordable, adaptable, and impactful solution to support both emotional and academic development.

This study seeks to fill this gap by exploring the role of mindfulness in reducing speaking anxiety among students at Banat Senior High School, a high school located in the Kolbano district of Timor Tengah Selatan, East Nusa Tenggara. The primary goal of this research is to investigate how mindfulness interventions affect students' ability to manage anxiety during English speaking activities, and whether these techniques can enhance their participation and engagement in class. By focusing on a rural school with limited resources, this study aims to provide insights into how mindfulness can be implemented in environments that are typically overlooked in the broader conversation about educational interventions. The findings of this research could

contribute to a more inclusive understanding of how mindfulness can be adapted to different educational settings, particularly those facing challenges similar to those of Banat Senior High School.

The unique challenges faced by students in remote and rural areas become the reason why this study should be done. In rural regions such as East Nusa Tenggara Province, where access to quality education and language learning resources is often limited, the emotional and psychological well-being of students is just as important as academic achievement. Speaking anxiety can significantly hinder students' ability to participate in language learning activities, and its effects are often compounded in areas where students may already feel disconnected from mainstream educational opportunities.

Mindfulness presents a simple yet effective intervention that requires few resources, making it particularly relevant for schools in such contexts. By incorporating mindfulness practices, schools like Banat Senior High School can provide students with valuable tools for managing their emotions, improving their speaking abilities, and fostering a more supportive and positive classroom environment.

Aimed to explore the potential of mindfulness to address speaking anxiety and enhance language learning among high school students in a remote area of Indonesia, this study is expected to bridging the gap between mindfulness research and its application in underserved schools, this research will not only add to the growing body of knowledge on mindfulness in education but also provide practical recommendations for educators in similar settings like Banat Senior High School.

Method

Research Design

This study adopts a qualitative research designing to explore and describe the implementation and its effect of mindfulness on reducing speaking anxiety in English language learning. Focusing on a rural setting, the research utilizes two primary data collection instruments namely: structured observations and semi-structured interviews. By combining these methods, this study aims to capture both behavioral changes during the mindfulness intervention and the personal perceptions of students and teachers regarding its effectiveness.

Participants

The participants in this study were 30 high school students from class X of Banat Senior High School, located in the Kolbano district of Timor Tengah Selatan, East Nusa Tenggara province. These students, aged between 15 and 17 years, were selected based on their demonstrated levels of speaking anxiety, as identified through teacher observations. The students gave informed consent to participate in the study. In addition, there are three English language teachers also participated in this study. These teachers were involved in facilitating the mindfulness sessions and were interviewed about their experiences and observations regarding the intervention.

Instruments

This study employs two instruments: structured observations and semi-structured interviews. Both of instruments provide complementary data for understanding the effects of mindfulness on speaking anxiety. First instrument is Structured Observations which serve as the primary method for gathering data on students' behavior and anxiety levels during speaking activities. Observations are conducted during both mindfulness sessions and regular speaking tasks throughout the intervention period. The researcher utilizes a structured observation rubric designed to assess the following areas:

Table 1. Structured observation rubric

Speaking Anxiety	Observable indicators of anxiety, including physical signs (e.g., body language, nervousness), speech-related behaviors (e.g., hesitation, vocal tremors), and overall comfort during speaking tasks
Participation	The level of student engagement in speaking activities, focusing on the frequency and quality of contributions made by the students during class discussions and individual speaking tasks
Emotional Regulation	The ability of students to manage their emotions and calm themselves during speaking activities. This includes signs of self-soothing or other mindfulness techniques applied during moments of anxiety
Social Interaction	The level of cooperation and interaction during group or pair activities, such as turn-taking, active listening, and collaboration among peers

These observations provide a detailed description of how mindfulness affects student behavior and engagement during speaking tasks. Taking field notes, which are analyzed for recurring patterns and themes related to the reduction of speaking anxiety and increased participation. Second instrument is semi-structured interview to gain deeper insights into the subjective experiences of both students and teachers. In its implementation, students are asked about their personal experiences before and after participating in the mindfulness sessions focusing on their feelings of anxiety during speaking tasks, their perceived confidence in speaking English, and any changes in their participation levels in class. Students are also asked how they felt the mindfulness techniques helped them manage their anxiety during speaking activities. Meanwhile teachers are interviewed about their observations of student behavior and engagement during speaking tasks, both before and after the mindfulness intervention. Teachers are asked to describe any noticeable changes in student anxiety levels, classroom participation, and emotional regulation. They are also invited to reflect on their experiences in facilitating the mindfulness sessions and any challenges they faced in implementing these practices in the classroom.

Data Analysis

The data analysis process involves analyzing both the structured observation data and the semi-structured

interview data. First, the observational data are analyzed using descriptive statistics to summarize the observed changes in speaking anxiety, participation, and emotional regulation. Specific behaviors such as the reduction of hesitation or the increase in verbal contributions during speaking tasks are noted and categorized. The analysis aims to identify patterns of behavior that suggest mindfulness techniques are helping students manage their anxiety and engage more actively in speaking activities. Second, the interview transcripts are analyzed using thematic analysis, which involves identifying recurring themes and patterns within the qualitative data. The process is divided into several stages:

Table 2. Stages of identifying themes and pattern

Initial Coding	The transcripts are read and coded to identify key themes related to students' experiences with anxiety, mindfulness, and participation. Codes include terms like anxiety reduction, confidence building, increased participation, and emotional regulation.
Theme Identification	Codes are grouped into broader themes, such as the effectiveness of mindfulness, the role of mindfulness in reducing anxiety, and the impact on classroom interactions.
Theme Review and Interpretation	The themes are reviewed for consistency and relevance, and the final analysis interprets these themes to provide a comprehensive understanding of how mindfulness affected both students' speaking anxiety and their overall classroom experience.

By combining structured observations with semi-structured interviews, this study is hoped to offer a detailed and nuanced understanding of the impact of mindfulness on speaking anxiety.

Findings

Impact of Mindfulness in English Language Learning to Reduce Speaking Anxiety

The key findings from the structured observations and semi-structured interviews conducted during the study will explained here. The observations focus on the behavioral changes in students during speaking activities before and after the implementation of mindfulness techniques, while the interviews provide insight into students' and teachers' experiences and perceptions of mindfulness in reducing speaking anxiety.

Impact on Speaking Anxiety

The structured observations revealed significant reductions in observable signs of speaking anxiety among students after the introduction of mindfulness practices. Initially, students exhibited high levels of anxiety during speaking tasks, marked by signs such as hesitation, nervous body language, and vocal tremors. These symptoms were particularly evident in the first few sessions of speaking activities, as many students appeared reluctant to participate in class discussions or speak in front of their peers.

However, over the course of the mindfulness intervention, there was a noticeable decrease in these signs of anxiety. In particular, students who had previously exhibited signs of nervousness and hesitation during

speaking tasks began to demonstrate more controlled speech, fewer physical signs of anxiety, and more fluid participation. Observations indicated that students were more able to manage their nervousness by utilizing the breathing exercises and grounding techniques they practiced during mindfulness sessions. These techniques appeared to help students maintain focus and manage anxiety in real time, reducing their fear of judgment and enabling them to engage more confidently in speaking activities.

For instance, one student, initially prone to long pauses and excessive self-correction, began to speak with greater fluency and confidence. This change was observed in multiple speaking tasks, from group discussions to individual presentations. Other students, who were previously more silent or hesitant, started to participate more actively in classroom discussions, offering their thoughts with less anxiety.

Increased Classroom Participation

A clear pattern emerged regarding increased classroom participation as a result of the mindfulness intervention. Before the intervention, students with high speaking anxiety would often refrain from volunteering answers or speaking up in group settings. However, after the mindfulness practices were implemented, a noticeable shift occurred. Students who had previously been reticent were observed taking more initiative in group discussions and engaging more fully in pair work. They were more willing to share their ideas, ask questions, and take risks with language use.

The intervention appeared to foster a classroom environment where students felt more comfortable engaging without the fear of making mistakes. According to the teachers, this shift in student behavior was also accompanied by greater collaboration and supportive peer interactions, as students became more comfortable with the idea of speaking in front of others. One teacher noted, "I've seen students who were once terrified to speak in front of the class now participating confidently, supporting their peers, and offering feedback.

Emotional Regulation and Self-Confidence

In addition to reducing anxiety, mindfulness also helped students with emotional regulation. Many students reported feeling less overwhelmed by emotions such as frustration or embarrassment when making mistakes in their speech. Instead, they became more accepting of their imperfections, focusing on the process of learning rather than fearing judgment. Interviews with students revealed that mindfulness exercises helped them remain grounded during moments of anxiety, allowing them to regain composure and continue speaking. One student shared, “Before the mindfulness sessions, I would freeze up or stop talking altogether when I made a mistake. Now, I just take a deep breath and keep going.”

Teachers also noted that students appeared more emotionally resilient, demonstrating the ability to manage stress and maintain composure during speaking activities. Teachers observed that students who previously seemed overwhelmed by anxiety were now more relaxed and engaged. One teacher commented, “Students are

much more composed now, even when faced with challenging tasks. They are no longer avoiding speaking; instead, they are managing their nerves better."

Teachers' Perceptions of Mindfulness

Teachers reported observing positive changes not only in students' speaking anxiety but also in the overall classroom environment. The mindfulness practices were seen as effective tools for creating a calmer, more focused classroom atmosphere, where students felt more supported and less judged. Teachers expressed that mindfulness techniques were simple yet effective in addressing the emotional and psychological challenges faced by students, especially those with higher levels of anxiety.

One teacher reflected, "Mindfulness has created a more positive learning environment. Students are less stressed and more willing to participate. It's clear that the mindfulness exercises helped them feel more comfortable in expressing themselves, both with me and with their classmates."

Challenges and Limitations

Despite the positive effects observed, some challenges were noted. Teachers expressed that mindfulness techniques required consistent practice and dedicated time during each lesson, which sometimes conflicted with the demands of the regular curriculum. Additionally, while most students responded positively to the intervention, a small group of students continued to experience higher levels of anxiety, suggesting that mindfulness may not be a one-size-fits-all solution. As one teacher mentioned, "Some students seem to benefit more than others, and it may require a more individualized approach for those who are still struggling with anxiety."

Discussion

The result of this study highlights the significant impact of mindfulness on reducing speaking anxiety and increasing classroom participation among Banat high school students. The structured observations and semi-structured interviews revealed that mindfulness not only helped students manage anxiety during speaking activities but also facilitated a more positive and interactive classroom environment.

Mindfulness and Speaking Anxiety

The reduction in speaking anxiety observed in this study echoes the findings of Khatami et al. (2025), who found that mindfulness practices helped English as a Foreign Language (EFL) students significantly reduce anxiety during oral communication tasks. In line with this, students in Banat Senior High School demonstrated fewer signs of nervousness, hesitation, and physical anxiety (e.g., trembling voice or body), and were able to focus more on the task at hand rather than worrying about judgment or making mistakes. The mindfulness

techniques, particularly breathing exercises and grounding activities, allowed students to stay present and calm during speaking tasks, which is consistent with Zarin (2025), who concluded that mindfulness reduces cognitive overload and promotes self-regulation, key factors in reducing anxiety in language learning contexts.

Mindfulness's effect on anxiety management is also supported by Sarkhosh and Almasoudi (2025), who noted that mindfulness exercises led to improvements in emotional regulation, allowing learners to manage stress and approach tasks with greater self-assurance. In this study, Banat Senior High School students' ability to regulate their emotions, specifically their anxiety, appeared to empower them to engage in speaking activities more effectively and confidently.

Increased Participation and Classroom Engagement

Another key finding from this study is the marked increase in classroom participation, a result that supports the findings of Martínez Reche (2025), who observed that mindfulness exercises in language classes significantly promoted student engagement and willingness to speak. Before the mindfulness intervention, many students in Banat Senior High School showed signs of reluctance to speak, often avoiding participation in discussions or responding minimally to questions. After the intervention, however, students demonstrated a higher frequency of volunteering answers, asking questions, and engaging in group discussions. This change suggests that mindfulness helped create a safer and more supportive environment, allowing students to feel less fearful of making mistakes and more willing to take risks in using English.

This increase in participation can also be explained by Creswell et al. (2014), who found that mindfulness not only reduces anxiety but also enhances focus and attention, which are critical for active participation. In the case of this study, mindfulness likely helped students focus on the content of the speaking tasks rather than on their self-consciousness or fear of being judged, which in turn boosted their confidence and participation.

Furthermore, the mindfulness practices helped establish a positive classroom atmosphere, as students were observed to engage in more collaborative and supportive interactions with their peers. The findings resonate with Roeser et al. (2013), who highlighted that mindfulness contributes to improved social dynamics in classrooms, as students learn to interact with greater empathy and openness. In this, some students who previously struggled with social anxiety were seen taking more initiative in group work, actively listening to their peers, and offering feedback in a more constructive and supportive manner.

