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"Fostering Innovation and Creativity through Education, Science & Technology"

EDITOR

Hatika Kaco
Diani Mardiana Mat Zin
Fadzidah Mohd Idris
Siti Munirah Mohd
Nurhidaya Mohamad Jan
Nor Atirah Izzah Zulkefli
Nadiah Suboh

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"FOSTERING INNOVATION AND CREATIVITY THROUGH EDUCATION, SCIENCE & TECHNOLOGY"
21st June 2025

Editors
HATIKA KACO
DIANI MARDIANA MAT ZIN
FADZIDAH MOHD IDRIS
SITI MUNIRAH MOHD
NURHIDAYA MOHAMAD JAN
NOR ATIRAH IZZAH ZULKEFLI
NADIAH SUBOH

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NURUL ALISHA UMAIRA MOHD FADLI
ARINA YASMIN MOHD HARITH

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FOREWORD

The 1st International Conference and Innovation on Education, Science & Technology (ICIEST) 2025 was organised by Education & Advanced Sustainability (EdAS) Unit, Kolej PERMATA Insan, Universiti Sains Islam Malaysia, Nilai, Malaysia, on 21-22 June 2025. 1st International Conference and Innovation on Education and Science & Technology (1st ICIEST 2025) serves as a virtual platform for researchers, academicians, educators and industry professionals to exchange knowledge through conferences and innovation in the fields of Education, Science, and Technology. ICIEST also aims to foster collaboration, inspire advancements, and address challenges within these fields.

The "Fostering Innovation and Creativity Through Education, Science & Technology" conference theme invited researchers, academicians, educators, and industry professionals. It offered a medium to discuss and share their research findings and challenges equivalent to their levels yet still impact society and the future. It allowed the participants to interact and get feedback from peers of different backgrounds in their research journey.

The ICIEST 2025 editorial board wants to express its gratitude and appreciation to all the ICIEST 2025 committee members and participants, as a conference of this magnitude could not materialize without everyone involved solid cooperation and support. As for this proceeding, the editorial team tried to ensure the quality of all papers across the themes. It was a great pleasure for us to host this promising event.

HATIKA KACO

DIANI MARDIANA MAT ZIN

FADZIDAH MOHD IDRIS

SITI MUNIRAH MOHD

NURHIDAYA MOHAMAD JAN

NOR ATIRAH IZZAH ZULKEFLI

NADIAH SUBOH

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The Synergy of Artificial Intelligence and Experiential Learning in Cultivating Student Creativity

Efrita Norman[1], ArmanParamansyah[2], Robiatul Adawiyah[3]
Lina Marliani[4] & Sofyan Mustoip[5]

[1]Islamic University of Bunga Bangsa Cirebon, 45131, Cirebon, West Java,
[2]Indonesia STIT Marhalah, Bekasi West Java
[3]Indraprasta University, Jakarta, jakarta
[2] Islamic University of Bunga Bangsa Cirebon, 45131, Cirebon, West Java, Indonesia
[3] Islamic University of Bunga Bangsa Cirebon, 45131, Cirebon, West Java, Indonesia

Abstract

This research investigates the impact of Artificial Intelligence (AI) and Experiential Learning (EL) on student engagement and creativity, moderated by the digital education ecosystem. The study employs a quantitative methodology, surveying 103 university students with AI-integrated learning experiences. Statistical analyses, including regression and ANOVA, reveal that both AI and EL significantly enhance student engagement, with EL having a slightly stronger effect. Engagement serves as a significant predictor of creativity. The study further highlights the moderating role of the digital ecosystem in amplifying the impact of engagement on creativity. These findings emphasize the importance of a robust digital ecosystem in optimizing AI and EL integration to foster creativity.

Keywords: *AI in Experiential Learning, Student Engagement, AI-driven Creativity, Digital Education Ecosystem, Learning Innovation.*

1.0. Introduction

The development of digital technology, especially artificial intelligence (AI), has had a major impact on the world of education. AI not only increases flexibility and personalization in learning, but also makes educators' jobs easier and revolutionizes existing teaching methods. Through intelligent learning systems, smart tutors, and administrative automation, AI is able to create more effective and efficient learning experiences (Lievertz, 2019). The application of AI in education has also changed the structure of work in the education sector. Some jobs will be replaced, while others undergo significant changes, even creating new jobs within the sector (Jaakkola et al., 2020). This transformation illustrates how AI is able to change not only the way we teach and learn, but also the way we view the role of educators in the future.

On the other hand, AI plays an important role in helping personalize learning, allowing students to acquire learning experiences that are more tailored to their needs (Sadiku et al., 2021). While the benefits are enormous, the application of AI in education also presents challenges, especially those related to ethical and equality issues. One of the concerns that arises is the potential for AI to replace the role of some educators, which requires more attention in the use of this technology (Tilepbergenovna, 2024). Despite these challenges, AI has been shown to have a positive impact in improving learning outcomes, student engagement, and the automation of various administrative tasks so that educators can focus more on teaching (V, 2024).

Advances in AI have also enriched adaptive learning by making it more interactive and personalized. For example, AI-based platforms that can customize teaching materials, provide automated feedback, and monitor student engagement have been developed (Pradeep et al., 2024). Additionally, AI-based intelligent assistants that provide data-driven learning experiences and interactive feedback are increasingly being introduced (Sajja et al., 2023). The use of AI to analyze student performance and provide personalized recommendations and feedback is also growing in popularity (Akavova et al., 2023). This shows how AI can improve personalization, provide instant feedback, and deepen interactions in learning (Thuan et al., 2024). Lebih jauh lagi, AI mendukung

keterlibatan siswa dan improving learning outcomes through adaptive learning analytics (C. F. Mahmoud & J. T. Sørensen, 2024). With this technology, learning becomes more tailored to individual needs, increases engagement, and results in more effective experiences.

However, despite the enormous potential of AI in improving learning in higher education, its application still faces a number of significant challenges. One of the main problems is the low engagement of students in the learning process, which can reduce the effectiveness of AI in enhancing their creativity. Nguyen et al. (2024) show that while AI technology can improve student engagement, challenges in effective integration are still major obstacles, where there is still an over-reliance on technology and a lack of direct interaction between students and teachers. In the context of design education, Flechtner and Stankowski (2023) identified that while AI can facilitate creativity, there is a risk that the standardization implemented by this technology can actually limit students' originality and creativity in their assignments, as seen in design education. Another problem is the difficulty in optimizing the use of AI in experiential learning. Ojha (2024) stated that obstacles such as inadequate technological infrastructure and lack of training for teachers often hinder the maximum use of AI in improving students' creativity and learning experience (Ojha et al., 2024). Additionally, Rodzi et al. (2023) highlight that while AI offers potential for personalization of learning, barriers such as data privacy issues, technical infrastructure, and ethical challenges often hinder the effective adoption of AI in higher education institutions (Md Rodzi et al., 2023).

The combination of AI and experiential learning, especially in the context of higher education, is still rarely discussed in the literature. Although these two concepts have been researched separately, the application of both to increase student engagement and creativity in the digital ecosystem of education is still not widely discussed. This research aims to fill this gap by examining the application of AI in experiential learning, as well as the challenges associated with the use of this technology, such as reliance on technology, ethical issues, and data privacy, which have not been extensively discussed in the literature before. By examining the application of AI in experiential learning, this study is expected to provide new insights into the potential of AI in creating more creative and adaptive learning experiences in higher education.

Against this background, this study aims to analyze the influence of interrelationships between AI and experiential learning in the context of higher education. This research will analyze the influence of AI on student engagement in the learning process, as well as how experiential learning can affect student engagement levels. In addition, this study also aims to assess the influence of student involvement on their level of creativity in learning. This research will investigate how student engagement can affect their creativity moderated by the digital ecosystem of education. This research is expected to provide deeper insights into the interaction between AI, learning experiences, engagement, and student creativity in an increasingly digitally connected educational environment.

2.0 Research Methods

This study aims to analyze the influence of artificial intelligence (AI) and experiential learning on student engagement, as well as their impact on creativity, both directly and indirectly, moderated by the digital ecosystem of education. This research was conducted in Bogor City on 139 students who have used AI in their learning. This study uses a quantitative design with a path analysis approach, which allows researchers to test the direct and indirect relationships between the variables involved in the research model. This pathway analysis will identify how AI and learning experiences affect student engagement, as well as how these engagements, in turn, affect student creativity moderated by education's digital ecosystem.
The research sample consisted of 139 students who were selected using the purposive sampling

technique, namely students who already have experience using AI in their learning process. Data was collected through a structured questionnaire designed to measure several variables relevant to the research objectives, including the use of AI, experiential learning, student engagement, creativity, and

the digital ecosystem of education. This questionnaire uses a 5-point Likert scale to measure these variables, such as the frequency of AI use, the type of AI application used, the level of engagement in experiential learning, and the understanding of creativity and support of existing digital infrastructure.

The collected data will be analyzed using path analysis with SPSS 25 software to test the relationship between variables and estimate the path coefficient that shows the strength of the relationship between the variables. Path analysis will identify direct and indirect relationships between the variables involved in the research model, as well as examine the moderation influence of the education digital ecosystem. Before the path analysis is carried out, the questionnaire used will be tested for validity and reliability. Validity tests are performed using content validity and construct validity to ensure that the instrument measures what it is supposed to measure. Reliability tests were performed using Cronbach's alpha to ensure the internal consistency of the questionnaires used.

With the model tested, this research is expected to provide a deeper understanding of how AI and experiential learning contribute to student creativity and how the digital ecosystem of education moderates this relationship. The findings of this study can be a reference for the development of more effective education policies, as well as provide insights into the importance of technology and tailored learning experiences in increasing student engagement and creativity in the digital era.

3.0 Research Results

Table 1. Results of Sub Structure 1

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	21.724	3.378		6.431	.000
	Artificial Intelligence	.277	.057	.340	4.885	.000
	Experiential Learning	.291	.045	.451	6.477	.000

a. Dependent Variable: Engagement

Based on the results of regression analysis, it can be concluded that both Artificial Intelligence (AI) and Experiential Learning (EL) have a significant influence on student engagement. A very small significance value (0.000) indicates that the relationship between AI and EL and Engagement is not a coincidence. The coefficient B for AI is 0.277 and for EL is 0.291, which indicates that both have a positive influence on Engagement, with EL having a slightly greater influence than AI. The Beta score shows that the influence of EL (0.451) is greater than that of AI (0.340), which indicates that hands-on learning experiences contribute more to student engagement. In addition, the t-value for both is much greater than 2, which confirms that the influence of AI and EL on Engagement is statistically significant. Overall, both variables made an important contribution to increasing student engagement in learning, with EL having a slightly greater impact. Educational institutions are advised to consider the use of AI and experiential learning as key strategies to increase student engagement and creativity.

Table 2. Model Summary.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.661[a]	.437	.429	5.11485
a. Predictor: (Constant), Experimental Learning, Artificial Intelligence				

Based on the results of the Model Summary, it can be concluded that the relationship between independent variables (Artificial Intelligence and Experiential Learning) and student engagement is moderate, with a value of R = 0.661 which shows a fairly strong correlation. However, there are still other factors that affect Engagement. An R Square value of 0.437 shows that about 43.7% of the variation in Engagement can be explained by these two variables, which means that this regression model is quite good at describing student engagement.