Teachers' Perceptions and Challenges

Teachers in the study claimed that mindfulness had a positive impact on the classroom environment. They noted significant improvements in students' ability to regulate their emotions, especially during speaking tasks, and observed that students became more relaxed and willing to participate in class. These teacher perceptions align with the research of Farah and Choe (2025), who found that mindfulness training enhanced both student well-

being and classroom dynamics by helping learners manage emotional responses and approach tasks with a calm and focused mindset.

However, teachers also noted that implementing mindfulness in the classroom was not without its challenges. One challenge identified was the time commitment required to integrate mindfulness techniques into the lesson plan. This is consistent with findings from Sarkhosh and Almasoudi (2025), who pointed out that while mindfulness can be highly beneficial, it requires consistent practice and dedicated time to yield optimal results. Despite these challenges, teachers in Banat Senior High School expressed that the benefits of mindfulness, especially in terms of reducing anxiety and improving classroom interaction, outweighed the time investment.

Conclusion

The findings from this study highlight the positive effects of mindfulness in reducing speaking anxiety and enhancing classroom participation among Banat Senior High School students. By fostering emotional regulation, building self-confidence, and promoting a positive classroom atmosphere, mindfulness serves as a powerful tool for language learners facing anxiety. These results align with and extend previous research on mindfulness in educational settings, offering evidence of its efficacy in both enhancing emotional well-being and improving language learning outcomes. While challenges remain, particularly in terms of time constraints and individual differences, the overall positive impact of mindfulness suggests it is a valuable practice that can be effectively integrated into language education, especially in under-resourced settings.

Recommendations

For future research, the author suggests to explore individualized approaches to mindfulness or consider the impact of additional interventions, such as cognitive-behavioral techniques, in combination with mindfulness. Moreover, because the study did not include a long-term follow-up to assess whether the benefits of mindfulness on speaking anxiety were sustained beyond the duration of the intervention or not so, future studies also could extend the intervention period and include follow-up measurements to examine the long-term impact of mindfulness on students' speaking anxiety and overall language proficiency.

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Decoding Passive Sentence Acquisition: Evidence from Indonesian Students in Kupang - East Nusa Tenggara

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Abstract: Research on second language acquisition has often investigated whether particular grammatical features are ultimately mastered, but less attention has been paid to the order or sequence in which such features are acquired and to the linguistic factors driving this sequence, especially in local Indonesian contexts. This study examines the acquisition of Indonesian passive constructions by Kupang Malay–speaking senior high-school students. It addresses two questions: The first, what is the acquisition order of different Indonesian passive constructions, and the second one is how do verb type and personal pronoun subjects influence this order? Using a descriptive case-study design within an SLA framework, 15 learners completed a written transformation test in which they converted transitive active sentences into passive sentences. The items systematically varied verb type (monotransitive vs. ditransitive) and the use of first-, second-, and third-person pronouns as subjects. The test was administered three times, and the System Acquisition Index (SAI) with a 90% mastery criterion was applied. The results show a clear sequence: passives derived from monotransitive active sentences (93.70%) are acquired earlier than those from ditransitive sentences (75.78%) and from sentences with personal pronoun subjects (57.27%). Within the latter group, third-person pronoun subjects yield the highest accuracy, followed by second- and first-person pronouns. These findings indicate that verb type, structural complexity, and pronominal reference jointly shape the acquisition of Indonesian passives and should be considered in the design of Indonesian language teaching for learners whose first language is Kupang Malay.

Keywords: second language acquisition; Indonesian passive sentences; Kupang Malay; verb type; personal pronouns

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Introduction

Language acquisition is often regarded as a natural and unconscious process, especially in the case of first language acquisition, where children effortlessly learn their native tongue. In contrast, language learning is a conscious effort, usually taking place in formal settings like classrooms, to master a second language (Chaer: 2015). In multilingual societies like Indonesia, many learners grow up speaking a local language at home and gradually acquire Indonesian as an additional language through schooling and social interaction. Although some learners attain proficiency relatively quickly, others experience a lengthy and staged process that requires substantial effort and adaptation. Within this broader context of second language acquisition (SLA) in Indonesia, grammatical features that differ markedly between the first language (L1) and the second language (L2) often pose persistent challenges. One such feature is the passive construction in Indonesian.

Passive constructions in Indonesian and their acquisition

Passive sentences have a distinct construction and interpretation, and are frequently regarded as structurally complex and difficult to process. Riches (in Fitriyani, 2013) notes that passives are harder to comprehend and produce than more basic sentence types. Alcock et al. (2011) report that, in many European language learning contexts, passive constructions are not introduced at early ages because of their syntactic and semantic complexity. Studies on first language acquisition also show that children typically acquire passive structures later than actives: De Villiers and De Villiers (in Dardjowidjojo, 2003) found that English-speaking children begin to use passives around the age of four, while Hebrew-speaking children may not employ them until the age of eight, and Baldie (1976) observed that Dholuo-speaking children did not produce English passives until approximately twelve years of age.

In Indonesian, passive constructions are likewise more complex than active ones, both morphologically and syntactically. Research on the acquisition of Indonesian passives indicates that in some languages or learner groups passive forms are acquired relatively quickly, whereas in others they emerge much later (Salim & Nur, 2020). Previous work on Indonesian has primarily examined how foreign learners acquire passive sentences (e.g. Fitriyani, 2013; Wahyuni, 2013) or has focused on general patterns of Indonesian acquisition among speakers of other regional languages (Dardjowidjojo, 2003).

A particularly interesting case within the Indonesian context is learners from Kupang, whose first language is Kupang Malay. Kupang Malay differs significantly from standard Indonesian in terms of grammar, word order, and affixation, including the way passive meanings are expressed. While Indonesian relies heavily on morphological markers such as the prefix di- in passive constructions, Kupang Malay often employs different strategies that do not always correspond directly to Indonesian passive forms.

Although Indonesian is formally taught from early schooling and functions as the official language of administration, education, and wider communication, students from Kupang frequently struggle with passive sentences in Indonesian. These difficulties have been linked to differences in lexicon, phrase structure, and

verbal morphology between Kupang Malay and Indonesian, which can lead to negative transfer and persistent errors in constructing Indonesian passive sentences.

Despite the abundance of research on Indonesian as a second or additional language in various regions, studies focusing specifically on the acquisition of Indonesian passive constructions by Kupang Malay-speaking learners are still scarce. Existing studies on Indonesian passives tend to examine foreign learners of Indonesian rather than local students whose first is a Malay variety. Most study focus on whether learners can ultimately produce or comprehend passive sentences, rather than on the order in which different passive constructions are acquired; and pay limited attention to how specific linguistic factors such as verb transitivity and the use of personal pronoun shape the sequence of passive acquisition.

Consequently, there is lack detailed picture of how Kupang Malay-speaking learners acquire Indonesian passive constructions over time, and how the structural differences between the two languages interact with verb type and pronoun use to influence this process. To address this gap, the present study investigates the acquisition of Indonesian passive sentences by senior high-school students in Kupang whose first language is Kupang Malay. The study focuses on passive forms derived from active transitive sentences and systematically varies (1) the type of transitive verb (monotransitive/ekatransitive vs. ditransitive/dwitransitive), and (2) the use of personal pronouns as subjects in the corresponding active sentences. Using the System Acquisition Index (SAI) with a 90% mastery criterion, the research aims to determine the sequence in which these different passive constructions are acquired and to identify the linguistic factors that contribute to this sequence.

The study is guided by the following research questions:

- What is the acquisition order of Indonesian passive constructions produced by Kupang Malay-speaking senior high-school students?
- How do verb type (monotransitive vs. ditransitive) and the use of personal pronouns as subjects influence this acquisition order?

By answering these questions, the study seeks to contribute empirical evidence on the role of L1–L2 structural differences, verb transitivity, and pronominal subject use in shaping the acquisition of Indonesian passive constructions. The findings are expected to inform both theoretical discussions in SLA and practical considerations for designing Indonesian language teaching materials that are sensitive to the linguistic background of learners from Kupang.

Method

Research Design

This study adopts a descriptive case-study design within a qualitative framework of Second Language Acquisition (SLA). The main purpose is to trace the order in which Kupang Malay-speaking learners acquire Indonesian passive constructions and to examine how this order is influenced by verb type and the use of personal pronouns as subjects, as formulated in the research questions presented in the Introduction.

To address the first research question on the sequence of acquisition, the study analyses learners' production of Indonesian passive sentences derived from different types of transitive active sentences. To address the second research question on the influence of linguistic factors, the study systematically varies (1) the type of transitive verb (monotransitive/ekatransitive vs. ditransitive/dwitransitive) and (2) the use of first-, second-, and third-person pronouns as subjects in the active sentences. The primary data consist of Indonesian sentences produced by the participants by altering active sentences with transitive verb predicates into their corresponding passive forms.

Research Participants

The participants who involve in this study were fifteen learners in Kupang, East Nusa Tenggara, aged approximately 15–17 years. All participants had lived in Kupang since childhood, acquired Kupang Malay as their first language, and learned Indonesian as a second language through formal schooling.

To reflect different levels of Indonesian proficiency, the learners' Indonesian try-out scores were used to classify them into three proficiency levels: beginner, intermediate, and advanced. Each level consisted of five participants. This classification made it possible to observe whether the acquisition order of passive constructions is consistent across different proficiency levels while still focusing on the overall pattern of acquisition required to answer the research questions.

Instruments

Data were collected using a written transformation test designed to elicit Indonesian passive sentences. The test required learners to convert Indonesian active sentences with transitive verb predicates into their passive counterparts. In line with the research questions, the instrument targeted three main types of active sentence constructions:

Monotransitive (ekatransitive) active sentences with the basic S–P–O pattern, which can be transformed into simple passive sentences.

Ditransitive (dwitransitive) active sentences with an S–P–dO–O pattern, requiring the rearrangement of two objects when forming passives.

Active sentences with personal pronoun subjects, in which first-, second-, and third-person pronouns function as the subject and must be appropriately transformed into passive constructions.

All active sentences were constructed using transitive verbs only, since only transitive active sentences can be passivized in Indonesian; in such cases, the object of the active sentence becomes the subject of the corresponding passive sentence (Badudu, 1985). The verb and pronoun choices were selected to reflect common patterns in school-related discourse and to make the items accessible to the learners while still engaging the structural contrasts required by the research questions.

Procedures

The transformation test was administered three times using the same set of items. To minimise the possibility that learners would simply recall previous answers, the order of the items was randomised in each administration. The three testing sessions were separated by an interval of approximately one month.

This repeated-measures procedure served two purposes. First, it allowed the researcher to examine stability and development in the production of each type of passive construction over time. Second, it provided a richer empirical basis for determining whether a given passive pattern could be considered "acquired" according to the System Acquisition Index (SAI) criterion. All tests were administered in classroom settings under similar conditions.

Data Analysis

Data analysis was conducted in several stages in order to answer the two research questions.

Scoring and categorisation

Learners' written responses were first corrected against standard Indonesian grammar.

Each response was scored dichotomously: a score of 1 for a grammatically correct passive construction and 0 for an incorrect or incomplete response.

The responses were then grouped according to the active sentence type from which they were derived:

monotransitive (ekatransitive) active sentences,

ditransitive (dwitransitive) active sentences, and

active sentences with first-, second-, or third-person pronoun subjects.

Descriptive statistics for each construction type (RQ1)

For each test administration, the percentage of correct responses was calculated for every construction type using a simple proportion formula (number of correct responses divided by the total number of responses for that construction, multiplied by 100).

The average percentage across the three test administrations was then computed for each construction type.

These percentages were used to determine the order of acquisition of Indonesian passive constructions, thereby addressing the first research question.

Application of the System Acquisition Index (SAI)

To decide whether a particular passive construction had been "acquired," the study adopted the System Acquisition Index (SAI), originally developed for first language acquisition research (De Villiers & De Villiers in Dulay, 1974) and adapted here for second language acquisition.

Within this framework, a target construction is considered acquired when it reaches at least 90% correct responses.

Constructions with higher percentages of correct responses are assumed to be acquired earlier than those with lower percentages.

Analysis of linguistic factors (RQ2)

To address the second research question, the percentages of correct responses were compared across: monotransitive vs. ditransitive passive constructions, and passive constructions derived from active sentences with first-, second-, and third-person pronoun subjects.

Patterns in these percentages were examined to identify how verb transitivity, structural complexity, and pronoun person influence the relative difficulty of each passive construction.

These patterns were then interpreted in light of the theoretical discussion on verb type, sentence complexity, and L1–L2 structural differences presented in the Introduction and Discussion sections.

Through these steps, the analysis links directly back to the research questions by (1) establishing a clear sequence of Indonesian passive construction acquisition among Kupang Malay-speaking learners and (2) identifying which linguistic factors most strongly shape that sequence.

Results

Sequence of Indonesian passive sentence production by learners from Kupang

The sequence of Indonesian passive sentence production was determined from the average percentage of correct responses for each type of transitive active sentence that learners transformed into passive sentences. The summary is presented in Table 1.

Table 1. The order of mastery levels

No	Sentence Pattern	%	Category
1.	S-P-O Ekatransitive	93.70	Very Good
2.	S-P-O Dwitransitive	75.78	Fair
3.	Pronoun as Subject	57.05	Bad

As shown in Table 1, the highest mastery was found in passive sentences formed from monotransitive (ekatransitive) active sentences, with an average of 93.70% correct responses. This type of passive construction therefore occupies the first position in the acquisition sequence. The second position is held by passive sentences derived from ditransitive (dwitransitive) active sentences, which reached an average of 75.78% correct responses. Finally, passive sentences formed from active sentences with personal pronouns as subjects had the lowest mastery, with an overall mean of 57.27% correct responses.

When the System Acquisition Index (SAI) criterion of 90% is applied, only the passive construction derived from monotransitive active sentences reaches the threshold and can be considered fully acquired. The other two construction types fall below the mastery criterion and are therefore regarded as partially acquired. The pattern of performance across the three test administrations is illustrated in Figure 2 on page 5, which shows that, although scores for all three construction types improve slightly from the first to the third test, the relative order of mastery (monotransitive > ditransitive > pronoun subject) remains stable throughout.

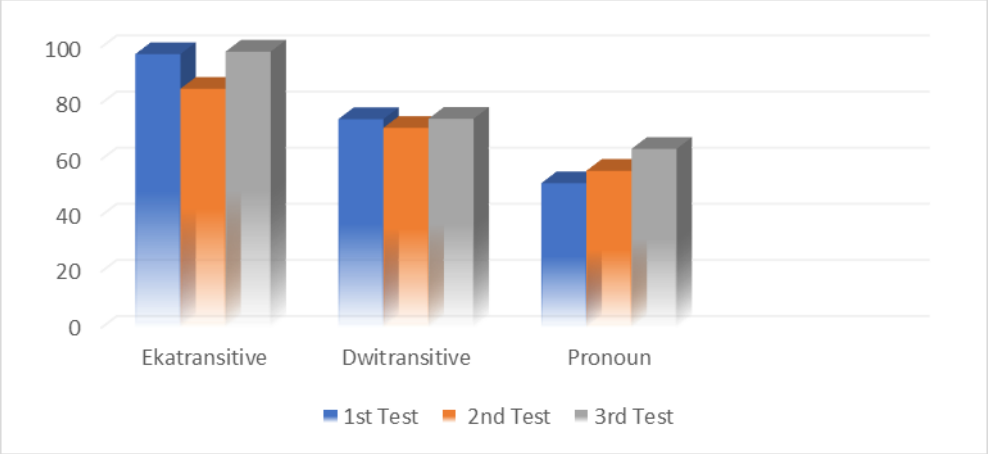

Figure 2. Percentage of Passive Indonesian Mastery based on Sentence Pattern

How verb type and personal pronoun subjects influenced the sequence

Here the results were examined in more detail with respect to verb type (monotransitive vs. ditransitive) and the use of personal pronouns as subjects in the active sentences.

1. Verb type

Comparing the first two rows in Table 1 shows a clear effect of verb transitivity. Passive sentences derived from monotransitive active sentences achieved a mean accuracy of 93.70%, while those derived from ditransitive active sentences reached only 75.78%.

This difference indicates that learners find it easier to form passive sentences from monotransitive constructions than from ditransitive ones. In other words, less structurally complex active sentences (with a single object) are more readily transformed into correct passive forms than more complex sentences that require the reordering of two objects.

2. Personal pronoun subjects

Within the group of passive sentences derived from active sentences with personal pronouns as subjects, mastery levels vary according to the person of the pronoun. The results can be summarised as follows:

Passive sentences derived from active sentences with a third-person pronoun as subject show the highest mastery, with an average accuracy of 80.86%.

Passive sentences derived from active sentences with a second-person pronoun as subject have a lower mastery level of 55.56%.

Passive sentences derived from active sentences with a first-person pronoun as subject have the lowest mastery, with only 35.38% correct responses.

These findings indicate that, even within the category of passive constructions involving personal pronoun subjects, there is a clear internal hierarchy of difficulty: third-person > second-person > first-person. However, none of these patterns reach the 90% SAI mastery criterion, confirming that passive sentences with personal pronoun subjects constitute the least acquired construction type among the learners in this study.

Discussion

This study set out to investigate the acquisition of Indonesian passive constructions by Kupang Malay-speaking learners and to identify the linguistic factors that shape the order of acquisition. In relation to the first research question, the findings reveal a clear and systematic sequence. Monotransitive passive sentences are acquired earlier than ditransitive passive sentences and passive sentences formed from active sentences with personal pronoun subjects. Monotransitive passives reach an average mastery of 93.70%, surpassing the 90% criterion set by the System Acquisition Index (SAI), whereas ditransitive passives and passives with personal pronoun subjects fall below this mastery threshold (75.78% and 57.27%, respectively). These results demonstrate that learners first acquire structurally simpler monotransitive passives, followed by more complex ditransitive passives, and only later begin to approximate mastery of passives involving personal pronoun subjects.

Linguistically, this pattern aligns with previous research on the acquisition of passive constructions in both children and second language (L2) learners. Actional and concrete verbs are generally easier to comprehend and retain than non-actional or abstract verbs, leading to earlier production of passive sentences derived from concrete verbs. This is consistent with findings by Dardjowidjojo (2003) and Wahyuni (2013), who showed that easily visualisable verbs are more readily accessed in long-term memory. Thatcher et al. (2008) and Fitriyani (2013) similarly reported that actional verbs are produced more rapidly than non-actional verbs in passive constructions. More recent SLA studies (Chen & Yang, 2022; Choi, 2022; Sun et al., 2023) emphasise that verb concreteness, input frequency, and salience strongly shape syntactic development in L2 learners, which helps explain why monotransitive passives with concrete verbs are acquired first.

Structural complexity also plays a central role. Monotransitive verbs, which involve only one object, are easier to convert into passive forms than ditransitive verbs, which require learners to manage two objects and their relative ordering. This pattern is in line with working-memory theories suggesting that sentences with fewer arguments impose a lower cognitive load and facilitate syntactic transformation (Matlin, 2003; Brown & Carr, 1993; Carr & Curran, 1994). Recent research further highlights that cognitive load and syntactic complexity interact to shape L2 acquisition, with learners showing slower production and higher error rates for constructions requiring simultaneous argument tracking (Ellis et al., 2021; de Bot et al., 2020; Wang & Liu, 2024). Together, these perspectives provide a cognitive explanation for learners' difficulty in producing ditransitive passives and support the acquisition order observed in this study.

The second research question in this study concerned about how verb types and the use of personal pronouns as subjects influence the acquisition order of Indonesian passive constructions. Regarding the second research question, the results show that both verb transitivity and pronominal subjects significantly affect learners' performance. First, the contrast between monotransitive and ditransitive passives confirms that verb type is a crucial factor: passive sentences derived from monotransitive verbs are consistently produced more accurately than those derived from ditransitive verbs. This finding supports the view that structural complexity and argument structure directly shape L2 learners' ability to process and produce passive constructions (Li & Shirai, 2020; Chen & Yang, 2022).

Second, within the group of passive sentences formed from active sentences with personal pronoun subjects, a clear internal hierarchy emerges: passives with third-person pronoun subjects show the highest mastery, followed by those with second-person pronoun subjects, while passives with first-person pronoun subjects display the lowest mastery. Learners thus experience greater difficulty when transforming active sentences that contain personal pronouns, particularly first-person pronouns. This pattern is consistent with Ellis (1997) and Cook (2016), who argue that variability in L2 feature acquisition is influenced by linguistic and systemic context, including pronoun use and discourse salience. Recent studies (Choi, 2022; Tanaka & Saito, 2021) also demonstrate that pronoun variability and contextual prominence affect syntactic processing and production, which helps explain why pronominal subjects make passive formation more challenging.

In the specific context of Kupang Malay–Indonesian bilingualism, these difficulties are likely intensified by cross-linguistic differences in word order, affixation, and the expression of passive meanings. Learners must not only manage increased structural complexity and pronoun variability, but also reconcile divergent patterns between their L1 (Kupang Malay) and L2 (Indonesian). This interaction of linguistic, cognitive, and cross-linguistic factors explains why passive constructions with pronominal subjects remain the least acquired type despite exposure and formal instruction.

The findings indicate that passive sentence production among Indonesian learners in Kupang is primarily shaped by three interrelated factors: verb type (especially the distinction between actional and non-actional verbs), structural complexity (monotransitive vs. ditransitive constructions), and the use of personal pronouns as subjects. While this study adopts a case-study design with a relatively small sample, it offers valuable insights into how L2 learners internalise passive constructions in a multilingual Indonesian context. It also underscores the importance of integrating linguistic, cognitive, and contextual dimensions in second language acquisition research and pedagogy. Future studies could build on this work by including larger and more diverse learner populations, incorporating online processing measures, and examining interactional classroom data to further clarify the cognitive mechanisms underlying passive sentence acquisition.

Conclusion

This findings show a clear acquisition order: passive sentences derived from monotransitive (ekatransitive) active sentences are mastered first, followed by passives derived from ditransitive (dwitransitive) active sentences, while passives formed from active sentences with personal pronoun subjects are acquired last. Only the monotransitive passive construction reaches the 90% mastery criterion of the System Acquisition Index (SAI), indicating full acquisition, whereas the other constructions remain partially acquired. This acquisition order is systematically influenced by verb type, structural complexity, and the use of personal pronouns as subjects. Monotransitive verbs and less complex sentence patterns facilitate passive formation, whereas ditransitive verbs, which require the reordering of two objects, impose greater processing demands. In addition, passive sentences involving personal pronoun subjects—especially first-person pronouns—are markedly more difficult for learners than those with third-person subjects. The findings of this study highlight the combined role

of linguistic, cognitive, and input-related factors in shaping the development of Indonesian passive constructions in learners whose first language is Kupang Malay. The study provides empirical evidence of how cross-linguistic differences between Kupang Malay and Indonesian interact with verb type and pronoun use in second language acquisition, and it offers a basis for designing more targeted instructional practices for teaching Indonesian passives in multilingual contexts.

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Between Tradition and Modernity: The Impact of Language Policy on the Use of Padoe Language at South Sulawesi, Indonesia

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Abstract: The preservation of minority languages faces significant challenges worldwide, especially in multilingual countries such as Indonesia. This study focuses specifically on the impact of language policy on the use of the Padoe language, an endangered indigenous language spoken in South Sulawesi. Employing a qualitative research approach, this study uses in-depth interviews, classroom observations, and document analysis within Padoe-speaking communities to explore how formal education influences language practices among children and adolescents. Guided by Fishman's theory of language shift and language domains, the research contextualizes the tension between traditional language use and modern educational demands. Findings reveal that the dominance of Indonesian as the medium of instruction and the absence of Padoe language integration in schools contribute to a decline in Padoe language use outside the home. This study argues that educational policies and practices play a crucial role in either accelerating language shift or supporting language maintenance. The results are valuable for policymakers, educators, and cultural activists aiming to design inclusive language education policies that balance modern education with local language.

Keywords: Educational policy, Language preservation, Language shift, Language use, Padoe language

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Introduction

Language is a vital medium through which individuals express their identity, transmit cultural heritage, and

participate in social interactions (OpenStax, 2023; Ianna, 2021; Yuliana & Wibowo, 2020). In multilingual societies like Indonesia, language also functions as a tool of integration and national unity, as demonstrated by the widespread promotion and institutionalization of Bahasa Indonesia. However, this emphasis on a national language often comes at the expense of minority and indigenous languages, many of which are now endangered. One such language is Padoe, a regional language spoken primarily in parts of South Sulawesi and Southeast Sulawesi, which is experiencing a rapid decline in use and intergenerational transmission. According to UNESCO (2003) and Crystal (2000), a language disappears approximately every two weeks, and nearly half of the world's languages are predicted to vanish within this century. This reality highlights the global urgency of language preservation, especially for small and endangered languages like Padoe in South Sulawesi.

Indonesia is home to over 700 languages, making it one of the most linguistically diverse countries in the world (Simons & Fennig, 2022). Despite this richness, language policy and educational practices have prioritized Bahasa Indonesia since the early days of national independence. While this policy has effectively promoted national cohesion, it has also contributed to the marginalization of local languages in formal domains such as education, governance, and media (Rohmani, 2018; Musgrave, 2014). The shift away from local languages is particularly visible in younger generations who, due to schooling and broader exposure to Indonesian media, have limited proficiency in their heritage languages.

The Padoe language, part of the Austronesian language family, is classified as endangered according to UNESCO's Language Vitality and Endangerment framework (UNESCO, 2003). It is currently spoken by a small population in remote areas and is under pressure from both Bahasa Indonesia and regional lingua francas like Bugis. Previous studies (Yallop, 2015; Lauder, 2010) have shown that the absence of a language from formal education systems is a strong predictor of language shift, especially in communities undergoing rapid socio-cultural changes.