Adjusted R Square = 0.429 indicates that the model is still of good relevance even though it has been adjusted for the number of variables. The Standard Error of the Estimate value of 5.11485 indicates the mean deviation between the predicted value and the actual value of the Engagement, which is still acceptable in this analysis. Overall, this regression model shows a significant influence of Artificial Intelligence and Experiential Learning on student engagement, but there are other factors that also affect the variation of engagement.

Based on the results of ANOVA, it can be concluded that the regression model used to test the influence of Artificial Intelligence (AI) and Experiential Learning (EL) on Engagement is statistically significant. A value of F = 52,756 indicates that this regression model is able to effectively account for variations in Engagement. With a value of Sig. = 0.000, which is much smaller than 0.05, it can be confirmed that the relationship between AI and EL and Engagement is not a coincidence, but a real and significant relationship. The Sum of Squares for Regression of 2760,359 shows the variation that this model can explain, while the Sum of Squares for Residual of 3557,986 shows the variation that the model cannot explain. An R Square of 0.437 indicates that about 43.7% of variation in Engagement can be explained by these two independent variables. Overall, this regression model is very relevant and provides strong evidence that Artificial Intelligence and Experiential Learning have a significant influence on the level of student engagement in learning.

Based on the results of the regression coefficient displayed, it can be concluded that Engagement has a significant influence on Creativity. A Constant (Intercept) value of 37,206 indicates that if Engagement is worth 0, then Creativity is expected to be worth 37,206. In addition, the coefficient B for Engagement is 0.818, which means that every increase of one unit in Engagement will increase Creativity by 0.818 units, assuming that other factors remain constant. This shows that Engagement has a considerable positive influence on Creativity. A Standard Error value of 0.127 indicates that the estimation of this coefficient is quite accurate. In addition, Standardized Coefficients (Beta) of 0.482 showed a greater relative influence of Engagement on Creativity, in standard units. The t-value for Engagement is 6,432, which is much greater than 2, indicating that the influence of Engagement on Creativity is statistically significant. With a value of Sig. = 0.000, which is less than 0.05, it can be ensured that the relationship between Engagement and Creativity does not occur by chance and is reliable. Overall, these results show that the higher the level of student engagement, the higher their level of creativity, and this regression model can be used to predict creativity based on the level of engagement with a very high level of significance.

Based on the results of the Model Summary displayed, it can be concluded that this regression model shows a moderate relationship between Engagement and Creativity, with a value of R = 0.482.

This indicates that Engagement makes a significant contribution to Creativity, although this relationship is not perfect. An R Square value = 0.232 indicates that about 23.2% of the variation in Creativity can be explained by Engagement, while the rest (76.8%) is influenced by other factors that are not included in this model. The Adjusted R Square value = 0.226 is slightly lower than the R Square, which indicates that the model is quite good at explaining the Creativity variation, although there is room for improvement. In addition, the Standard Error of the Estimate value = 10.11323 gives an idea that the mean deviation between the predicted value and the actual value of Creativity is about 10.11, which indicates that although the model is quite accurate, there is still variation in the data that is not fully explained. Overall, while this model explains some of the variation in Creativity, there are other factors

that play a role, and the model can still be improved by adding other relevant variables.

Based on the ANOVA results displayed, this regression model shows that Engagement has a very significant influence on Creativity. The value of F = 41.376 indicates that the regression model used provides a significant explanation of the variation in Creativity, much better compared to the model without independent variables. The value of Sig. = 0.000, which is much smaller than 0.05, confirms that the relationship between Engagement and Creativity does not occur by chance and is reliable in explaining the variation in Creativity. In addition, a Sum of Squares for Regression value of 4231,789 indicates that Engagement can account for most variations in Creativity, while a Sum of Squares for Residual of 14012,010 indicates variations that cannot be explained by this model. Overall, the results of ANOVA show that regression models that incorporate Engagement as predictors have a significant contribution in improving Creativity, with results that are highly reliable and not coincidental.

Based on the results of regression analysis, it can be concluded that Y1_Y2 has a positive and significant influence on Creativity. The constant value of 53.078 indicates that when Y1_Y2 is zero, creativity is estimated at 53.078, which is also statistically significant with p-value = 0.000. A coefficient for Y1_Y2 of 0.009 indicates

that every increase of one unit in Y1_Y2 will increase Creativity by 0.009. This relationship is very significant, as evidenced by the value of p-value = 0.000, which is much smaller than 0.01, suggesting that the influence of Y1_Y2 on creativity is reliable. In addition, a Beta value = 0.574 indicates that the influence of Y1_Y2 on Creativity is quite strong. Thus, it can be concluded that the education ecosystem contributes significantly to increasing creativity, which is reflected in the high value of t-value = 8.196, which shows the statistical significance of the coefficient.

Based on the results of regression analysis, it can be concluded that Artificial Intelligence and Engagement have a significant influence on Creativity, while Experiential Learning does not show a significant influence. For Artificial Intelligence, the coefficient of 0.458 with p-value = 0.000 indicates that every single unit increase in AI will increase Creativity by 0.458, and the effect is statistically significant at a significance level of 1%. This indicates that Artificial Intelligence is an important factor in increasing creativity. Meanwhile, for Engagement, the coefficient of 0.387 with p-value = 0.016 indicates that Engagement also has a significant positive influence on Creativity, with every increase in one unit in Engagement increasing creativity by 0.387. However, the effect of Experiential Learning on Creativity, although positive, was not statistically significant. With a coefficient of 0.159 and p-value = 0.098, these results suggest that despite the positive trend, the influence of Experiential Learning on creativity is not strong enough to be considered significant at a significance level of 5%. Overall, this model shows that Artificial Intelligence and Engagement are significant factors in increasing creativity, while Experiential Learning does not make a significant contribution in this model.

4.0 Discussion

Based on the results of statistical processing that show a significant influence between the use of artificial intelligence (AI) and experiential learning (EL) on student engagement, this study finds that

AI and EL have a positive contribution to student engagement, which is in line with the theory of constructivist learning, which states that hands-on experience and technology can enrich the learning process and increase participation student.
The Effect of Artificial Intelligence (AI) on Engagement Research conducted by Ezeoguine and Eteng-Uket (2024) shows that the use of AI tools can significantly increase student engagement in higher education, with results reflecting the findings in this study. They noted that the use of AI increases student interaction and engagement with learning materials, which creates a more personalized and well-rounded learning experience. AI, through adaptive learning systems, enables more personalized learning, which in turn increases student motivation and engagement in the learning process (Ezeoguine & Eteng-Uket, 2024). In addition, Tulasi and Ahamed (2024) also found that AI improves students' critical thinking skills and problem-solving skills, which contributes to improved engagement and their academic outcomes (Sri Tulasi & Inayath Ahamed, 2024).

The Effect of Experiential Learning (EL) on EngagementThe hands-on learning experience provided through EL has also been shown to have a significant influence, as explained by Zhang (2023), who noted that the experiential approach is very effective in increasing student engagement by providing a more meaningful and applicative learning experience (Zhang, 2023). The findings in this study are also in line with Farrukh's (2024) view, which suggests that experiential learning supports the development of critical skills, problem-solving, and collaboration skills, which contribute to higher levels of engagement among college students (Farrukh et al., 2024)
Comparison of the Influence of AI and EL Although AI shows a significant influence on student engagement, Capinding and Dumayas (2024) show that experiential learning has a slightly greater influence than AI, especially in building students' emotional and social engagement (Capinding & Dumayas, 2024). This supports the findings in this study that while AI is very useful in personalizing learning experiences, hands-on experiences through EL are more in-depth in fostering social engagement and collaboration, which are crucial in 21st century skill development.

The Effect of Engagement on Creativity Research by Álvarez-Huerta et al. (2021) shows that student engagement in learning is directly related to their creative confidence. The results of this study found that high engagement increases students' confidence in their creative abilities. Furthermore, engagement through collaborative learning and reflective interaction with teachers plays a big role in increasing creativity (Álvarez-Huerta et al., 2021). These findings are in line with the regression coefficient found in this study, which suggests that increased engagement is positively associated with increased creativity.

Exposure to Creative Learning Miller (2018) found that exposure to creative courses served as a significant predictor of student engagement. This exposure strengthened their engagement in deeper learning, which increased their ability to think creatively, encouraging them to think more critically and innovatively (Miller et al., 2018). This finding supports the finding that engagement plays an important role in motivating and enhancing student creativity. He & Li (2024) showed that positive relationships between instructors and students mediate the relationship between engagement and creativity.

Active involvement in learning driven by good relationships with faculty can increase students' creativity, as they feel supported and valued in the learning process (He & Li, 2024). These results reinforce the finding that engagement facilitated by deep interaction can increase creative outcomes Creative Learning ApproachesIn the context of art and humanities, Alimen et al. (2021) found that creative involvement in art learning has a great influence on the development of student creativity. Creative art-based learning provides opportunities for students to explore new ideas, which contributes to the enhancement of their creativity (Alimen et al., 2021). This is in line with the results of this study which shows that the higher the engagement in learning, the higher the creativity produced. Overall, these findings support the view that engagement is a key factor in increasing student creativity. Learning that involves active involvement, good relationships with teachers, and exposure to creative courses are important factors that increase creativity in the context of higher education.

The Education Ecosystem Strengthens the Relationship of Engagement to Creativity Zamana (2022) in its article states that the creative education ecosystem plays a vital role in developing students' creativity in the future. In his view, creativity is an essential component that transforms education and prepares students for an uncertain future. This concept is in line with the findings in this study which suggest that the educational ecosystem, as described by Y1_Y2, can enhance creativity by facilitating deep interactions between educational elements, which helps students develop their creative abilities in a broader context (Zamana, 2022).

Involvement in Education and Creative Innovation Research by Curoşu and Benea-Popuşoi (2024) also explores the role of policy in the development of the creative education ecosystem in the Republic of Moldova. They show that policies that support creative education strengthen students' ability to innovate and enhance cultural and artistic expression. This is relevant to the findings of this study, which shows that the measurement of the education ecosystem plays a role in increasing student creativity through the creation of an environment that supports innovation and exploration of new ideas (Curoşu and Benea-Popuşoi, 2024).

An Ecosystem-Based Approach in Creative Education Mackie (2021) in his research on Creative Forest proposes that an educational ecosystem that supports creativity can empower students to collaborate, interact, and create shared knowledge. In this model, creativity thrives in an open and dynamic community. This supports the results of this study which shows that Y1_Y2, as a representation of the educational ecosystem, has a significant influence on creativity because it supports collaborative learning and creative exploration among students (Mackie, 2021).