The role of education in either promoting or inhibiting language maintenance is well-documented in sociolinguistic literature (Hornberger, 2008; Spolsky, 2009). Schools are not only institutions for cognitive development but also powerful agents of socialization and identity formation. When the language of instruction excludes a community's mother tongue, students may come to view their heritage language as inferior, irrelevant, or even a hindrance to academic and economic success (Benson, 2004). This perception is reinforced when textbooks, teachers, and school policies uniformly operate in a dominant language, thereby creating a symbolic and functional hierarchy among languages.

Fishman's (1991) theory of Reversing Language Shift (RLS) provides a useful framework for understanding how domains of language use (such as home, school, religion, and work) influence language vitality. According to Fishman, the erosion of minority languages often begins in the domain of the family but is significantly accelerated when the school domain is dominated by a different language. In the context of Padoe, early findings suggest that while the language is still spoken in some homes, its use is steadily declining among children who attend schools where only Indonesian is used.

Studies in other parts of Indonesia have shown similar patterns. For instance, an ethnolinguistic study by Cahyani, de Courcy, and Barnett (2018) in Bali found that Balinese children who received their education exclusively in Indonesian had lower competence in Balinese and were less likely to use it in peer interactions. Likewise, in Papua, Sawaki (2017) reported that students who were not taught in their local languages exhibited lower levels of cultural engagement and linguistic confidence. These findings support the argument that education plays a central role in the preservation or erosion of local languages.

In the case of Padoe, field observations indicate that formal education does not currently accommodate or acknowledge the language. Teachers, even those who are native speakers of Padoe, rarely use the language in classroom settings. There is no structured curriculum, teaching material, or training that supports bilingual or mother tongue-based instruction involving Padoe. This institutional neglect contributes to the perception that the language is irrelevant to modern life and future opportunities.

Furthermore, the sociocultural values embedded in the Padoe language; such as respect for elders, traditional ecological knowledge, and community-based ethics, are not being transmitted through the education system. When children are not exposed to these cultural narratives in their mother tongue, their understanding of identity and belonging becomes fragmented. The lack of representation of local culture in school curricula also signals to students that their traditions are of lesser importance compared to national or global cultures.

It is within this context that this study seeks to explore the impact of modern education on the use and transmission of the Padoe language in South Sulawesi. The research aims to examine how formal schooling influences language practices among children and adolescents in Padoe-speaking communities, and how educational policies and practices contribute to either the maintenance or marginalization of the Padoe language. This study contributes to the growing body of research on indigenous language endangerment and offers insights into how inclusive education policies can be formulated to support both national integration and cultural diversity.

Language Shift and Maintenance in Multilingual Societies

Language shift refers to the process by which a speech community gradually abandons its native language in favor of another, usually more dominant, language (Fishman, 1991). This phenomenon is particularly common in multilingual societies where one language becomes associated with economic opportunity, education, or national identity. In many cases, the process of language shift is unidirectional and leads to the eventual extinction of the minority language. Conversely, language maintenance is the effort to sustain the use of a language within a community across generations. Fishman's (1991) theory of Reversing Language Shift (RLS) proposes a framework of eight stages of language decline, emphasizing the importance of intergenerational transmission as a key factor in maintaining language vitality. Language loss often begins when younger generations stop using their heritage language, especially when its use is restricted to informal domains such as the home. When formal institutions like schools and government offices operate exclusively in a dominant

language, the subordinate language is relegated to secondary status and may gradually disappear from daily life.

Hornberger (2006) introduced the Continua of Biliteracy, a model that maps the complex interplay between languages in multilingual settings. This model emphasizes the need for educational policies that allow minority languages to coexist and function alongside dominant languages. Hornberger argues that educational environments can either reinforce language hierarchies or promote linguistic equity, depending on how language policies are designed and implemented.

The Role of Education in Language Endangerment

Education systems play a crucial role in shaping linguistic practices and ideologies. Numerous studies have shown that when education is delivered exclusively in a dominant or national language, it can lead to the devaluation of minority languages (Skutnabb-Kangas & Phillipson, 1995; Benson, 2005). Schools are often the first formal institutions that children encounter, and the language of instruction significantly influences their linguistic preferences and proficiencies.

In contexts like Indonesia, where Bahasa Indonesia serves as the national and instructional language, minority languages are often excluded from the curriculum (Musgrave, 2014; Lauder, 2008). This exclusion contributes to the perception that indigenous languages are obsolete, irrelevant, or inferior. Over time, this ideological stance is internalized by children and even their parents, who may choose to raise their children in Indonesian to ensure their academic success and social mobility (Rohmani, 2018).

A study by Cahyani, de Courcy, and Barnett (2018) highlighted how Balinese students in schools that did not include Balinese in the curriculum showed limited competence and declining use of their heritage language. Similarly, Sawaki (2017) reported in his research on Papua that children educated solely in Indonesian experienced a disconnection from their indigenous roots and culture. These studies reinforce the notion that exclusionary language policies in education accelerate language shift.

Benson (2004) and Malone (2007) advocate for Mother Tongue-Based Multilingual Education (MTB-MLE) as a solution to bridge traditional language use and formal education. MTB-MLE not only improves students' cognitive development and academic performance but also supports language maintenance and cultural pride. However, implementing MTB-MLE in linguistically diverse countries like Indonesia presents logistical and political challenges, especially in regions with limited resources and infrastructure.

Indigenous Language Endangerment in Indonesia

Indonesia's linguistic diversity is under severe threat. According to Simons and Fennig (2022), more than 200 of Indonesia's 700+ languages are currently endangered. UNESCO (2003) has identified several key factors

affecting language vitality, including intergenerational transmission, community attitudes, institutional support, and media presence. In many Indonesian communities, rapid urbanization, migration, and the spread of Indonesian media content have further marginalized local languages.

Musgrave (2014) notes that many Indonesian languages are losing their domains of use due to both internal and external pressures. While some languages retain ceremonial or religious functions, their communicative functions in everyday life are rapidly diminishing. This phenomenon is exacerbated by educational systems that fail to accommodate linguistic diversity and instead promote a monolingual ideology centered around Bahasa Indonesia. Despite the recognition of cultural and linguistic diversity in the Indonesian constitution and education law (UU No. 20/2003), in practice, minority languages are seldom integrated into school curricula. This gap between policy and practice has contributed to the erosion of linguistic rights and the decline of indigenous languages (Lauder, 2010).

The Padoe Language in Context

Although limited scholarly work has focused exclusively on the Padoe language, its situation is like many other endangered languages in Indonesia. Spoken in remote regions of South and Southeast Sulawesi, Padoe faces increasing pressure from both Bahasa Indonesia and regional lingua francas such as Bugis. The language is still used in limited domestic contexts but is nearly absent from public institutions, especially schools.

Based on field reports and community narratives, the younger generation of Padoe speakers is increasingly unable or unwilling to use the language. The influence of modern education, which privileges Bahasa Indonesia, is cited as a major factor. The fact that teachers in Padoe-speaking areas rarely use the language, despite often being fluent themselves, suggests an institutional discouragement or neglect that further marginalizes Padoe. The current study seeks to fill a gap in literature by focusing specifically on the intersection of education and language use in Padoe communities. By drawing upon existing theories of language shift and maintenance, and grounding the research in the lived experiences of Padoe speakers, this study provides a nuanced understanding of how education can either contribute to or resist linguistic erosion.

Method

This study employed a qualitative descriptive approach to explore in depth how modern education impacts the use of the Padoe language within its native-speaking communities in South Sulawesi, Indonesia. The qualitative design was chosen because it allows for a rich understanding of sociocultural experiences, language practices, and personal perceptions, particularly in contexts of linguistic transition influenced by institutional forces like formal education. The research was further guided by an ethnographic orientation, allowing for close observation of linguistic behavior and social interactions in both formal (school) and informal (home and community) domains where intergenerational language transmission occurs.

The theoretical framework is based primarily on Fishman's theory of language shift (1991), especially his concept of "domains of language use." According to Fishman, the survival and vitality of a minority language depend significantly on its function and presence across domains such as the home, school, religion, marketplace, and media. In this study, the focus is on the contrast between the home and school domains, analyzing how language practices are shaped by the competing demands of traditional use and the formal education system. In addition to Fishman's theory, the study incorporates the language ideology framework, which posits that speakers' beliefs and attitudes toward languages, often shaped by institutions like schools, influence language choices, hierarchies, and transmission patterns (Woolard & Schieffelin, 1994).

The research was conducted in two Padoe-speaking villages located in East Luwu Regency, South Sulawesi, chosen through purposive sampling. These locations were selected because they represent areas where the Padoe language is still actively spoken within families but where children are increasingly exposed to modern education dominated by the Indonesian language. Each village has both elementary and junior high schools, making them suitable for studying school-based language interactions and the influence of educational policies on local language practices.

Participants in this study were selected using purposive sampling, ensuring the inclusion of individuals who are directly involved in language use and transmission within their communities. A total of 23 participants were involved, including six parents from Padoe-speaking households, four teachers (two elementary and two junior high), eight students (from upper elementary and early junior high levels), and two school principals, and one community elders or cultural leaders. All participants were either fluent in Padoe or actively engaged in discussions or practices related to the use or preservation of the language.

To collect the data, the study used three main methods: in-depth interviews, participant observation, and document analysis. Semi-structured interviews were conducted with all participant groups to gather insights on their perceptions, experiences, and ideologies regarding Padoe language use, particularly within educational settings. Each interview lasted between 45 and 90 minutes and was conducted in either Indonesian or Padoe, depending on the participant's preference. Participant observations were carried out in classrooms (Grades 4 to 7) to examine language use in teaching, student interactions, and spontaneous speech. In addition, the researcher observed social interactions in homes, religious events, and community gatherings to capture the use of the Padoe language in non-formal domains. Meanwhile, document analysis involved reviewing school curricula, lesson plans, policy documents, and meeting records to determine the extent to which the Padoe language is acknowledged or included within the school environment.

The data collected through these methods were analyzed using thematic analysis (Braun & Clarke, 2006). The process began with familiarization through transcription and repeated reading of interview and observation data. This was followed by coding relevant data segments and organizing them into broader thematic categories such as "language use at home," "school language policy," and "attitudes toward Padoe." These themes were then interpreted through the lens of Fishman's domain theory and the language ideology framework to understand the

dynamics of language maintenance or shift in the context of modern schooling. This multi-method approach provided a rich and nuanced picture of the interplay between education and language vitality in Padoe-speaking communities.

Results

This study reveals how modern education influences the use and perception of the Padoe language among children and adolescents in two Padoe-speaking villages in East Luwu, South Sulawesi. The findings are presented according to three core themes, with direct excerpts from interviews and observation notes used to illustrate each theme.

Language Use in the Home vs. School Domain

The findings indicate that the Padoe language remains relatively strong in the home domain, especially among older generations. Parents and grandparents frequently use Padoe in daily interactions, particularly when discussing traditions, family matters, or religious practices. One parent (Mother, age 42) explained:
"We always use Padoe at home, especially when talking to our parents or during family gatherings. But my children usually respond in Indonesian, even though they understand what we say."
This pattern illustrates a growing generational gap in productive language use. Children comprehend Padoe but seldom speak it actively. From the 21 participants, 7 children (out of 8) reported that they "only use Indonesian" when speaking with siblings or peers, even though they "can understand Padoe."

In contrast, the school domain is entirely dominated by Indonesian. Classroom observations in two elementary schools and one junior high school revealed zero use of Padoe in both instruction and informal interactions. Teachers used Indonesian in all subject areas, including when speaking to students from fully Padoe-speaking households. One Grade 5 teacher noted:
"Even if students speak Padoe at home, at school they must learn to use proper Indonesian. It's part of preparing them for exams and the national standard."

During a science lesson, the researcher observed that a student mistakenly used a Padoe word ("tao") while answering a question. The teacher corrected the child, saying, "That's not the right word; use the Indonesian term." This subtle correction reinforced the idea that Padoe has no place in academic contexts.
Thus, there is a clear compartmentalization of language domains: Padoe is associated with the home and informal family life, while Indonesian is positioned as the legitimate language of knowledge and the public sphere.

Language Ideologies and Attitudes

Students' language choices are strongly influenced by underlying ideologies that elevate Indonesian and

marginalize Padoe. Most student participants expressed the belief that Indonesian is more "useful," "modern," and "important for the future." One 13-year-old student stated:
"We only speak Indonesian at school. Padoe is not used anymore, it's like an old people's language."

This internalized ideology demonstrates a linguistic inferiority complex: students perceive Padoe as a marker of backwardness and Indonesian as a symbol of modernity. Although teachers recognize the cultural importance of Padoe, their attitudes often align with this dominant view. One school principal mentioned:
"We are proud of our local language, but we cannot use it in school because we follow the national curriculum. The children must be fluent in Indonesian first."

Interestingly, even some parents began to doubt the relevance of Padoe. A father (age 46) commented:
"I want my children to speak Padoe, but I also want them to succeed. Maybe speaking Indonesian helps them get better opportunities."
Such statements illustrate how language shift is driven not only by institutional policy but also by evolving family aspirations shaped by formal education.

The Role of Educational Policy and Curriculum

The analysis of curriculum documents, lesson plans, and school meeting notes confirmed that no formal space exists for the Padoe language in the current educational system. The 2013 Indonesian National Curriculum (K13), implemented in both schools, makes no mention of indigenous or minority languages. Local adaptations, though technically permitted under the Merdeka Belajar policy, are absent.

A review of 12 lesson plans across three subjects (Bahasa Indonesia, Social Studies, and Science) showed complete uniformity in using Indonesian as the language of instruction. Teachers confirmed that they had received no training on how to integrate local language content or how to approach multilingual classrooms.
Teachers explained:
"We follow the textbook. There's no section that mentions Padoe. If we include it, we worry about being marked down during supervision."

This institutional fear limits creative pedagogical decisions, reinforcing a one-language-fits-all model that disadvantages minority language speakers.
The school principal stated, "So far, there has been no directive or policy from the local government to include Padoe language materials in the school curriculum; we simply follow the national curriculum.

Furthermore, during an observation of a school assembly, the researcher noted that the national anthem and moral guidance were delivered in Indonesian, with no reference to local culture or language. Students appeared disengaged during such events, suggesting a disconnect between institutional values and local identity.

Discussion

This study has examined the impact of modern education on the use and perception of the Padoe language among children and adolescents in South Sulawesi. The findings reveal a clear tension between the traditional home domain, where Padoe remains relatively active, and the school domain, which is dominated entirely by Indonesian. These results confirm, elaborate, and at times challenge existing research on language shift, language ideology, and educational policy in multilingual and minority language contexts.

Language Use and Domain Compartmentalization

The compartmentalization of Padoe and Indonesian across home and school domains found in this study aligns closely with Fishman's (1991) theory of language domains, which posits that language use is strongly tied to social contexts, and language shift often occurs when minority languages become restricted to informal or private domains. In the Padoe context, as in many minority language settings, the home remains the last stronghold of the indigenous language, primarily maintained by older generations (Grenoble & Whaley, 2006; Hornberger, 2006). This domain restriction is a classic marker of language endangerment, where active language use is marginalized to intimate contexts (Evans, 2010).

Supporting this, recent research in Indonesia and similar multilingual contexts shows that younger generations often possess passive competence in heritage languages but predominantly use the national language in public and educational domains (Luykx & Searle, 2014; Abdurrahman, 2021). The observation in this study, that children understand Padoe but prefer Indonesian in active communication, is consistent with this pattern. For example, Abdurrahman (2021) documented a similar tendency among the Makassarese, where younger speakers favored Indonesian due to school and media influence, even though they comprehended their ethnic language fluently. Likewise, Rusdiansyah et al. (2023) note that the absence of institutional support has left the Tae' language with insufficient space to develop within the school environment, reinforcing how formal education structures contribute to the declining active use of local languages.

Importantly, this study contributes qualitative evidence from classroom observations demonstrating how formal education environments actively reinforce the domain separation. The zero use of Padoe in classrooms and direct correction of Padoe words by teachers (e.g., the rejection of "tao" in a science lesson) echo findings by Pujolar (2007) and McCarty (2003), who highlight how institutional language policies marginalize indigenous languages. Such corrective practices contribute to language shift by discouraging minority language use in prestigious domains, effectively accelerating language loss.

Language Ideologies and Attitudes

The study's findings on language ideologies reveal a critical internal dimension of language maintenance: the attitudes and beliefs held by the speakers themselves. Students' perceptions of Indonesian as more "modern,"

"useful," and "important for the future" reflect a widespread global pattern whereby dominant languages gain prestige and minority languages are stigmatized (Woolard, 1998; Edwards, 2009). This internalized linguistic hierarchy is a key driver of language shift because it influences personal language choices beyond external pressures (Garrett & Baquedano-López, 2002).

The "old people's language" stigma attributed to Padoe by young speakers mirrors documented attitudes in indigenous communities worldwide, where minority languages are often associated with backwardness and obsolescence (King, 2001; Fishman, 2001). This study's qualitative data shows how these attitudes can become entrenched early, further entrenching language discontinuity.

Moreover, parental ambivalence plays a pivotal role. While parents express a desire for their children to maintain Padoe, they prioritize Indonesian fluency due to perceived socioeconomic benefits. This dual attitude corresponds with findings by Grenoble and Whaley (2006) and Spolsky (2004), who emphasize that parental language choices are often influenced by aspirations for their children's education and economic mobility. In the Indonesian context, this tension is well-documented, with many families viewing Indonesian as essential for access to higher education and better job opportunities (Siregar & Siregar, 2018). Similarly, Rusdiansyah et.al. (2024) show that even when communities express positive attitudes such as loyalty and pride toward the Tae' language, these attitudes do not necessarily translate into consistent use, demonstrating that positive affect alone is insufficient to counteract the social and economic pressures that favor the national language.

Educators' perspectives further reinforce institutional ideologies that privilege Indonesian as the language of national progress. The reluctance to incorporate Padoe in classrooms, for fear of sanctions or poor evaluations, reflects a gatekeeping role often played by teachers (Pujolar, 2007). This institutional pressure constrains local language use and reproduces dominant language ideologies, as McCarty (2003) found in Indigenous American schools, where the formal education system often acts against language revitalization efforts.

Educational Policy and Curriculum Implications

The study confirms critiques of Indonesian educational policies concerning minority languages. The absence of Padoe in formal curricula and the lack of explicit provisions for indigenous languages in the 2013 National Curriculum (K13) reflect persistent gaps between policy rhetoric and practice (Arifin, 2014; Alwi et al., 2016). Although the Merdeka Belajar policy theoretically permits local curriculum adaptation, this study's findings show that schools do not implement such adaptations, primarily due to a lack of clear mandates, resources, and teacher training (Rahman, 2018).

At the local level, the situation is further exacerbated by the absence of any initiative or directive from the district education authorities to incorporate the Padoe language into school instruction. Interviews with school administrators revealed that schools simply follow the national curriculum, as there are no local regulations or policy frameworks supporting the inclusion of Padoe language materials. This lack of institutional support

signals that Padoe is not recognized as a valuable linguistic or cultural asset within the formal education system. Consequently, both teachers and students internalize the perception that Indonesian is the legitimate language of education and progress, while Padoe remains confined to domestic and traditional contexts.

Curriculum uniformity using Indonesian exclusively across subjects is consistent with Kasim's (2017) observation that standardization unintentionally suppresses linguistic diversity in Indonesian schools. This has significant consequences for minority language vitality, as language education is a crucial domain for language maintenance (Hornberger & King, 2001). The observation of school assemblies delivered entirely in Indonesian without local cultural references illustrates Bourdieu's (1991) notion of symbolic violence, where dominant institutions impose cultural and linguistic norms that alienate minority language speakers. This institutionalized marginalization may contribute to student disengagement and weakened cultural identity, reinforcing Hornberger and King's (2001) argument that effective language education must affirm linguistic and cultural diversity to foster positive identity and engagement.

Considering these findings, it is evident that meaningful policy intervention at the regional level is essential to reverse the marginalization of the Padoe language in education. The integration of local languages into the curriculum; supported by teacher training, learning materials, and community involvement; would not only strengthen linguistic diversity but also promote cultural continuity and inclusive educational development in multilingual settings such as Luwu Timur.

This study enriches the discussion on educational policy and minority language maintenance by offering detailed, context-specific insights into how modern schooling shapes language practices and attitudes in a small, endangered language community. It confirms established theories of language shift and domain-specific language use while expanding understanding of the classroom as a key site where institutional constraints and limited teacher support manifest, accelerating language decline (Pujolar, 2007; McCarty, 2003).

Furthermore, the findings highlight the intricate interplay between family aspirations and language maintenance, showing that revitalization is not solely a cultural concern but is deeply connected to socioeconomic realities (Fishman, 2001; Spolsky, 2004). Hence, revitalization programs must consider both identity formation and the practical advantages of bilingualism or multilingualism.

Finally, by focusing on the Padoe language, this study contributes to the underexplored linguistic diversity of South Sulawesi and reinforces the need for localized, culturally responsive education policies that move beyond national-level mandates. This aligns with previous calls for grassroots empowerment and community-driven language planning (Arifin, 2014; Rahman, 2018).

Conclusion

This study highlights the significant impact of modern education on the use and perception of the Padoe

language in South Sulawesi. The findings demonstrate a marked domain shift, where Padoe is predominantly used within the home environment, while Indonesian dominates the school and public spheres. This domain restriction reflects a classic pattern of language endangerment, confirming Fishman's (1991) theory of language domains and the global trend of minority languages losing ground to national or global languages. The research also uncovers prevailing language ideologies among Padoe speakers, particularly younger generations, who view Indonesian as the language of modernity, progress, and socioeconomic opportunity, while perceiving Padoe as the language of older generations with limited practical value. This internalized hierarchy of languages plays a crucial role in accelerating language shift and poses a major barrier to language maintenance. Educational policies and classroom practices further reinforce these dynamics. The absence of Padoe in formal curricula, combined with teacher attitudes that discourage its use, creates an environment where minority language use is marginalized or even penalized. This institutional marginalization reflects broader challenges faced by minority languages in Indonesia and underscores the need for more inclusive and flexible educational frameworks. In sum, the Padoe language is at a critical juncture, facing endangerment pressures intensified by the forces of modernization, education, and language ideologies. Without targeted efforts to revitalize and integrate the language into both educational and community domains, the likelihood of its continued decline remains high.

Recommendations

To strengthen the maintenance and revitalization of the Padoe language, several strategic recommendations are proposed. First, educational policies must explicitly recognize and accommodate indigenous languages by integrating Padoe into local curricula, ensuring that children encounter the language in formal learning spaces. Strengthening teacher training is also essential so that educators possess both the pedagogical skills and confidence to use Padoe alongside Indonesian, thereby creating linguistically inclusive classrooms. At the community level, awareness and advocacy programs should be intensified to reshape public attitudes by highlighting the cultural value of Padoe and the cognitive and social benefits of bilingualism. The development of learning resources; such as textbooks, storybooks, digital materials, and audio recordings; will further support intergenerational transmission and improve literacy among younger speakers. Continued documentation and academic research are also critical for safeguarding linguistic knowledge and informing future revitalization initiatives. Finally, emphasizing the practical advantages of bilingualism within modern educational and economic contexts can motivate younger generations to view Padoe not only as a symbol of cultural identity but also as an asset for their personal and professional development.

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Investigation of the Effect of Thiazolidinedione Inhibitor on *QscR* gene in Different Isolates of *Pseudomonas aeruginosa*

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Abstract: *Pseudomonas aeruginosa* possesses a virulence factor represented by biofilm construction that aids the bacteria to persist for a long period within the host. The goal of the study was to know the effect of thiazolidinedione inhibitor with 0.002 mM on biofilm formation through affecting on *QscR* gene. The result showed that the addition of an inhibitor led to an increase in the capacity of the isolates to construct biofilm and we thought this was because mutation occurred on *QscR* gene that helped *QscR* protein to escape from binding with the inhibitor (thiazolidinedione inhibitor), therefore, *QscR* protein activate lasI and rhI genes to produce acyl-homoserine lactone synthase that helped in the construction of biofilm. However, in silico analysis showed that the genic variation result revealed all the changes in *QscR* gene were synonymous and therefore this does not lead to a change in *QscR* protein that will bind with repressor and activate genes encoded to acyl-homoserine lactone synthase that helped in the construction of biofilm.

Keywords: thiazolidinedione inhibitor**,** *QscR* gene, *Pseudomonas aeruginosa* and biofilm

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Introduction

One of the bacteria that is clinically important is P. aeruginosa which behaves as an opportunistic that enrolled with nosocomial infections related to gram-negative in most patients with immune system deficiency (Abdulameer & Abdulhassan, 2021; AL-Maeni, 2024; Diggle & Whiteley, 2020; Niederman, 2010). The increasing of resistance mechanisms to various antibiotic agents in this bacterium species makes it more difficult to treat P. aeruginosa, and enhance mortality and increased period of hospitalization (Papadimitriou-Olivgeris et

al., 2022; Wood et al., 2023). The huge genome of P. aeruginosa that is correlated with phenotypic adaptability enhances its pathogenicity with hosts in different environments. One of the strategies in P. aeruginosa that increases their pathogenicity is generating biofilms through the growth of bacterial populations together rather than individual colonies. biofilms generate under the control of signaling substances and play a crucial role in protecting microbes from antimicrobial agents (Kiratisin et al., 2002; Qin et al., 2022; Wolfmeier et al., 2022).