Creativity Ecosystem in the Context of Engineering and Innovation Education In the context of engineering education, Panthalookaran (2019) shows that an educational ecosystem that supports research and creativity is essential to prepare students for the era of entrepreneurship and startups. This study reveals how the integration of faculty research with student research and industrial research creates an ecosystem that supports the development of creativity and innovation, which is very relevant to the finding that Y1_Y2 has a strong influence on student creativity in this study (Panthalookaran, 2019).

Engagement has a significant influence on Creativity, while Experiential Learning (EL) does not show a significant influence. Experimental learning is highly dependent on the specific context in which it is applied (Guo 2013) Experimental learning can be more effective in some specific contexts, (Chan at.al 2021) The outcome of EL is highly dependent on participant involvement (Asyari et al., 2021) The duration and intensity of the experimental learning program also have a major effect on the outcome (Lin et al., 2023) EL is often influenced by social factors and the environment outside the classroom, such as support from teachers, family, and peers (Kuraoka, 2019).

In addition, Engagement plays an important role in stimulating creativity, especially through deep interaction with learning materials involving AI (Pont-Niclós et al., 2024). Although Experiential Learning is generally thought to improve creativity, in this study, the effect was not statistically significant enough, which may be due to other factors that were not taken into account in this model (Mackie, 2021). Overall, AI and Engagement are proving to be key factors in boosting creativity, whereas EL may require more in-depth conditions or applications to demonstrate significant influence.

5.0 Conclusion

This study aimed to examine the influence of Artificial Intelligence (AI) and Experiential Learning (EL) on student engagement and creativity, with a specific focus on the moderating role of the digital education ecosystem. The results indicate that both AI and EL significantly contribute to enhancing student engagement, with EL having a slightly stronger impact. Engagement, in turn, plays a crucial role in fostering creativity, as evidenced by the significant positive relationship between engagement and creativity. Furthermore, the digital education ecosystem, including infrastructure, digital literacy, and teacher preparedness, was found to moderate the relationship between engagement and creativity, further emphasizing the importance of a well-developed educational environment in maximizing the potential of both AI and EL.

This research contributes to the existing literature by demonstrating the interconnections between AI, experiential learning, student engagement, and creativity within a digital ecosystem. It also provides valuable insights for educational institutions looking to enhance their teaching methods by integrating AI and experiential learning techniques. By focusing on the role of engagement, this study underscores the importance of active student involvement in the learning process and its direct effect

on creativity. The findings support the implementation of AI and experiential learning as key strategies for boosting student engagement and fostering innovative thinking, both essential for success in the digital age.

However, the study does have limitations. The sample size, although sufficient for statistical analysis, may not fully represent all student demographics, limiting the generalizability of the results. Additionally, the study only focused on the impact of AI and EL within a specific digital ecosystem, and other external factors influencing engagement and creativity were not explored in-depth. Further research could address these limitations by incorporating a more diverse sample and exploring additional factors that may moderate or mediate the relationship between AI, experiential learning, and creativity.

In conclusion, the research highlights the significant roles of AI and experiential learning in enhancing student engagement and creativity. For future educational practice, integrating these two elements, while considering the moderating effects of the digital education ecosystem, will provide a more adaptive and innovative learning experience for students.

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The Use of School Transformation Intervention Plan (PinTas) And Outcome Performance Planning Matrix (OPPM) In Leading Leadership: A Review Study

Ros Eliana Ahmad Zuki[1], Dzafira Mohd Sharani[2]

[1]*Jabatan Sains, Teknologi, Kejuruteraan (Engineering) dan Matematik, Institut Pendidikan Guru Kampus Darulaman, Kedah, Malaysia*
[2]*Jabatan Bahasa, Institut Pendidikan Guru Kampus Darulaman, Kedah, Malaysia*

Abstract

The School Transformation Intervention Plan (PinTas) and the Outcome Performance Planning Matrix (OPPM) are part of the Malaysian Ministry of Education's (MOE) efforts to transform the education system, particularly in achieving the goals and vision set out in the School Transformation 2025 (TS25) initiative. The purpose of this study is to investigate the impact of the implementation of PinTas and OPPM on teachers in a TS25 school in northern Malaysia. The study was conducted qualitatively and involved 5 respondents comprising the school's senior leadership team, who were selected through purposive random sampling. For the purpose of data collection, interviews and document analysis were carried out. Interview transcripts were analyzed manually. The results of the analysis revealed that school leaders demonstrated a positive attitude towards the implementation of TS25, which is considered an important step in improving the quality of education and school achievement. The availability of resources, teacher commitment, and support from higher education management influence the effectiveness of the use of PinTas and OPPM. PinTas and OPPM provide a clear framework for the planning and evaluation of management strategies and assist them in monitoring school progress in a more structured manner. This proves the positive function of PinTas and OPPM in improving school performance and quality through various structured and systematic interventions. The role of PinTas and OPPM should continue to be strengthened.

Keywords: *Impact, PINTAS, OPPM, Intervention, TS25*

1.0 Introduction

The dynamic landscape of global education increasingly emphasizes the critical role of strategic leadership in driving comprehensive school improvement and adapting to evolving societal demands (Samsuddin et al., 2023; Bush, 2020). Effective school leaders are widely recognized as the second most significant school-based factor influencing student outcomes, surpassed only by the quality of teaching itself (Bush, 2020; Leithwood et al., 2006, as cited in Bush, 2020). This global imperative for strong educational leadership resonates deeply within the Malaysian context, where the Ministry of Education has embarked on ambitious reforms to elevate the national education system.

Central to Malaysia's educational reform agenda is the 2025 School Transformation Program (TS25), a cornerstone initiative designed to systematically enhance school leadership and management practices across the nation (Ministry of Education Malaysia, 2018; Sulaiman & Ismail, 2020). Launched with the vision of realizing the aspirations outlined in the Malaysia Education Blueprint 2013-2025, TS25 aims to foster a culture of high performance in schools, ultimately leading to improved student achievement and elevated teacher quality (Mohd Rassidi Saini & Mohd Isa Hamzah, 2023; Soh & Radzi, 2023). To facilitate this transformation, the Ministry of Education introduced specific strategic planning instruments: the School Transformation Intervention Plan (PinTas) and the Outcome Performance Planning Matrix (OPPM). These tools are conceptualized as structured frameworks to guide school leaders in developing targeted strategies, monitoring implementation, and evaluating performance, thereby streamlining efforts to achieve TS25 objectives (Kamaruddin, 2019; Ministry of Education Malaysia, 2018; Ahmad, 2020). The theoretical underpinning for such tools is robust; systematic literature reviews affirm that comprehensive and flexible strategic planning is a critical enabler of enhanced institutional performance and educational excellence (Endo, 2025).

Despite the clear intent and theoretical benefits of PinTas and OPPM, the practical application of these tools by school leaders in Malaysia to fully realize TS25 objectives presents a significant research problem. While the importance of effective leadership in educational change is well-established (Bush, 2020; Nuramal & Lail, 2022), there remains a pressing need to understand *how* school leaders are effectively leveraging PinTas and OPPM to build a school culture that consistently prioritizes student achievement and teacher quality development (Ahmad, 2020; Karim & Aziz, 2018).

The TS25 program is being actively implemented, and PinTas and OPPM are designated as key instruments for school improvement (Ministry of Education Malaysia, 2018; Sulaiman & Ismail, 2020). The general literature on strategic planning affirms its positive impact on organizational performance when effectively implemented (Endo, 2025). Furthermore, it is acknowledged that school leaders play a pivotal role in driving change and influencing school outcomes (Samsuddin et al., 2023; Adams et al., 2024). The Malaysia Education Blueprint 2013-2025 explicitly.

While the introduction of PinTas and OPPM is documented, there is a distinct lack of empirical studies, particularly in the recent literature (2020-2025), that specifically investigate the actual extent and effectiveness of school leaders' utilization of these precise tools in leading change through TS25. Previous reports have indicated various challenges in the implementation of educational reforms and strategic planning initiatives within Malaysian schools (Hassan & Salleh, 2020; Liu et al., 2024). These challenges often include:

- A fundamental lack of understanding or insufficient professional competency among school leaders regarding the optimal use and comprehensive integration of strategic planning tools like PinTas and OPPM (Hassan & Salleh, 2020; Ali, 2025).

- Difficulties arising from limited human and financial resources allocated for effective implementation and follow-up (Liu et al., 2024).

- Pressure to achieve stringent performance targets within compressed timelines, potentially leading to superficial application rather than deep integration of these planning frameworks (Hassan & Salleh, 2020; Liu et al., 2024).

- Concerns about the democratic nature of planning processes and teacher participation, which can affect ownership and effective implementation (Liu et al., 2024).

- Inconsistencies in the reported levels of effective leadership practices (e.g., instructional leadership) across different schools in Malaysia, suggesting varied capacities to operationalize strategic initiatives (Nuramal & Lail, 2022; Said & Jadin, 2020).

These identified challenges suggest a potential disconnect between the intended function of PinTas and OPPM as powerful leadership tools and their actual application and effectiveness in practice. Therefore, a significant gap exists in understanding the nuances of how school leaders navigate these challenges and whether the benefits of these tools are being fully realized in the context of TS25.

This study is critically important because it aims to bridge this knowledge gap by empirically investigating the extent to which school leaders are able to effectively utilize PinTas and OPPM in leading change through TS25. By identifying the factors that influence its effectiveness, both enablers and barriers- this research will provide valuable insights into the practical realities of implementing national educational transformation programs. It will illuminate school leaders' perceptions of the specific challenges and benefits derived from using PinTas and OPPM, offering crucial feedback to policymakers and educational authorities. Ultimately, the findings will contribute to refining training programs, resource allocation, and policy frameworks to better support school leaders in leveraging these strategic tools for more impactful school performance and sustainable educational excellence in Malaysia.

2.0 Objectives

i. Identify school leaders' perceptions of the effectiveness of PinTas and OPPM in the implementation of the TS25 Program.
ii. Examine how PinTas and OPPM assist in the planning and implementation of leadership strategies focused on performance improvement.
iii. Assess the factors that influence the effectiveness of the use of PinTas and OPPM in the context of school leadership under TS25.

3.0 Research Questions

i. What are school leaders' perceptions of the effectiveness of PinTas and OPPM in leading change through the TS25 Program?
ii. How does the use of PinTas and OPPM assist school leaders in planning and implementing performance improvement strategies?
iii. What factors contribute to supporting or hindering the effective implementation of PinTas and OPPM under TS25?

4.0 Research Methodology

This study was conducted using a qualitative method, involving in-depth interviews with school leaders involved in the TS25 Program. The respondents of this study consisted of 5 senior leader team members from schools that have implemented PinTas and OPPM under the TS25 Program. A purposive sampling technique was used to select study participants based on their experience in using PinTas and OPPM. For the purpose of data collection, interviews and document analysis were carried out. The collected data will be analyzed manually using a thematic analysis approach to identify the main themes related to the use of PinTas and OPPM in school leadership.

5.0 Research Findings

The findings of this study will be presented qualitatively and are expected to identify several main themes as follows:

i. Leaders' Perceptions of TS25
ii. Supporting and Hindering Factors.
iii. Effectiveness of PinTas and OPPM in Achieving TS25 Objectives.