Under stress conditions, biofilms become an important tool in protecting the microbes compared with planktonic cells, especially against the immune system and disinfectants (Pachori et al., 2019; Wu et al., 2015) . To eradicate P. aeruginosa infection, treatment of biofilm formation becomes an important issue through using different antibiotics in combination (Yin et al., 2022). the synergistic effect of other substances including thiazolidinedione, and antibiotics may become important strategies to get rid of P. aeruginosa biofilms (Chen et al., 2020; Ciofu et al., 2017; Lidor et al., 2015).

Method

Isolates Collection

The 10 isolates of *P. aeruginosa* was collected from sputum and urine of different patients at different hospitals in Baghdad city.

Biofilm Formation

The inoculum of *P. aeruginosa* with tryptic soy broth and 1% glucose was kept at 37 ^{0}C for 24 hr. Then addition of bacterial suspension with 100 µl to the wells of microtitre plate was carried out, after that the microtitre plate was kept at 37 ^{0}C for 24 hr. Again addition of mixture of 100 µl bacterial suspension and 100 µl of 0.002 mM thiazolidinedione to the wells of microtitre plate was achieved, after that the microtitre plate also kept at 37 ^{0}C for 24 hr.

Furthermore, crystal violet with 1% added to the the plate for staining, then the plate was cleaned by DW. OD was measured for each well using ELISA reader at 630 nm. Each test was achieved in triplicate for statistical purposes while the control was used as media without inoculation with bacteria. The isolates were detected as strong, moderate and weak biofilm former relying on optical density of samples (Al-Khazraji, 2023; Al-Sheikhly et al., 2019; Fouad et al., 2021).

Effect of Inhibitor on Planktonic Cells

Addition of 100 µl of bacterial suspension was carried out to 10 tubes each tube with specific isolate kept at 37 0C for 24 hr. Again addition of mixture of 100 µl bacterial suspension and 100 µl of 0.002 mM thiazolidinedione was achieved to each 10 tubes each tube with specific isolate kept at 37 0C for 24 hr. For measuring OD of each sample, ELISA reader with wavelength of 630 nm was used.

Bioinformatics Analysis

QSCR DNA sequence for the isolate under the study was extracted from NCBI website and https://pubmlst.org. Alignment of DNA and protein sequence was achieved by using CLUSTAL Omega program while Expasy tool was used to change DNA to amino acid sequence. Then SNAP program was used to detect type of mutation as synonymous and non-synonymous mutation and Position of variable amino acids sequence was detected in conserved domain by NCBI . Finally, the tree was constructed using PhyML program.

Results

Biofilm formation for the 10 isolates of P. aeruginosa showed that 50% of isolates did not form biofilm while 40% of isolates from weak biofilm and 10% of isolates were moderate biofilm producer. However, the effect of the thiazolidinedione inhibitor on biofilm construction was studied with 0.002 mM concertation. Biofilm was constructed for the isolates with inhibiter in concentration 0.002 mM and the result showed that 40% of isolate were weak biofilm producer and 50% of the isolates were moderate biofilm producer and 10% of isolates were strong biofilm producer (see Figure 1). There was significant difference in increasing the isolates to form biofilm in addition of thiazolidinedione inhibitor with P-value equal 0.0003.

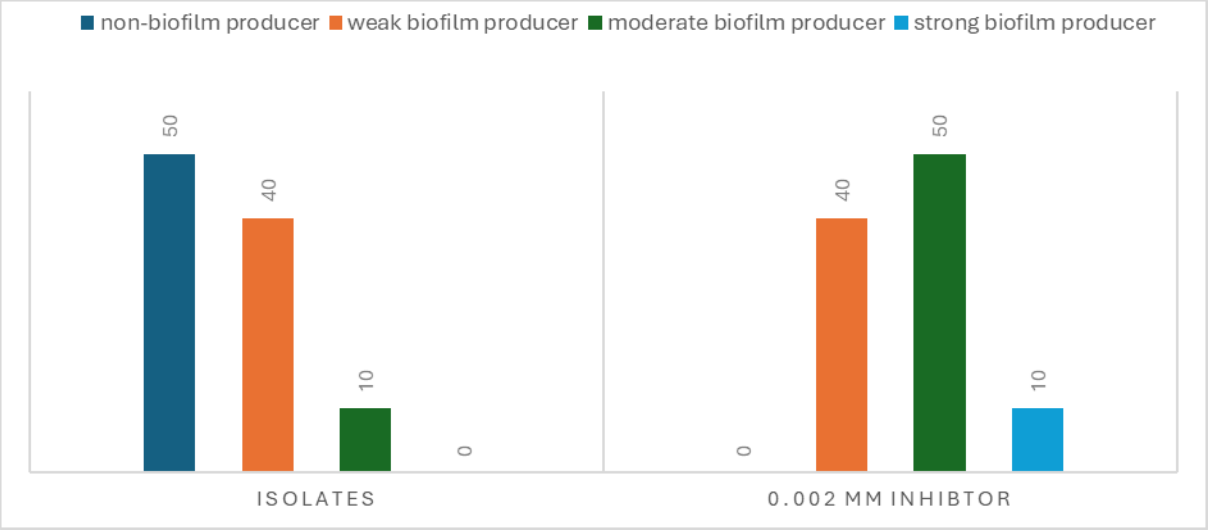

Figure 1. Schematic Representation of Biofilm Scheme for the Isolates without Inhibitor and Isolates with Inhibitor with 0.002 mM Concentration

QscR gene encodes for protein that binds with repressor and activate the transcription of LasI and rhI genes to produce protein known as acyl-homoserine lactone synthase that participate in generation signal molecules called autoinducer that stimulate formation of biofilm. The addition of thiazolidinedione inhibitor increases the ability of strains to form biofilm and we think this because this inhibitor stimulate mutation in QscR gene and produce structural change in protein that prevent binding thiazolidinedione inhibitor with protein encoded by QscR gene therefore QscR protein binds with repressor and production of acyl-homoserine lactone synthase to

form biofilm.

Effect of thiazolidinedione inhibitor with 0.002 mM on planktonic cells was observed and the result showed that there was no significant effect for thiazolidinedione inhibitor on planktonic cells (see Figure 2).

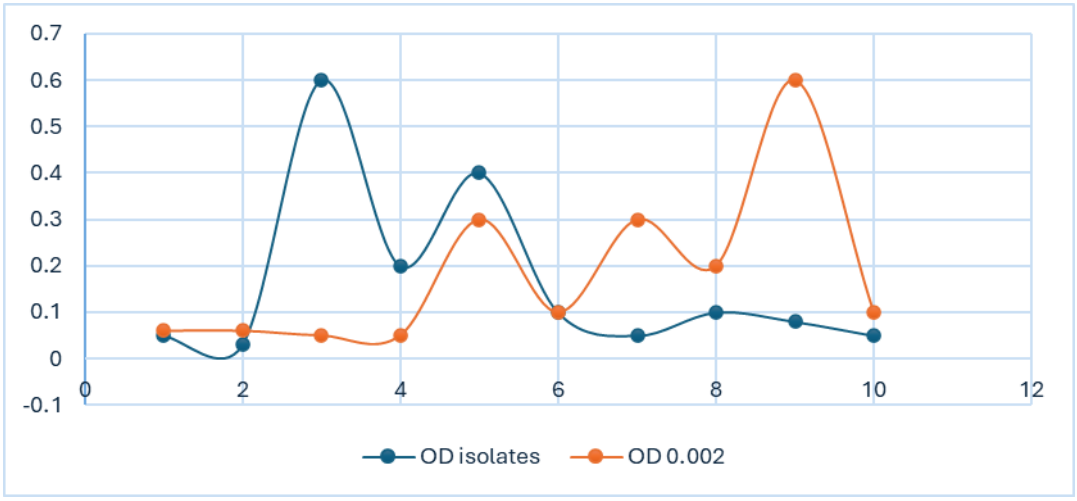

Figure 2. The Effect of Thiazolidinedione Inhibitor with 0.002 mM on Planktonic Cells

Depending on the fact that thiazolidinedione generated genic variation in QscR gene that may help in formation of biofilm, therefore we intend to investigate the genetic variation in QscR in different strains collected from different patients in USA 2017 and the sequence of the QscR gene of different strains were taken for website (See material and methods). Analysis of genetic varaition showed that there were 9 subsitiution but no indel was detected and analysis of variation in protein showed there was no change in any amino acid (see Figure 3)

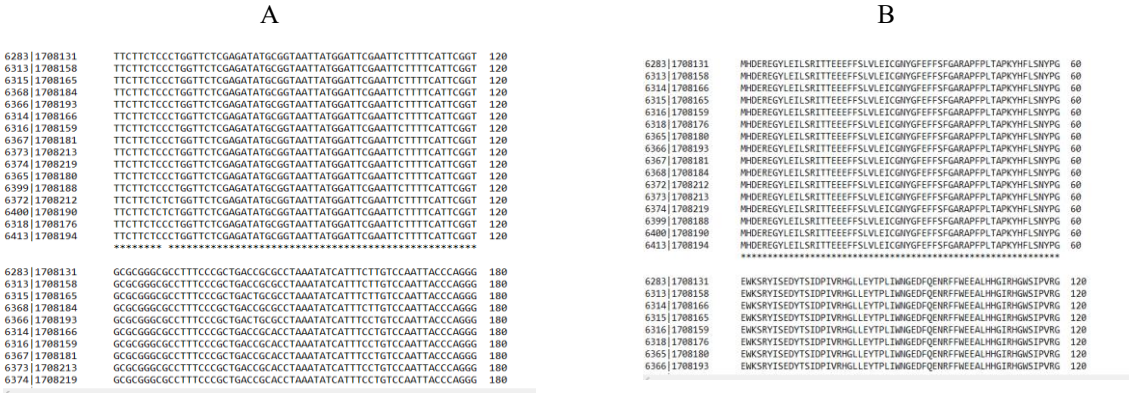

Figure 3. Alignment of DNA and Amino Acid Sequence for QSCR Gene

Analysis showed 9 synonymous change while non-synonymous was not detected. QscR gene codes for a protein that binds with repressor and activate the genes that important for the synthesis of PAI consisting of homoserine lactone, an autoinducer molecule which enhance bacterial cell to accumulate with each other and trigger the formation of biofilm.

Table 1. Codon Number, synonymous or Non-synonymous Changes

codon	synonymous	non-synonymous	a.a. changed
23	Found	Not found	
48	Found	Not found	
49	Found	Not found	
55	Found	Not found	
82	Found	Not found	
169	Found	Not found	
174	Found	Not found	
208	Found	Not found	
230	Found	Not found	

All changes were synonymous and 5 of them were located within the AutoindIbind superfamily domain and 1 was located within the HTH superfamily. Most change were located within domain and all the change were synonymous, this indicate the protein coded by QscR was not change therefore it can binds with repressor and activate the the ability of the bacterial cell to form biofilm (Figure 4).

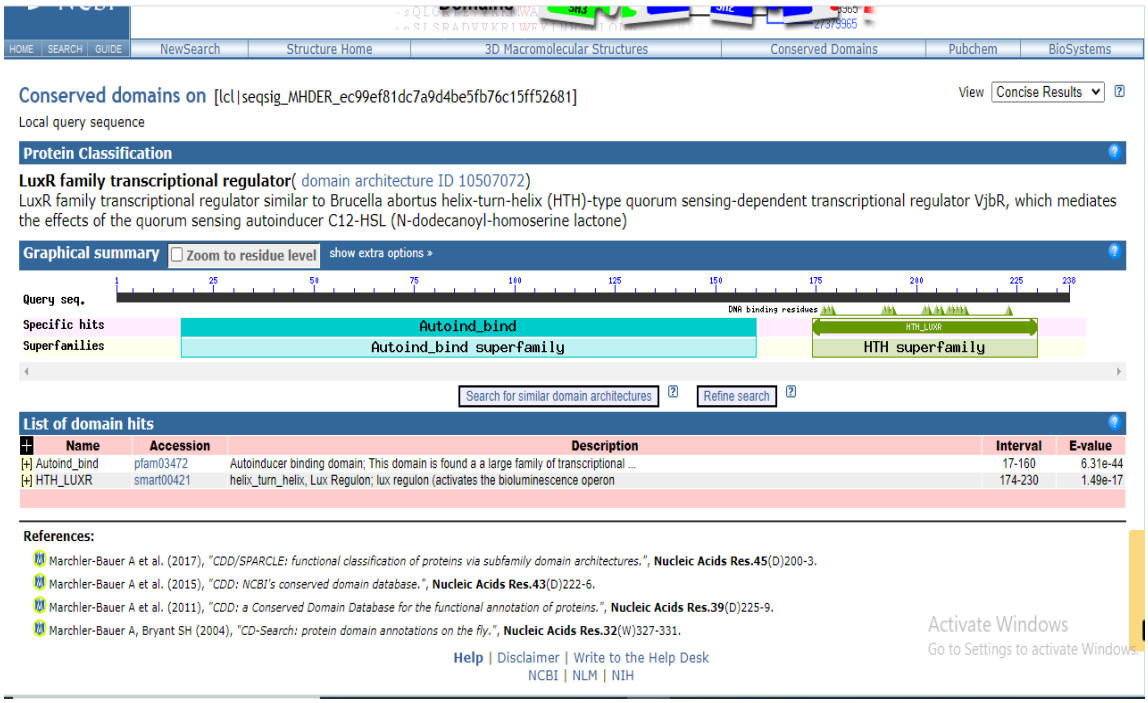

Figure 4. Conserved Domain Database Fro QSCR Protein

The tree showed two clusters were constructed and each cluster has many isolates, in addition in each cluster the isolates n6372_1708212, n6315_1708165 and n6314_1708166, n6366_1708193 and n6313_1708158 which taken from urine tract were cluster with isolates which are taken from sputum sample this indicate the isolate travel from sputum to cause UTI infection (see Figure 5).