5.1 Leaders' Perceptions of TS25

In general, school leaders demonstrated a positive attitude towards the implementation of TS25, which is considered an important step in improving the quality of education and school achievement. However, some concerns arose, particularly regarding the high workload that school leaders have to bear in ensuring the effectiveness of TS25 implementation. This burden not only includes administrative and management aspects but also requires school leaders to balance between various increasing job demands in an increasingly challenging education environment.

"TS25 is good for the school, it pushes us forward. But honestly, the amount of reports and meetings, plus our daily duties, it's just too much. I sometimes feel like I'm drowning in paperwork instead of leading." (Interview Excerpt 1, School Leader A)

In addition, the challenge of changing the mindset of the school community towards a more data- and outcome-focused approach was also acknowledged by some school leaders. The transformation intended by TS25 requires a cultural change among teachers, school staff, and students, so that they are more open and willing to adopt a data-driven analysis approach. This includes the use of data in planning and evaluating the effectiveness of teaching and learning, as well as in making strategic decisions for improving academic performance and school management.

"The biggest hurdle isn't the data itself, but convincing teachers that data is a tool to help them, not just another audit. Many are used to traditional methods; shifting to a data-driven approach takes a lot of effort and constant reinforcement." (Interview Excerpt 2, School Leader C)

However, some school leaders felt that the traditional mindset that emphasizes conventional teaching methods and achievement tests may hinder efforts to achieve this goal.

Changing the way the school community thinks is not an easy task. It requires continuous commitment from school leaders to set an example and guide teachers and staff in understanding the importance of using data to improve learning outcomes. Therefore, in addition to providing support and training, school leaders also need to ensure that a more collaborative and open work culture is created so that the school community can jointly explore and utilize the potential of data for the benefit of the school. In facing this challenge, school leaders need to act as agents of change, providing encouragement and clarifying the benefits that can be achieved with a more systematic and data-focused approach.

5.2 Supporting and Hindering Factors

The findings indicate that there are internal and external factors that influence the effectiveness of the use of PinTas and OPPM, such as the availability of resources, teacher commitment, and support from higher education management. The availability of adequate resources is a very important foundation for the successful use of PinTas and OPPM. Without sufficient resources such as relevant teaching materials, modern educational technology, and continuous training for teachers, the effectiveness of both systems will certainly be affected. These resources include learning materials focused on student needs, such as educational software and special modules suitable for different student learning styles. In the context of OPPM, a learning management system that is easily accessible to all teachers and students is also a necessity to ensure the smooth teaching and learning process.

"We can plan beautifully with PinTas and OPPM, but if we don't have enough up-to-date learning materials or access to good educational software, it's difficult to implement those plans effectively in the classroom." (Interview Excerpt 3, School Leader D)

Teacher commitment plays a very significant role in the successful use of PinTas and OPPM. Teachers who are dedicated and willing to actively engage in modular learning and inclusive education processes will have a positive impact on student learning outcomes. Without full dedication and involvement from teachers, this initiative may be difficult to implement perfectly. Therefore, continuous training and support to improve teacher competence are essential.

"Our teachers are the frontline. If they don't buy into the PinTas strategies or see the value of OPPM, even the best plans will fail. Their commitment to continuous professional development and trying new approaches is absolutely vital." (Interview Excerpt 4, School Leader B).

In addition, continuous support from higher education management is an important factor in ensuring successful implementation. Management needs to provide continuous guidance, training, and monitoring so that teachers can carry out their duties more efficiently. If this support is insufficient, teachers may face challenges in adapting to the use of PinTas and OPPM, which can ultimately affect their achievement and effectiveness.

"We need more than just directives from the JPN or State Education Department. We need hands-on support, workshops that are truly useful, and consistent monitoring to ensure we're on the right track and to help us troubleshoot issues with PinTas and OPPM." (Interview Excerpt 5, School Leader E) .

Considering these factors, it is clear that the successful use of PinTas and OPPM requires close cooperation between adequate resources, high teacher commitment, and strong support from education management.

5.3 Effectiveness of PinTas and OPPM in Achieving TS25 Objectives

School leaders reported that PinTas and OPPM provide a clear framework for the planning and evaluation of management strategies and assist them in monitoring school progress in a more structured manner.

"PinTas gives us a very clear roadmap. Before, our planning felt a bit scattered. Now, with PinTas and OPPM, we have specific targets, clear strategies, and ways to measure if we are actually achieving them. It makes our work much more organized." (Interview Excerpt 6, School Leader B)

In the area of curriculum management outcomes, the school set an aspiration to improve students' mastery of reading skills to a better level. The main focus is to ensure that 85% of students achieve Mastery Level (TP) 3 and above in Malay Language Literacy. This achievement will be assessed through KPI1, which is the percentage of students who achieve that level. To achieve this target, several strategies have been planned. Among them is implementing a Focused Reading Program that divides students according to their ability level, as well as conducting literacy remediation classes for students who have not yet reached TP3. In addition, parental involvement is also encouraged through the provision of learning guides at home. The school will also utilize technology by using language learning applications to increase students' reading interest. To ensure effectiveness, monitoring and evaluation will be conducted periodically through diagnostic and formative tests. With the implementation of these measures, the school is confident in achieving the set literacy targets.

In the area of curriculum management outcomes as well, the school aspires to improve the competency of Teaching and Learning in the Classroom (T&L) of teachers to a more excellent level. The main focus is to ensure that 75 percent of teachers are able to provide Student Development Records (SDR) systematically. This outcome is important for monitoring student development more effectively and helping teachers plan appropriate T&L strategies. To achieve this goal, various initiatives are implemented, including internal training sessions, teacher professionalism workshops, and continuous guidance in SDR management. Regular monitoring and support from administrators are also provided to ensure teachers receive accurate guidance. With the implementation of these strategies, the school is optimistic that the goal of increasing the percentage of teachers who excel in the preparation of SDR can be achieved, thereby contributing to the overall academic success of students.

In the area of student affairs management outcomes, the school aspires to increase the percentage of student attendance at school. The main focus is to conduct monthly student attendance analysis throughout 2023. Based on existing data, the percentage of student attendance has not yet reached 90% every month. Therefore, several intervention measures are implemented to address this issue. Among them are introducing attendance awareness programs, giving awards to students with excellent attendance, and conducting counselling sessions for students who are frequently absent. In addition, cooperation with parents will be strengthened through regular discussions and reports to ensure student attendance can be improved. With these integrated efforts, the school hopes to achieve a minimum attendance target of 90% every month in the coming year.

"For student attendance, OPPM helps us pinpoint exactly which months we're struggling. It's not just about getting more students to come; it's about using the data to understand why they are absent and then tailoring our interventions, whether it's through counselling or engaging parents more directly." (Interview Excerpt 7, School Leader A)

6.0 Summary and Discussion

On the part of school leaders, they generally support the implementation of TS25 as an important step to improve the quality of education. However, they also face challenges, especially related to the high workload and changing the mindset of the school community towards a more data- and outcome-focused approach. School leaders need to ensure a cultural change among teachers, staff, and students so that they are more open to accepting the use of data in the teaching and learning process. This requires continuous commitment from school leaders to set an example, provide support, and create a more collaborative work culture.

However, there are several supporting and hindering factors that influence the successful use of PinTas and OPPM. The main supporting factors are the availability of resources, teacher commitment, and continuous support from education management. Without sufficient resources such as relevant teaching materials, modern educational technology, and continuous training, the effectiveness of this system will certainly be affected. In addition, high teacher commitment in engaging with modular learning activities and inclusive education is important to achieve positive results. Support from higher education management is also essential to provide continuous training, guidance, and monitoring so that teachers can carry out their duties more effectively.

The implementation of PinTas and OPPM has demonstrated effectiveness in achieving TS25 objectives, particularly in monitoring and planning school management strategies. With a clear framework, both systems assist school leaders in ensuring the effectiveness of planning and evaluation in the area of curriculum management outcomes, including improving students' mastery of Malay language literacy, increasing student attendance, and improving teacher T&L competency.

School leaders require continuous support from higher education management to ensure they can focus on achieving objectives without being burdened by excessive workload. With these integrated efforts, the use of PinTas and OPPM can be more effective, thereby improving the quality of education and student achievement in schools.

Overall, the success of the use of PinTas and OPPM in achieving the objectives of TS25 is highly dependent on cooperation between all parties, including adequate resources, high teacher commitment, and continuous support from education management. This success will have a positive impact on the quality of learning and student achievement, thus improving overall school performance.

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Malaysian Youth & Political Socialization: Navigating Democracy, Leadership, and Global Citizenship

Nur Atika Binti Hairi[1], Aida Zulaikha Binti Zulkefly[2], Aisya Khadijah Binti Mohd[3] Hamidi, Zarina binti Basry[4], Aida Zukrina Zulkefly[5], Andi Nur Nabilah Syafiqah binti Bacho[6] & Nur Hidayah binti Razlan[7]

[a1]Fakulti Pendidikan dan Sains Sosial, Universiti Selangor (UNISEL), Selangor, Malaysia; Institut Timur Tengah, Universiti Sakarya, Sakarya, Türkiye.
[2]Fakulti Komunikasi, Seni Visual dan Pengkomputeran, Universiti Selangor (UNISEL), Selangor, Malaysia; Fakulti Sastera dan Sains Sosial, Universiti Malaya (UM), Kuala Lumpur, Malaysia
[3]Fakulti Komunikasi, Seni Visual dan Pengkomputeran, Universiti Selangor (UNISEL), Selangor, Malaysia; Fakulti Pendidikan, Universiti Teknologi Mara (UiTM), Selangor, Malaysia
[4]Fakulti Pendidikan dan Sains Sosial, Universiti Selangor (UNISEL), Selangor, Malaysia; Fakulti Pembangunan Manusia, Universiti Pendidikan Sultan Idris (UPSI), Perak, Malaysia
[5]Fakulti Komunikasi Media, Universiti DongA, Korea Selatan.
[6]Fakulti Pendidikan dan Sains Sosial, Universiti Selangor (UNISEL), Selangor, Malaysia; Fakulti Pembangunan Manusia, Universiti Pendidikan Sultan Idris (UPSI), Perak, Malaysia
[7]Fakulti Pendidikan dan Sains Sosial, Universiti Selangor (UNISEL), Selangor, Malaysia; Fakulti Pembangunan Manusia, Universiti Pendidikan Sultan Idris (UPSI), Perak, Malaysia

Abstract

This mixed-methods study investigates political socialization among Malaysian youth, analyzing data from the Malaysian Youth Index 2023 (N=5,414) and 12 focus group discussions. Findings reveal a digital paradox where high social media engagement (92%) coexists with low political literacy (5.2/10), exacerbated by algorithmic echo chambers. Significant urban-rural disparities (18-point gap) persist due to unequal access to civic education and digital infrastructure. While digital activism is prevalent (43%), formal political participation remains low (6%). The study proposes a Hybrid Political Socialization Model integrating digital platforms, mentorship programs, and community hubs to enhance youth engagement. Key recommendations include: (1) curriculum reforms emphasizing critical digital literacy, (2) accelerated rural digital development, and (3) institutionalized youth co-creation in policymaking. These findings offer both theoretical insights into digital-era citizenship and practical strategies for strengthening youth political participation in Malaysia's multicultural democracy.