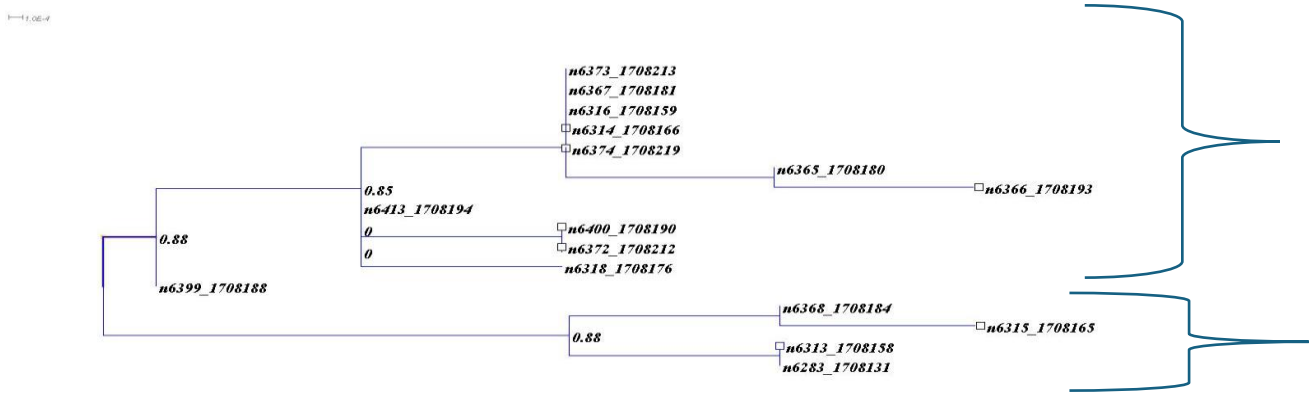

Figure 5. Phylogenetic Tree for the DNA Sequence of QSCR Gene

Conclusion

The conclusion of our study was mutation in QSCR gene may play important role in construction of biofilm in P. aeruginosa isolates.

We highly recommended that studying of genic variation should have occurred on isolates collected from Iraq.

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Seroprevalence of Herpes Simplex Virus Type 1 And 2 in Albania: An Eight Year Study

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Abstract: An eight-year study (2017-2024) focused on Herpes simplex infection held in Albania included an overall of 10,953 individuals coming from a wide range of ages and collected in private laboratory chain "Intermedica". In association with their clinical background, patients were tested about Herpes simplex 1 or 2 for both fractions of antibodies: IgM (Serion ELISA Classic; HSV1 and HSV2 IgM) and IgG (Roche, Electrochemiluminescence; Elecsys HSV-1 IgG and Elecsys HSV-2 IgG) in sera. Starting from 396 samples in 2017, the number of tests has increased significantly, except for 2019 due to COVID19 pandemic restrictions and reaching 2403 patients in 2024. 31-40 years old was the largest age group tested followed by 21-30 years old with 4701 and 4091, respectively. It was observed that, females had a consistently higher risk of HSV-2 infection compared to males in almost all years. This article will provide an eight-year data analysis, understanding the trend of infection and discussing the Herpes prevalence in our group of study.

Keywords: Herpes simplex, IgG, IgM, ECL, ELISA, prevalence

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Introduction

The herpes virus belongs to the Herpesviridae family, which includes 8 types subdivided into 3 groups: alpha, beta and gamma. In the alpha group, also known as the Alphaherpesvirinae subfamily, are HSV-1, HSV-2, and varicella zoster virus (Whitley, 1996). The herpes simplex virus is an enveloped DNA virus, its infection begins with lesions in the skin or mucosa and replication in epithelial cells subsequently, in the autonomic nerves and finally it lodges in the neuronal ganglia, where it remains latent. There is scientific evidence that HSV-1 mostly causes primary infections, while HSV-2 infections are mostly recurrent and cause genital herpes (Whitley, 1996).

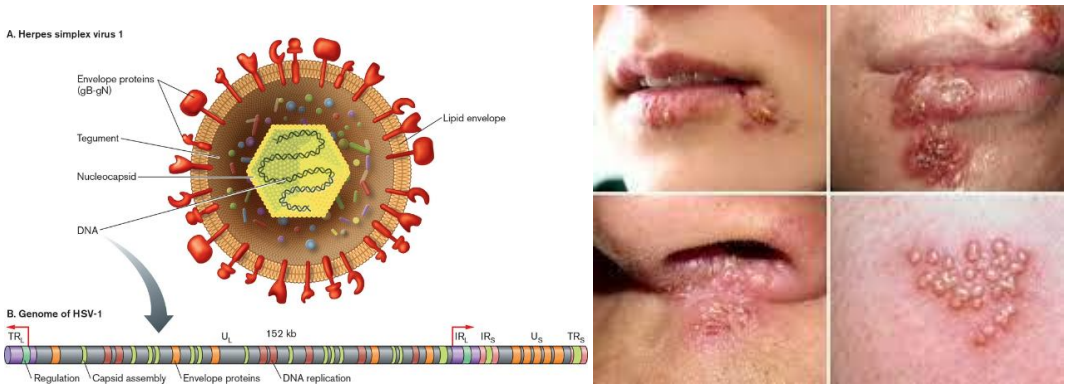

Figure 1. Herpes Simplex Virus 1

Despite this, HSV-1 can also cause genital herpes. Magdaleno et al. observed that, in Spain, there was a higher prevalence of genital herpes caused by HSV-1 in women around 26 years of age. On the other hand, Durukan *et al.* observed that, in Australia, HSV-1 has caused anogenital herpes at a higher rate than HSV-2, especially in young female patients and in men who have sexual relations with men.

HSV - 1

It has been hypothesized that approximately one-third of the world's population has experienced symptomatic HSV-1 at some point throughout his or her lifetime (Saleh et al., 2023). An oral herpes infection causes cold sores on your lips and around your mouth. Some people develop herpetic gingivostomatitis (sores inside their mouths and other symptoms) when they first get infected**.** A genital herpes infection causes sores in your genital area, including the parts you can see (like your vulva or penis) and those you can't see (like your cervix).

Due to HSV infection, various complications can occur such as encephalitis**,** keratitis, or more organs in your chest and belly can be effect from HSV, including your esophagus (herpes esophagitis), lungs (HSV pneumonia) and liver (HSV hepatitis). These types of infections are more likely to affect people who are immunocompromised (*Herpes Simplex Virus (HSV)*, 2025).

The gold standard for diagnosing HSV-1 infection is HSV-1 serology (antibody detection via western blot). The most sensitive and specific mechanism is viral polymerase chain reaction (PCR). However, serology remains the gold standard (Saleh et al., 2023b).

HSV – 2

It remains one of the most common sexually transmitted infections (STI) but continues to be underestimated, given the vague presentation of its symptoms. HSV-2 is transmitted through direct contact with secretions in a seropositive individual who is actively shedding the virus (*Herpes Simplex Type 2*, 2025).

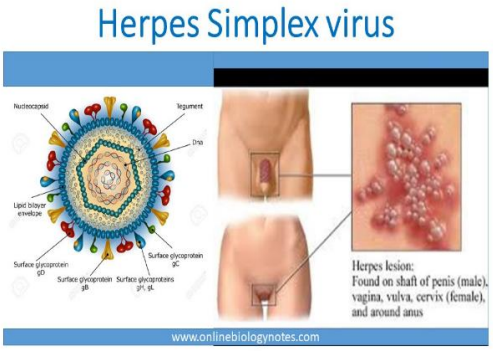

Figure 2. Herpes Simplex 2

The virus preferentially affects the skin and mucous membranes, invading epithelial cells on initial exposure and ultimately replicating intracellularly at that site. After the initial exposure and symptoms are resolved, in 10 to 14 days, on average, the virus then lays dormant in the periaxonal sheath of the sensory nerves of either the trigeminal, cervical, lumbosacral, or autonomic ganglia (Mathew & Sapra, 2024). Antibodies to HSV-2 are often present by the time of puberty, and their presence often correlates with the degree of sexual activity of that individual. More women than men have been reported to be infected, and as expected, the prevalence increases with an increasing number of sexual partners (Schiffer & Corey, 2009c).

Method

From 2017 to 2024, there have been 10,953 specimens of humans suspected of Herpes infection from their physician, are collected and tested in “Intermedica”, a private laboratory in capital of Albania. Blood was collected by VACUETTE® TUBE 7 ml CAT Serum Separator Clot Activator 16x100 red cap-yellow ring, non-ridged, double gel, and then centrifuged 4000 rpm speed for 10 minutes. All of them were tested for herpes simplex type 1 and type 2 IgG/IgM, regarding their clinical manifestations. No exclusion criteria were applied for sampling: all ordered tests were included in the retrospective analysis. The age of tested people varied from 1 to 90 years.

Testing for HSV-1and HSV-2 IgG is accomplished with test ECLIA (Roche, Electrochemiluminescence; Elecsys HSV-1 IgG and HSV-2 IgG). This method represents a reaction with the total duration of assay of 18 minutes. In the 1st incubation, 12 µL of sample, biotinylated recombinant HSV-1and HSV-2 specific antigens, and HSV-1 and HSV-2 specific recombinant antigens labeled with a ruthenium complex) form a sandwich complex, while in the 2nd incubation, after addition of streptavidin-coated microparticles, the complex becomes bound to the solid phase via interaction of biotin and streptavidin.

Next, the reaction mixture is aspirated into the measuring cell where the microparticles are magnetically captured onto the surface of the electrode. Unbound substances are then removed. Application of a voltage to the electrode then induces chemiluminescent emission which is measured by a photomultiplier. Results are

determined automatically by comparing the electrochemiluminescence signal obtained from the reaction product of the sample with the signal of the cutoff value previously obtained by a calibration curve.

Results obtained with the Elecsys HSV-1and HSV-2 IgG assay can be interpreted as follows: Non-reactive: < 1.0 COI, Reactive: ≥ 1.0 COI. Samples with a cutoff index < 1.0 are non-reactive in the Elecsys HSV-1 IgG assay. These samples are considered negative for HSV-1 IgG-specific antibodies and do not need further testing. Samples with a cutoff index ≥ 1.0 are considered reactive in the Elecsys HSV-1 IgG assay.

Testing for HSV 1 and HSV 2 IgM is accomplished with (Serion ELISA Classic; HSV1 and HSV2 IgM). In the ELISA test, the antibodies present in the serum form immune complexes with the antigen bound on the microtiter plate. Unbound immunoglobulins are removed by a washing process. The enzyme conjugate attaches to this complex. Unbound conjugates are removed by the next washing process.

After adding the substrate solution (para-nitrophenyl phosphate) the bound horseradish peroxidase enzyme produces blue dye. The color changes to yellow after adding a stopping solution (sodium hydroxide). The optical density was read using a spectrophotometer (Tecan Sunrise) at wavelength 405 nm and 620 nm reference filters within 10 min after stopping the reaction. The results were expressed in Virotech units (VE) and interpreted as follows: <20negative U/mL; 20-30 U/mL borderline; >30 positive U/mL.

Results

An Overall of HSV IgG and IgM Samples and Age Distribution

In recent years there has been an increase in infertility problems not only in couples who are of a certain age but also, in young couples. One of the leading causes of infertility problems is STI. STI in most cases are asymptomatic, causing harm without being understood here and the determination of the immunological situation, of some STI s such as Herpes simplex 1 & 2, Syphilis, Cytomegalovirus, Mycoplasma hominis and Ureaplasma urealyticum (Wang et al., 2019). In combating STI, it is of great importance to detect them as quickly as possible in the most efficient way possible and with a procedure as easy as possible for the person undergoing detection.

Table 1 An Overall of HSV IgG and IgM

Test	**HSV-1**		**HSV-2**	
Class	IgM	IgG	IgM	IgG
Total of Testing	1885	1558	4193	3361
Positivity	89	1311	29	327

The first word in solving these problems is marker-based immunological tests used in diagnostics. Immunological tests with markers make it possible to quickly measure very small amounts of Ag and At by revolutionizing the diagnosis, monitoring a range of diseases, leading to their rapid treatment. In this study

10953 serums were analyzed for the presence or absence of specific IgG and IgM antibodies, serum testing was performed through the most efficient immunological methods: HSV 1 IgG, HSV 2 IgG via ECL method, brydging principle; HSV 1 IgM & HSV 2 IgM via SERION ELISA classic method, sandwich principle.

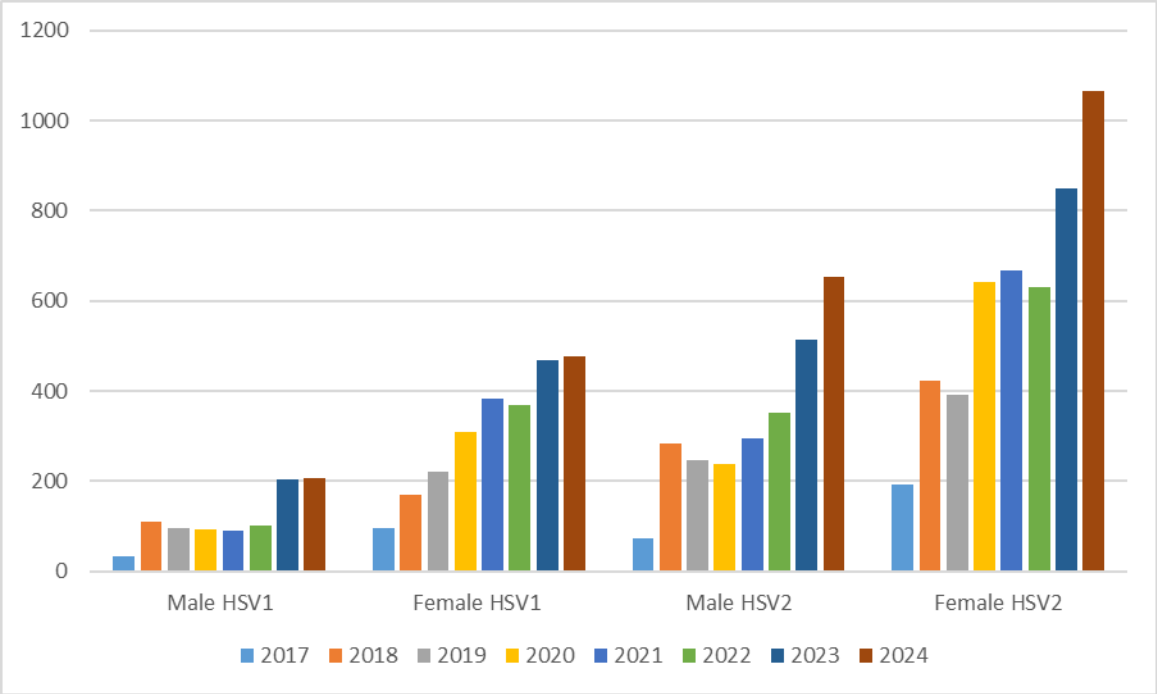

Figure 3. HSV Patient Samples 2017-2024

The data from 2017 to 2024 shows a steady increase in herpes simplex virus (HSV) positivity, particularly for HSV I and HSV II IgG, which indicates past infections. This rise can be attributed to multiple factors, including increased awareness, improved diagnostic methods and changing social behaviors. From 2017-2019 we have a gradual increase. The rise in positive cases during these years suggests improved testing availability and increased public awareness about HSV.

Women have higher recorded HSV positivity rates than men due to biological behavioral, and healthcare-seeking differences. The higher number of females testing positive for HSV-1 and HSV-2 compared to males can be explained by several key factors: Women are more biologically vulnerable to HSV infections due to the larger surface area of mucosal tissues in the genital tract, which makes virus transmission easier. Studies show that male-to-female transmission of HSV-2 is more efficient than female-to-male transmission. Women are more likely to seek regular STI testing during routine gynecological exams, pregnancy checkups, or contraception consultations.

Men often avoid STI testing unless they have symptoms, leading to more undetected cases in males. In many cases, when a woman is diagnosed with HSV, her partner (who may be asymptomatic) does not get tested and for this reason we have an artificially higher number of reported female cases because male partners may carry

the virus but remain untested. Women may feel more responsible for reproductive and sexual health and are more likely to seek medical advice, leading to higher positivity rates. Men, on the other hand, may avoid STI clinics due to stigma, embarrassment, or lack of symptom.

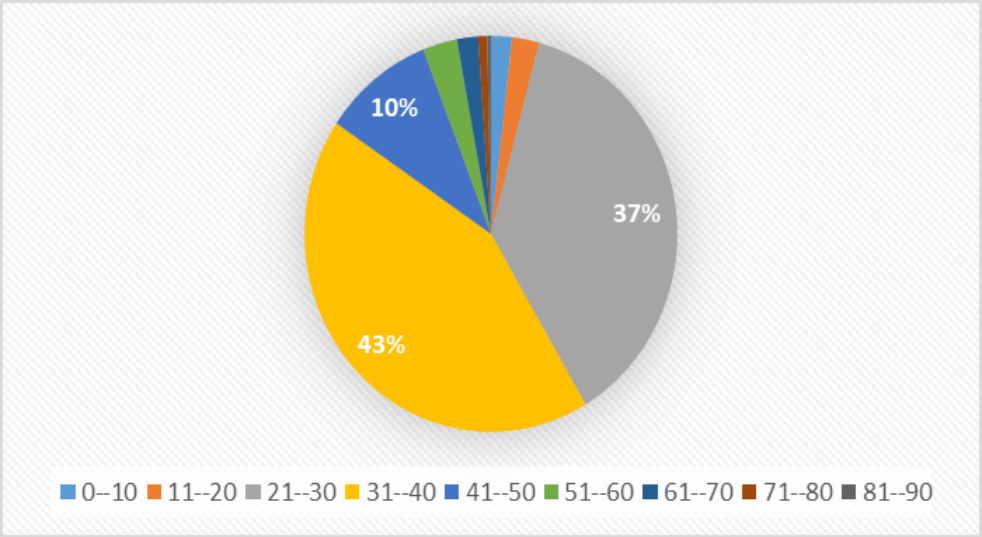

Figure 4. Age Distribution

The increase in HSV positivity from 2017 to 2024 is driven by expanded testing, increased awareness, and external societal factors. While the data indicates a rise in cases, it is largely due to higher detection rates rather than an uncontrolled outbreak. All the people can be affected by the herpes simplex virus.

The high prevalence of HSV positivity among individuals aged 21-30 years and 31-40 years can be explained by several key factors such as increased exposure and social behavior. People in the 21-40 age range are typically more socially active, increasing the likelihood of HSV exposure through close personal and intimate contact. Research suggests that HSV transmission is most common in sexually active adults, especially those in their 20s and 30s.

Many people contract HSV-1 through oral contact and HSV-2 through sexual contact in these age groups, so young adults are more likely to undergo routine STI screenings, which increases the detection rate of HSV. People in their 20s and 30s are more health-conscious and may proactively seek testing after potential exposures. This is also the age range where individuals tend to have multiple partners compared to older age groups, which increases transmission risks.

Children are commonly infected with HSV-1 through non-sexual contact, such as kissing, shared items, and exposure from caregivers. Newborns can acquire HSV-2 during birth if the mother has an active infection. The lowest number of HSV cases in the 71-90 age group is due to reduced exposure, fewer new sexual partners, underdiagnosis, and immune system adaptation over time.

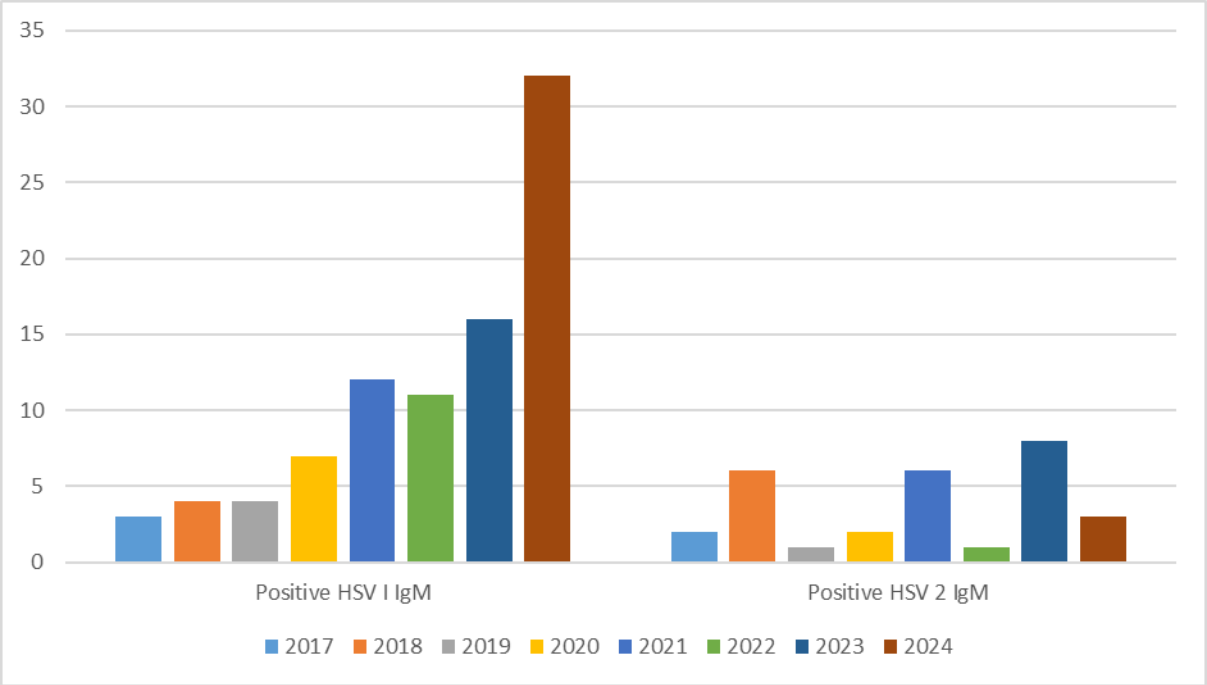

Figure 5. No. of Positive IgM HSV Patient Samples 2017-2024

The data from 2017 to 2024 reveals a steady increase in herpes simplex virus (HSV) positivity, particularly in HSV1 IgM. Over time, more people may have been tested due to greater awareness of herpes and sexually transmitted infections (STIs). Improved diagnostic methods and wider availability of tests had contributed to detect more positive cases. From 2017-2019 we have a gradual increase's rise in positive cases during these years suggests improved testing availability and increased public awareness about HSV. Also from 2020-2022 we have a sharp increase in positivity rates. A notable increase in HSV cases during these years suggests that external factors, such as the COVID-19 pandemic, may have influenced transmission. Changes in social behavior (stress, lockdowns, and altered relationship dynamics) may have affected transmission rates. More people resumed routine STI testing after disruptions in 2020-2021. And from 2023-2024 we have continued high positivity. The ongoing rise suggests that HSV is becoming more commonly diagnosed, possibly due to improved testing protocols and greater public health awareness. Also, urbanization and population growth contribute to higher transmission rates. Medical professionals are increasingly recommending routine HSV testing, leading to higher detection rates.

Many healthcare providers began recommending routine HSV screening alongside other STI tests. Awareness campaigns about asymptomatic HSV transmission encouraged more people to get tested. Some labs introduced more sensitive HSV tests, detecting previously undiagnosed cases.

Conclusion

Many people carry HSV without symptoms but can still transmit the virus. Urbanization and population density

increase transmission rates.Public health initiatives encouraged early testing and awareness.

The increase in HSV positivity from 2017 to 2024 is driven by expanded testing, increased awareness, and external societal factors such as the COVID-19 pandemic.

The 21-40 age group is at the highest risk for HSV exposure due to increased social interactions, higher sexual activity, and routine STI screenings. Encouraging safe practices, regular testing, and awareness can help manage and prevent infections in these age groups.

The lowest number of HSV cases in the 71-90 age group is due to reduced exposure, fewer new sexual partners, underdiagnosis, and immune system adaptation over time.

Women have higher recorded HSV positivity rates than men due to biological behavioral, and healthcare-seeking differences. The higher HSV positivity rate in women is a result of biological susceptibility, healthcare-seeking behavior, partner transmission dynamics, and routine pregnancy screenings.

Encouraging more frequent HSV testing among men could help balance the detection rates and provide a clearer picture of infection distribution.

Recommendations

The rise in HSV positivity from 2017 to 2024 is likely due to a combination of increased testing, better detection methods, and changing social behaviors. While the pandemic may have temporarily influenced trends, the consistent increase suggests that HSV remains a widespread infection. Public health efforts should focus on awareness, early diagnosis, and preventive measures to manage transmission rates effectively.

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