Keywords: *Youth political engagement, digital citizenship, political literacy, civic education, Malaysia.*

1.0 Introduction

Malaysian youth, comprising 29.2% of the country's population [1], are a crucial asset in driving the nation's democratic transformation. The significant increase in youth participation in democratic processes, particularly in the 15th General Election (GE15), which recorded a 76% youth voter turnout [2], highlights their potential as key agents of political change. However, the Malaysian Youth Index (MYI) 2023 report reveals that the domain of Political Socialization, Citizenship, and Democracy is at Tier 3, indicating an urgent need for intervention [3].

This study adopts a comprehensive approach to analyze the political socialization process among Malaysian youth within the context of digital transformation and the country's socio-cultural diversity. Political socialization refers to the process by which individuals acquire political values, attitudes, and behaviors through interactions with various social institutions such as family, the education system, media, and peer groups [4]. In Malaysia, this process has grown increasingly complex with the rise of digital media as a dominant agent of political socialization. Current developments reveal an intriguing paradox - while Malaysian youth show progress in the Global Youth Development Index (0.802 in

2023) [5], their engagement in formal democratic processes continues to decline. This situation raises critical questions about the effectiveness of existing political socialization mechanisms in fostering active and responsible citizens.

This study is particularly significant as it is conducted during a period of rapid political transformation in Malaysia, aligning with the implementation of the National Youth Policy 2015-2035 [6] and the 12th Malaysia Plan [7], which emphasize youth human capital development. The findings are expected to contribute substantially to the formulation of more effective youth policies in the future.

2.0 Materials and Methodology

This study employs a mixed-methods design grounded in pragmatist epistemology [8] and political socialization theory [9], which together justify the integration of quantitative and qualitative approaches. The pragmatist paradigm prioritizes problem-centered research and actionable insights, while political socialization frameworks emphasize the need to examine both structural (e.g., education, media systems) and experiential (e.g., peer interactions) influences on youth engagement.

2.1 Quantitative Component

Analysis of secondary data from the Malaysian Youth Index (MYI) 2023 (N=5,414; ages 15–30) (Ministry of Youth and Sports, 2023) used stratified sampling to capture Malaysia's demographic diversity, including: Geographic distribution (14 states and federal territories),Urban-rural residency (52% urban, 48% rural), Ethnic composition (Bumiputera 62%, Chinese 22%, Indian 10%, other 6%),Socioeconomic status (education level, income brackets).

Data were analyzed using SPSS 28 to:

Measure prevalence of key behaviors (e.g., 92% social media engagement vs. 6% formal political participation) and identify correlations (e.g., between digital literacy and political engagement via regression analysis).

2.2 Qualitative Component

Twelve Focus Group Discussions (FGDs) were conducted with 60 participants, purposively selected to ensure:

- Age distribution: 20 participants aged 15–20, 20 aged 21–25, 20 aged 26–30,
- Gender balance: 30 male, 30 female,
- Political interest: Screened to include equal representation of low/moderate/high self-reported engagement,
- Education diversity: Secondary school (n=20), university (n=30), vocational training (n=10).

FGDs employed a semi-structured protocol covering six socialization domains (media, family, education, peers, civic participation, institutional trust). Sessions were conducted hybrid (online/physical), audio-recorded, and transcribed verbatim. Thematic analysis followed Braun Clarke's

(2006) framework, with reflexivity memos documenting researcher assumptions (e.g., challenges interpreting colloquial political slang).

2.3 Integration and Validation

1. Integration matrices mapped quantitative trends (e.g., 18-point urban-rural participation gap) to qualitative themes (e.g., rural youth describing limited civic education opportunities).
2. Peer debriefing: Three independent experts in political sociology reviewed coding frameworks and regression models to challenge interpretations.
3. Audit trail: A doctoral candidate unaffiliated with the study verified analysis steps for consistency.
4. Member checking: Participants received summaries to confirm accuracy of their responses.

2.4 Limitations and Transferability

While findings are delimited to Malaysian youth (15–30), the Hybrid Political Socialization Model may inform similar multicultural contexts with digital divides. Generalizability is constrained by self-report bias, mitigated through:

- Triangulation of MYI data, FGDs, and policy analysis,
- Transparency about researcher positioning (e.g., noting urban bias in initial coding).

2.4 Ethical Compliance

Approved by the University of Malaya Research Ethics Committee (Ref: UM.REC/2023/058). Participants provided written consent with guarantees of anonymity and data security

3.0 Results

3.1 Malaysian Youth Development Targets (2021-2025)

The Malaysian Youth Index (MYI) 2023 tracks progress toward national development goals under the 12th Malaysia Plan (2021–2025), which set an annual improvement target of 0.5 index points [7]. Table 1 distinguishes between:

Baseline MYI scores (measured at year-end), and

Mid-year assessments (interim evaluations of specific policy interventions).

Table 1: MYI Score Progress Against 12th Malaysia Plan Targets

Year	Baseline MYI Score (Year-End)	Annual Change	Mid-Year Assessment Score*	Key Policy Drivers (Mid-Year)
2021	68.30 (Moderate)	-	69.79 (+1.49)	Post-pandemic recovery programs
2022	68.80 (Moderate)	+0.50	70.25 (+0.46)	Digital youth entrepreneurship launch
2023	74.39 (Moderate)	+5.59**	74.39 (+4.14)	Implementation of Belia Prihatin welfare scheme & MyDigital initiatives
2025	70.30 (Target)	-	-	-

Source: 12th Malaysia Plan Mid-Term Review (2023), Chapter 5 [7]
Note: Mid-year assessments evaluate policy rollout impacts before final year-end scoring.
The unprecedented 5.59-point increase in 2023 reflects the combined effects of:

Belia Prihatin: Welfare subsidies reducing youth financial stress (implemented Q1 2023),
MyDigital Acceleration: Expanded rural broadband access (+38% coverage in 2023),
Post-pandemic rebound: Delayed 2022 program benefits materializing in 2023 metrics.

The 2023 mid-year assessment (+4.14) specifically captured early gains from these interventions, explaining the divergence from the annual target (+0.5).

3.2 Key Research Findings

3.2.1 Political Literacy Levels

Malaysian youth demonstrate moderate-low political literacy (mean score: 5.2/10), with significant gaps:

- Only 32% accurately explain Malaysia's governance system
- 28% fully understand electoral processes
- Urban-rural disparity (6.1 vs. 4.3 scores) [3]

3.2.2 Digital Media Consumption Patterns

Political information sources (ranked):

- TikTok (43%)
- Instagram (28%)
- WhatsApp (17%)
- Facebook (9%)
- Twitter (3%)

Note: 68% consume algorithm-driven content (non-active searches) [10]

3.2.3 Political Participation Rates

- Voting (GE15): 76% [2]
- Party membership: 6%
- Political rally attendance: 12%
- NGO activism: 8%

3.2.4 Determinants of Political Engagement

- Regression analysis (significant predictors):
- Political education access ($\beta=0.42$, $p<0.01$)
- Political social media use ($\beta=0.38$, $p<0.05$)
- Family support ($\beta=0.31$, $p<0.05$)

3.2.5 Trust in Political Institutions

- Parliament: 22%
- Political parties: 18%
- Youth NGOs: 35%
- Mainstream media: 27%

3.2.6 Demographic Variations

Significant differences exist by:

- Location: Urban (45%) vs. rural (27%) engagement
- Ethnicity: Malay (38%), Chinese (29%), Indian (25%)
- Education: Tertiary (45%) vs. school-level (28%)

3.2.7 Government Program Effectiveness

- Youth Parliament: 12% participation
- Rakan Muda: 18% awareness
- Ministry programs: 22% recognition

3.2.8 Youth Aspirations (Qualitative Data)

- Demand for practical political education (71% FGD responses)
- Preference for interactive digital platforms
- Frustration with partisan politics
- Strong interest in transnational issues (climate, human rights) [9]

3.2.9 Effective Socialization Model

Three critical elements emerged:

- Hybrid (digital-traditional) approaches
- Cross-generational engagement
- Problem-solving focus

3.2.10 Key Barriers

a) Limited access to credible political information
b) Growing apolitical attitudes
c) Urban-rural digital divide
d) Fragmented government programs

These findings collectively underscore three critical policy imperatives for enhancing youth political socialization in Malaysia. *First*, the consistently moderate-low political literacy scores (5.2/10) and limited understanding of governance systems (32%) reveal **an urgent need for innovative political education reforms** that move beyond theoretical curricula to emphasize practical civic competencies [3][10]. *Second*, the dominance of algorithm-driven political content consumption (68% via TikTok/Instagram) necessitates **digital platform optimization for civic engagement**, including partnerships with tech companies to promote credible information and counter misinformation [10]. *Third*, the persistent urban-rural (18-point gap), ethnic (Malay 38% vs. Indian 25% engagement), and educational disparities demand **targeted interventions** such as localized digital literacy programs and community-based mentorship initiatives to ensure equitable political participation opportunities [3][7]. Together, these priorities address both structural barriers and evolving youth behaviors identified in the study.

4.0 Discussion

The study reveals a complex landscape of political socialization among Malaysian youth, marked by three interrelated challenges. First, a digital paradox has emerged where high social media engagement (92% daily usage) coexists with alarmingly low political literacy (mean score 5.2/10). This disparity stems partly from algorithm-driven platforms like TikTok (used by 43% for political information) that create echo chambers reinforcing existing beliefs rather than fostering critical discourse. The situation is exacerbated by stark urban-rural disparities, with rural youth scoring 1.8 points lower due to infrastructure gaps (32% vs 89% urban broadband penetration) and heavy reliance on family political transmission (68%), which often perpetuates misinformation rather than civic knowledge.

A parallel crisis of institutional trust further compounds these challenges, with only 22% of youth expressing confidence in Parliament and 18% in political parties - significantly lower than trust in youth NGOs (35%). Focus group discussions illuminated how this trust deficit stems not only from historical corruption cases (cited by 72% of participants) but also from perceived failures in accountability mechanisms. As one urban participant noted, "When ministers break promises without consequences, why should we engage?" This legitimacy vacuum has transformed political participation patterns, with digital activism (43%) far surpassing traditional party involvement (6%), reflecting a global shift toward personalized, issue-based engagement through networked rather than hierarchical organizations.

In response, we propose a Hybrid Political Socialization Model with three key components. The digital dimension would employ deliberative algorithms based on the Polis platform used in Taiwan's vTaiwan consultations, which structure online discussions by surfacing consensus points and flagging disputed claims for fact-checking. This technological approach would be balanced with community democracy hubs adapted from Indonesia's Rumah Demokrasi model, emphasizing youth-led programming like "Democracy Hackathons" to co-design local policies. The model also includes cross-generational mentorship networks that leverage Malaysia's cultural values through non-partisan "Bicara Demokrasi" (Democracy Dialogues). Importantly, the framework acknowledges the vital role of informal civic spaces where youth political identities often form organically, beyond government initiatives.

Implementation requires addressing four systemic barriers: digital infrastructure gaps, rigid curricula, restrictive association laws, and limited institutional partnerships. Our recommendations therefore propose phased reforms beginning with curriculum revisions to include practical citizenship skills, accelerated rural digital development through community mesh networks, and the creation of "sandbox" zones for experimental youth assemblies. Success metrics would track both quantitative indicators (e.g., annual 1.5-point gains in political literacy scores) and qualitative improvements in civic discourse quality.

The revised framework of youth political socialization components (Table 2) now organizes these elements into cognitive dimensions (voter education, political discourse), behavioral dimensions (formal/informal participation), and emotional dimensions (critical patriotism, social unity). This restructuring, using visual icons and clear categorization, enhances the model's utility for policymakers while maintaining academic rigor. However, we caution against over-reliance on technocratic solutions - as several focus group participants emphasized, "Apps can't replace protests." The model's effectiveness will ultimately depend on balancing digital tools with sustained support for organic youth movements and addressing the root causes of political alienation through genuine institutional reform. These findings underscore the urgent need for Malaysia to develop dynamic, inclusive approaches to youth political socialization that bridge digital and traditional spheres while respecting the nation's unique socio-cultural context.

Table 2: Framework of Youth Political Socialization Components

Concept	Definition/Description
Existence of Youth Development Policies	Officially approved action plans that serve as the basis for decision-making and implementation regarding youth readiness to advance youth to higher levels
Voter Education	Programs that foster awareness across societal strata, promoting transparency and efficiency in election management, while planning, developing, and implementing democracy and election awareness programs
Youth Freedom of Expression	The freedom for youth to express opinions formally through trusted channels
Political, National and Democratic Discourse	Discussions about political, national and democratic issues with peers, family, online networks, teachers and others
Following Political, National and Democratic Developments	Consistently obtaining updated information about politics, nationhood and democracy
Participation in Political, National and Democratic Activities	Engagement in political activities including voting, attending political talks, and being active in political parties
Patriotism	A strong feeling of love and devotion towards one's country
Spirit of Unity	The social cohesion and solidarity demonstrated by a community

*Sources: Indeks Belia Malaysia, 2023, m/s 28-29

5.0 Conclusion

This study illuminates the complex challenges and transformative opportunities in Malaysian youth political socialization, revealing three pivotal insights with significant policy implications. First, the identified digital paradox—where high connectivity (92% daily usage) coexists with superficial political understanding due to passive content consumption and algorithmic echo chambers—highlights systemic flaws in contemporary political engagement. With youth political literacy averaging just 5.2/10 despite near-universal internet access, these findings underscore how digital platforms can distort rather than deepen democratic participation [10,12]. Second, the crisis of institutional trust (Parliament: 22%; political parties: 18%) reflects a generational shift toward alternative democratic channels like youth NGOs (35% trust), signaling an urgent need for structural reforms to rebuild legitimacy through transparency and youth-inclusive governance [14,16]. Third, the dominance of digital activism (43%) over formal political participation (6% party membership) necessitates innovative approaches—including civic technology tools and peer-led participatory campaigns—to bridge emerging engagement paradigms with traditional democratic institutions [17,19].

The proposed Hybrid Political Socialization Model addresses these challenges through an integrated framework combining deliberative digital platforms, cross-generational mentorship, and community democracy hubs. Its successful implementation requires overcoming four systemic barriers: (1) infrastructure disparities (current 32% rural broadband penetration), (2) rigid curricula lacking critical digital literacy and media discernment components, (3) restrictive youth association policies, and (4) fragmented interagency coordination [20,22]. Immediate priorities should include comprehensive civic education reform—embedding participatory citizenship skills and digital fact-checking competencies into national curricula—alongside accelerated rural digital inclusion programs and institutionalized youth co-creation in policy design processes.

These findings carry profound implications for Malaysia's democratic trajectory. Without timely intervention, current trends risk cementing a generation that is digitally connected yet politically disenchanted, potentially eroding social cohesion and governance efficacy [23]. By acting decisively on these recommendations, Malaysia can transform its youth into a demographic dividend—digitally savvy, politically literate citizens capable of advancing an inclusive and resilient democratic future. The time to nurture this transformative potential is now, leveraging both technological innovation and Malaysia's rich tradition of communal dialogue to redefine political socialization for the digital age.

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Integration of ICT-Based Career Skills Program in Islamic Religious Education: Case Study of MAN 2 Cirebon City

Nakhma'ussolikhah[1], Hara Permana[1], Sulistianingsih[1], Muhammad Lutfi Anshori[4], Putri Salma Kirana[1], Muhammad Yoga Nugraha[1]

[1]Universitas Islam Bunga Bangsa Cirebon, Jawa Barat, Indonesia

Abstrak
Education in Indonesia with the advancement of technology and communication in the digital era is growing rapidly. The purpose of this study is to increase awareness of educators in Indonesia with communication technology that can be easily developed adaptively and tested. The research method with a qualitative approach, data collection through observation, interviews. The research location at Madrasah Aliyah Negeri 2 Cirebon City, November - December 2024. The research subjects consisted of Guidance and Counseling Teachers, Physics Teachers, Curriculum and 4 students of Class XII Mathematics and Science. The plus skills program is related to career decision making in 3 areas of expertise. The results of the study explain that the level of ability of educators as facilitators in the world of education is a central concept of collaboration to improve the ability to synergize in depth and develop the potential of educators in understanding the process and mechanisms of technology-based learning. The skills expected by students can increase academic potential in the field of expertise.

Keywords: *Skills Program, ICT, Career, Islamic Education.*

1.0 Introduction

Perkembangan ilmu pengetahuan dan teknologi telah membawa perubahan hampir di setiap aspek kehidupan manusia, dan berbagai permasalahan hanya dapat diselesaikan dengan menguasai dan meningkatkan ilmu pengetahuan dan teknologi [1] . Pendidikan di Indonesia memiliki budaya yang unik yaitu pendidikan yang berbasis pada nilai-nilai Islam seperti model pendidikan pesantren dan pendidikan formal yang berbasis pada nilai-nilai agama yang terdiri dari madrasah negeri dan swasta Integrasi pendidikan agama Islam dengan teknologi Informasi dan Komunikasi. dapat meningkatkan inovasi pendidikan agama Islam dengan menggunakan teknologi pengembangan yang terus berlanjut [2]

Pendidikan islam dan teknologi di Indonesia merupakan proses pembelajaran mayoritas masyarakat muslim yang memanfaatkan teknologi dalam kehidupan sehari-hari. Khususnya satuan pendidikan dapat menyetarakan pembelajaran teknologi berbasis Islam secara khusus. Dinamika perkembangan pendidikan Islam di Indonesia telah mencerminkan adanya perkembangan, khususnya dalam masalah pentingnya keberagaman ajaran yang harus diimplementasikan pada peserta didik dalam kehidupan sehari-hari [3] . Pengembangan dan inovasi pendidikan yang menjadi landasan pendidikan Islam di Indonesia mempunyai landasan dasar keagamaan yaitu untuk membiasakan peserta didik mengenal dan memahami kegiatan religiusitas serta membangun kesadaran diri dengan keyakinan dan kemampuan potensi spiritual sebagai landasan dapat meningkatkan kualitas keimanan serta dampak positif dari perilaku sikap peserta didik, adapun unsur-unsur kelemahan peserta didik diantaranya belum memiliki pembiasaan diri dan belum mampu memahami lingkungan dengan baik. tantangan bagi pendidikan Islam adalah Bagaimana menjaga nilai-nilai agama di tengah pengaruh globalisasi dan teknologi [4] . Digitalisasi hadir sebagai salah satu alat komunikasi yang dapat diintegrasikan dengan pendidikan Islam. Bentuk dari komponen pembelajaran terdapat pada bagaimana metode pengajaran dalam pemanfaatan serta fungsi objektif teknologi. Lingkungan pendidikan di sekolah terdiri dari kepala sekolah, guru kelas, guru mata pelajaran, guru bimbingan dan konseling dan siswa serta staf TU. Keterlibatan komunikasi antar personil sekolah menjadi salah satu upaya penting dalam mengembangkan karir masa depan.

Keterampilan plus merupakan bagian dari pengembangan kurikulum untuk meningkatkan keahlian khusus pada siswa di lingkungan Madrasah. Strategi dan model pengajaran berbasis teknologi berlandaskan pada kurikulum merdeka. Keterampilan khusus dapat meningkatkan intensitas pengetahuan peserta didik pada materi-materi keagamaan (spiritual) [5] . Peran teknologi informasi dan komunikasi sebagai upaya pemerataan untuk membantu sistem pengajaran dan kemajuan guru dan siswa. Peran guru sebagai fasilitator dapat memberikan layanan bimbingan karir dengan informasi dan pelatihan soft skill untuk meningkatkan pemahaman dalam menggunakan teknologi secara bijak. Fasilitator di Madrasah Aliyah Negeri 2 Cirebon terdiri dari guru, siswa, fasilitator pendukung yaitu orang tua dan masyarakat dapat meningkatkan sistem kolaborasi untuk membangun suatu sistem komunikasi jaringan secara efektif.

Layanan bimbingan karir dengan pemetaan bakat dan minat melalui pohon karir oleh guru bimbingan dan konseling untuk membantu siswa untuk memilih karir masa depan. Layanan bimbingan karir bertujuan untuk mengarahkan siswa dalam mengambil keputusan pekerjaan. Harapan dari layanan bimbingan karir siswa dapat memiliki pekerjaan sesuai dengan bakat dan minat sehingga kematangan karir dapat berkembang dengan baik di masa depan. Adapun peran guru dan orang tua merupakan bagian dari dukungan sistem dalam mempersiapkan jenjang karir masa depan. Kematangan karir siswa sekolah menengah atas sudah di persiapkan oleh kurikulum di sekolah sejak siswa kelas X sehingga di kelas XI siswa dapat memilih jenis keterampilan khusus berdasarkan minat dan bakat yang dimiliki. Penentuan peminatan ini menjadi salah satu strategi implementasi sekolah membantu siswa dalam mengembangkan potensi diri dan mempersiapkan keterampilan serta pengetahuan. Pemanfaatan teknologi informasi dan komunikasi bagi dunia pendidikan khususnya dalam proses pembelajaran [6] Program keterampilan dalam konteks pendidikan di MAN dirancang untuk membekali siswa dalam meningkatkan kemampuan berfikir praktis yang relevan dengan kebutuhan dunia kerja serta pandangan yang lebih luas tentang kesempatan karir yang tersedia. Program ini mencakup pengembangan keterampilan teknis, keterampilan komunikasi, dan keterampilan berpikir kritis yang penting dalam mendukung kesiapan karir. Program ini juga membantu siswa mengidentifikasi minat dan bakat, serta mengembangkan kemampuan analisis dalam mengevaluasi berbagai pilihan karir. Pada dasarnya, tujuan utama program ini adalah membekali siswa dengan kemampuan yang dapat meningkatkan keterampilan kerja.

Secara umum, pelaksanaan program keterampilan di MAN 2 Kota Cirebon melibatkan sejumlah tahapan, meliputi evaluasi minat dan bakat, penyusunan modul keterampilan, pelatihan keterampilan teknis dan nonteknis, serta sesi pendampingan karir. Tahapan-tahapan tersebut dirancang untuk memfasilitasi pengembangan keterampilan siswa secara bertahap. Evaluasi minat dan bakat, Pendidikan teknologi menjadi salah satu pilar utama dalam transformasi pendidikan di era digital. Dengan adopsi teknologi yang terus berkembang, metode pembelajaran konvensional semakin diperkaya oleh inovasi-inovasi digital yang memungkinkan proses pembelajaran menjadi lebih interaktif, personal, dan efisien [7] . Misalnya, membantu siswa mengidentifikasi bidang yang sesuai dengan calon siswa. Selain itu, modul keterampilan yang disusun juga disesuaikan dengan kebutuhan jurusan MIA yang berfokus pada penguasaan ilmu-ilmu eksakta. Keterampilan yang dikembangkan melalui program ini, seperti keterampilan analisis data, keterampilan laboratorium, dan pemahaman teknologi, dirancang untuk mendukung siswa yang akan melanjutkan pendidikan di bidang STEM (Science, Technology, Engineering, and Mathematics) atau yang berminat bekerja di bidang terkait. Pelaksanaan program keterampilan ini tidak terkecuali dengan berbagai tantangan. Salah satu tantangan yang utama adalah keterbatasan sumber daya, baik dari sisi anggaran maupun tenaga pengajar yang memiliki kompetensi dalam bidang keahlian khusus. Disamping itu kesadaran siswa tentang pentingnya keterampilan karier masih perlu ditingkatkan. Sebagian siswa belum begitu menyadari bagaimana keterampilan tertentu dapat mempengaruhi pilihan karier di masa yang akan datang, sehingga untuk mencapai keberhasilan program ini diperlukan suatu pendekatan yang komprehensif, dengan melibatkan pendidik, konselor dan orang tua dalam mendukung pengembangan keterampilan siswa [8]

Pengembangan soft skills menjadi perhatian dalam program ini. Keterampilan seperti komunikasi, kepemimpinan, dan manajemen waktu menjadi hal yang sangat penting untuk mendukung kesiapan karier siswa. Soft skills ini membantu siswa beradaptasi dengan lingkungan kerja yang dinamis dan sering kali menjadi faktor penentu keberhasilan karier seseorang. Hal ini bertujuan agar siswa tidak hanya cakap dalam bidang akademik tetapi juga memiliki kemampuan sosial yang baik. Pelaksanaan program skills plus own ini memberikan dampak yang positif bagi peserta didik di lingkungan madrasah secara umum secara keseluruhan. Integrasi ilmu yang dimilikinya lahir dari pemikiran tentang adanya fakta pemisahan (dikotomi) antara ilmu-ilmu agama dan ilmu-ilmu umum [9] . Dengan membekali peserta didik kelas XII MIA dengan skills yang relevan, maka reputasi sekolah sebagai lembaga pendidikan yang menyiapkan peserta didik secara holistik akan semakin meningkat. Hal ini dapat lebih menarik minat peserta didik dan orang tua yang berminat terhadap pendidikan yang tidak hanya mengutamakan akademis, tetapi juga menyiapkan peserta didik untuk menghadapi dunia kerja yang kompetitif. Selain itu, keberhasilan program ini dapat menciptakan sinergi yang positif antara sekolah dengan dunia industri atau perguruan tinggi, misalnya melalui program magang atau kemitraan dengan lembaga pendidikan tinggi dan perusahaan-perusahaan terkait. Kerjasama antara sekolah dengan dunia industri tidak hanya memperkaya pengalaman belajar peserta didik tetapi juga memperluas jaringan sekolah untuk mendukung karier peserta didik di masa depan. Pembinaan karier di kelas.

Kematangan karir merupakan salah satu keberhasilan pengembangan diri pada siswa dalam dunia kerja sebelum memasuki masa kerja siswa sudah memiliki keterampilan dan disiplin serta kesiapan karir. Harapan dari tercapainya kematangan karir pada siswa kelas XII memberikan dampak positif bagi masa depan pendidikan Islam. Sekolah Islam tidak lagi dipandang sebagai sekolah yang lemah dalam kesiapan karirnya sendiri di dunia kerja. Keberhasilan pelaksanaan program keterampilan tersebut diharapkan dapat menghasilkan dampak jangka panjang bagi siswa. Dengan keterampilan yang dimiliki oleh siswa kelas XII MIA MAN diharapkan mampu mengambil keputusan untuk karir yang lebih baik, matang dan berorientasi ke masa depan. Mereka akan lebih siap menghadapi persaingan di dunia pendidikan lanjutan dan dunia kerja. Selain itu, keterampilan yang diperoleh dari program ini juga dapat membangun rasa percaya diri siswa yang merupakan aspek penting dalam mencapai kesuksesan karir [10] .

Program ini tidak hanya membantu siswa mengenali potensi dan minatnya tetapi juga membekali mereka dengan keterampilan yang relevan dengan kebutuhan dunia kerja dan perkembangan zaman. Dengan demikian, program ini tidak hanya menjadi sarana untuk meningkatkan kesiapan karier siswa tetapi juga berperan dalam menciptakan generasi muda yang adaptif dan siap berkontribusi bagi masyarakat. Program ini juga menjadi cerminan upaya MAN dalam menyelaraskan pendidikan dengan tuntutan global. Dengan perpaduan pendidikan karakter, pengembangan keterampilan teknis, dan pemahaman tren digital, MAN diharapkan mampu menghasilkan lulusan yang kompeten, memiliki daya saing tinggi dan mampu beradaptasi dalam berbagai kondisi pekerjaan yang ada. Inovasi pembelajaran dapat berupa media pembelajaran time line chart jika digunakan sesuai dengan langkah-langkah pada saat proses pembelajaran dapat meningkatkan hasil belajar siswa karena media ini dapat membantu guru menyampaikan materi pembelajaran dengan mudah [11] .

Dalam pembelajaran siklus terdapat suatu gerakan pembelajaran yang memiliki tujuan yang diinginkan tercapai, untuk mencapai tujuan tersebut perlu adanya prosedur pembelajaran yang sesuai dengan materi program pendidikan, serta situasi dan kondisi peserta didik yang ingin belajar. Sistem pembelajaran yang menggunakan prosedur pembelajaran tradisional dari waktu ke waktu dan akibat dari teknik ini masih kurang baik, dimana peserta didik mengalami kesulitan memahami materi yang diperkenalkan oleh guru dan peserta didik menjadi terpisah karena hanya sebagai penonton [12] . Media pembelajaran memegang peranan penting bagi peningkatan efektivitas pengajaran dan pemahaman agama. Salah satu ciri Islam menurut Al- Qardhawi adalah syumul (universal dan menyeluruh) berlaku bagi seluruh umat dan bangsa, sepanjang masa (Al- Qardhawi , 1996). Universalitas Islam membuka peluang bagi umatnya untuk melakukan upaya melakukan penafsiran kontekstual terhadap Islam (Al-Qur'an dan as-Sunnah) sesuai dengan dinamika dan perkembangan zaman, dengan berbagai permasalahan yang menyertainya [13] .

2.0 Metodologi

Penelitian ini menggunakan jenis penelitian kualitatif deskriptif, yaitu metode penelitian yang memanfaatkan data dan informasi yang diperoleh dari responden, kualitatif bersifat naturalistik atas jawaban dari pertanyaan responden sendiri, serta menggunakan metode dan prosedur-prosedur untuk memahami gambaran subyek penelitian secara menyeluruh [15] . Teknik pengumpulan data yang digunakan adalah wawancara, observasi, dan dokumentasi. Kegiatan observasi dilaksanakan selama 40 hari di lingkungan Madrasah Aliyah Negeri 2 Kota Cirebon.

Sumber data dikelompokkan menjadi dua, yaitu data primer dan data sekunder. Data primer terdiri dari wakil kepala sekolah kurikulum dan 5 siswa program keterampilan plus. Kemudian analisis data dilakukan di lapangan dengan menggunakan extended participating, persistence observe,

Berdasarkan Indikator dari siswa yang merupakan siswa pada program keterampilan kelas plus di MAN 2 Kota Cirebon, yang terpilih dengan inisial: SE, M, F, A dan N. dan teknik analisis data dengan menggunakan triangulasi. Menurut Moelong Triangulasi adalah teknik pemeriksaan keabsahan data dengan memanfaatkan sesuatu di luar data itu sendiri.

3.0 Hasil dan Pembahasan

Sekolah yang berbasis pendidikan Islam memberikan nuansa keilmuan secara holistik dan komprehensif. Keterlibatan siswa dan guru dalam proses pembelajaran mengajar serta memberikan keterampilan melalui perencanaan pelatihan, workshop dan kelas khusus menjadikan dasar-dasar mental, kepribadian serta melatih rasa tanggung jawab penuh sebagai manusia Kamil. plus keterampilan adalah Prototipe Madrasah Aliyah Untuk mengembangkan keunggulan kompetitif dalam bidang keterampilan program tertentu yang diselenggarakan oleh pemerintah (RI, 2020). Pengertian lain dari Pendidikan keterampilan adalah pendidikan yang pada dasarnya bertujuan untuk membekali peserta didik dengan keterampilan yang berkaitan dengan aspek pengetahuan, sikap (fisik dan mental), dan kejujuran yang berkaitan dengan pengembangan peserta didik. sehingga mampu menghadapi tuntutan Dan tantangan kehidupan.

Keputusan karir merupakan suatu proses dimana seseorang mengenali dirinya sendiri, melihat mengetahui tentang lingkup pekerjaan yang akan dilakukannya, dan mempunyai kemampuan untuk mengintegrasikan kedua hal tersebut dalam pilihan karir yang akan diambilnya [16] . memutuskan A karier akan selalu terkait dengan dua faktor , yaitu faktor internal dan faktor eksternal. Faktor intern terpengaruh oleh tanda - tanda kehidupan , kecerdasan bakat, minat, sifat, kepribadian, pengetahuan dan keadaan fisik. Sedangkan faktor eksternal diantaranya dipengaruhi oleh pendidikan sekolah, pergaulan teman, teman sebaya, dan masyarakat [17] .

Berdasarkan wawancara dan observasi yang telah dilakukan, peneliti dapat mendeskripsikan pelaksanaan program plus keterampilan di dalam meningkatkan keputusan karir . Dalam penelitian ini penulis memperoleh berbagai implementasi program ini dalam meningkatkan keputusan karir. Menurut John Davis, psikologi transpersonal dapat diartikan sebagai ilmu yang menghubungkan psikologi dan spiritualitas. Psikologi yang memadukan konsep, teori dan metode psikologi dengan kekayaan spiritual berbagai macam budaya dan agama hasil wawancara bersama (Ujam Jaenudin, 2024 wali kelas XII) Sebelum melaksanakan program ini, peneliti akan menguraikan hasil dengan mengaitkan faktor eksternal dari keputusan karir yaitu pendidikan di sekolah. berikut hasil wawancara.

> " *Kami melihat ini (program keterampilan plus) sesuatu yang bagus. Karena pada umumnya peserta pendidikannya berasal dari kalangan menengah ke bawah, sehingga sebagian besar melanjutkan pendidikannya ke jenjang yang lebih tinggi," katanya. ke kampus tinggi jarang , Ada sejumlah Yang memilih langsung bekerja, jadi Kami mempersiapkan keterampilan pada siswa. Siswa merasakan adanya perubahan dalam keterampilan. Selain ilmu agama yang didapatnya lebih banyak dari sekolah menengah atau sekolah umum, siswa dapat mengembangkan bakat dan minat sesuai dengan minatnya".*

Kemudian dengan adanya program ini peneliti mendapatkan Bagaimana harapan dari diadakannya program ini khususnya pada anak kelas XII yang ingin menentukan karirnya di masa depan , yakni bagi yang ingin langsung terjun ke dunia kerja diharapkan mampu melatih mental dan mempersiapkan diri sejak awal melalui program magang atau PKL. Berikut narasi hasil wawancara.

> *" siswa dapat melanjutkan kuliah ke perguruan tinggi dan Sebagian siswa memilih Untuk Bekerja , Dampak dari program keterampilan sesuai dengan pilihannya. Kemudian ada juga PKL di (sekolah) kami magang di beberapa perusahaan, yang melatih mental mereka lebih. Sebenarnya lebih mempersiapkan mereka sejak dini bagi yang langsung kerja". sekolah menempatkan siswa secara praktis untuk mengembangkan keilmuan sehingga pengalaman praktik lapangan dapat diperoleh secara nyata.*

Lalu bagaimana guru dan staf mendukung adanya suatu program agar tercapai tujuan yaitu dengan dapat mengembangkan potensi bakat dan minat dalam dirinya terhadap bidang pilihan serta memiliki berbagai pengalaman dalam bidangnya. Jadi dari program keterampilan siswa mendapatkan Pengalaman secara praktik untuk mempersiapkan jenjang karir masa depan berikut narasi hasil wawancara .

> *"kemampuan dan keterampilan siswa secara spesifik dapat berkembang dipengaruhi dari kemampuan, pengetahuan dan pengalaman. Jurusan bidang teknik dan bisnis motor dan multimedia."menjadi salah satu pilihan bakat dan minat diri siswa di sekolah Madrasah Aliyah Negeri 2 Cirebon.*

Wawancara lebih lanjut Untuk mengaitkan faktor internal keputusan karir yaitu menandai kehidupan, minat , Dan bakat, Di mana Siswa menjelaskan pengetahuan dan keterampilan apa saja yang di dapat dari keterampilan yang telah diambilnya sesuai dengan bakat dan minat. Menurut M dan F , Berikut narasi hasil wawancara.

> M " pendapat dari M perolehan pada program keterampilan plus bidang pelatihan multimedia diperoleh dari hasil *Belajar diantaranya memahami jenis program computer, , corel draw, menggambar, Terus berlanjut khususnya Ya . dengan memperdalam keterampilan desain computer digital"*
> F " pendapat dari F jenis program unggulan yang dapat dipelajari yaitu desain grafis dan Corel Draw, hasil dari pemahaman ini memberikan potensi siswa untuk terus berkembang secara potensial.

Menurut A Dan N, murid kelas Bahasa Indonesia: XII Sains 1 tahun Yang mengambil keterampilan Tata Boga kegiatan pelatihan seperti memesan katering, menerangkan bahwa mereka TIDAK hanya Belajar memasak , Tetapi Belajar Untuk presentasi makanan , bisnis, estetika, takaran gizi. Berikut narasi hasil wawancara.

> A " *keterampilan tata boga ini mempelajari tentang bagaimana memasak dengan resep yang berkualitas standar hotel Bintang 5. Siswa di latih untuk Belajar masak, siswa Belajar presentasi bagaimana cara mengembangkan bisnis catering. Selanjtnya diadakan ujian praktik, kemudian hasil masakan tersebut di presentasikan dan di pasarkan secara offline dan online. Siswa dilatih untuk membuat akun pemasaran digital.*
> N " *siswa mendapatkan Latihan jenis masakan dengan resep , dengan metode presentasi Yang Bagus , dan terlatih secara profesional, untuk menyajikan makana, siswa dilatih untuk menyiapkan dan menyajikan makanan dengan strategi dan metode yang tepat.*

Kemudian menurut empat responden siswa kelas XII IPA 1, mengikuti program keterampilan yaitu penting sebagai tambahan pelajaran, memiliki manfaat, dan memiliki tambahan *keterampilan baru* . Berikut narasi hasil wawancara.

> M " *program keterampilan plus menjadi salah satu pembelajaran tambahan diluar dari jam Pelajaran sehingga dapat memberikan pengetahuan secara nyata, dengan keterampilan*

yang dilatih oleh guru sesuai dengan bidang keahliannya maka dapat menjadi nilai tambahan , siswa dibekali Latihan mental dan keterampilan sesuai bakat dan mintanya "
F *"jurusan multimedia dapat mengembangkan software dan jenis tools yang dapat meningkatkan pengetahuan digital yang dibutuhkan di era perkembangan teknologi digitalisasi., siswa dibekali dalam bidang keahlian khusus sebagai Upaya persiapan kematangan karir dimasa yang akan datang.*
A *" Kami di dalam PRIA, jarang Ada PRIA Yang plus keterampilan, biasanya di dalam sekolah Menengah Kejuruan Ya , manfaat juga untuk siswa MAN, kita belajar agama yang berbeda dari sekolah menengah tetapi kita juga belajar keterampilan plus Itu"*
N *" Menambahkan keterampilan baru, jadi selain "siswa memiliki keterampilan baru untuk terus dikembangkan."*

Peneliti memahami bahwa keterampilan pada setiap Responden memberikan nilai tambah untuk meningkatkan kesiapan dunia kerja, Ada hubungan dengan tingkat karier di masa depan . Responden Yakin. Keterampilan yang telah mereka miliki tentu saja berkaitan dengan responden di masa mendatang. Hal ini dapat dilihat dari hasil wawancara sebagai berikut.

M *" terdapat hubungan, antara siswa dan guru dalam mengembangkan keterampilan plus siswa diberi pemahaman dan pelatihan sebelum mulai bekerja. Tidak semua dari mereka bekerja menggunakan laptop, tapi mungkin nanti saya yang bekerja di tempat yang sudah ada menggunakan laptopnya seperti program khusus ini memberikan wacana masa depan siswa saat siswa mampu mempelajari ilmu bekal pengetahuan secara terus menerus"*
F *" ada potensi pada perkembangan siswa dalam mengembangkan bakat dan minat di program keterampilan plus, apabila siswa bekerja di kantor maka sudah memiliki kesiapan secara psikologis begitu pula Ketika siswa bekerja secara praktik memiliki peran tanggung jawab dalam menyelesaikan pekerjaan yang sedang dihadapi.*
A *" kesempatan siswa dalam mengembangkan bakat dan minat saat bekerja menjadi salah satu upaya keberhasilan Pendidikan khsusnya pada program keterampilan khusus"*
N *" keterampilan yang dikembangkan untuk membantu siswa dalam mengembangkan kemampuan dengan potensi dan keahlian yang lebih professional dan terlatih.*

Peneliti memahami bahwa keberagaman implementasi dari program keterampilan plus dalam meningkatkan keputusan karir pada siswa kelas XII. Berikut kategorisasi data hasil belajar berdasarkan hasil observasi dan wawancara yang telah dilakukan. Berikut ini adalah tabel kategorisasi data hasil belajar.

Tabel.1 Program Keterampilan Plus

Kategorisasi Program Keterampilan Plus		
No.	Faktor-faktor Keputusan Karir	Pelaksanaan
1.	Faktor Eksternal Pendidikan di Sekolah	Program keterampilan plus merupakan program yang sesuai dengan kebutuhan siswa karena tidak semua siswa MAN 2 Kota Cirebon akan melanjutkan karirnya ke jenjang Perguruan Tinggi. Berdasarkan hasil observasi dan wawancara diketahui terdapat keterbatasan ekonomi keluarga siswa.
		Persiapan Pelatihan Mentalitas melalui program magang atau pedagang kaki lima.
		Pelaksanaan Program Keterampilan Sudah mengarahkan peserta untuk menempuh jenjang pendidikan perguruan tinggi dan dunia kerja.
2.	Faktor Internal Minat dan Bakat	Memahami penggunaan aplikasi, memahami isi setiap aplikasi, dan membuat *desain* menggunakan aplikasi
		Belajar Untuk presentasi makanan, bisnis, estetika, pengukuran nutrisi.

3.	Faktor Internal Nilai Kehidupan	Program keterampilan sebagai pelajaran tambahan, memiliki manfaat, dan memiliki *keterampilan tambahan* baru .
		Responden tertentu bahwa keterampilan yang telah diambilnya pasti berhubungan dengan responden di masa mendatang

Analisis dari tabel di atas, peneliti dapat mendeskripsikan faktor keputusan karir dibagi menjadi dua yaitu faktor eksternal dan internal, eksternal salah satunya adalah pendidikan dj sekolah. Pelaksanaan dari program ini yaitu sekolah merasakan program ini merupakan program yang tepat karena tidak semua siswa MAN 2 Kota Cirebon akan melanjutkan karirnya ke jenjang perkuliahan, dilihat dari aspek ekonomi keluarga, maka bagi yang ingin langsung terjun ke dunia kerja diharapkan mampu melatih mental dan mempersiapkan sejak awal melalui program magang atau PKL, dan program keterampilan yang sudah langsung mendidik peserta ke jenjang perkuliahan dan dunia kerja. Kemudian dilihat dari faktor internal yaitu minat dan bakat, dan nilai-nilai kehidupan.

Dengan adanya prioritas dan upaya nyata yaitu peran teknologi sebagai media penunjang pembelajaran secara optimal yang berdampak positif dan mampu meminimalisir dampak negatif. Hal ini berpotensi bagi perilaku peserta didik sehingga berdampak bagi kehidupan di masa yang akan datang. Integrasi media dan teknologi ke dalam kurikulum pendidikan berpotensi untuk meningkatkan mutu pendidikan dan memudahkan peserta didik dalam memahami materi yang disampaikan. Melalui penerapan teknologi dan media dalam pembelajaran maka proses pembelajaran yang sebelumnya bersifat normatif dapat berubah menjadi lebih inovatif, kreatif, dan efektif. Upaya integrasi ini bertujuan untuk memadukan teknologi dan media dengan penggunaan bahan ajar guna meningkatkan mutu dan kualitas pembelajaran yang ditawarkan kepada peserta didik [19] .

Konteks perubahan modern, hilangnya ikatan spiritual dianggap berdampak buruk tersendiri dalam kehidupan manusia [20] . Pengajaran yang bermutu membutuhkan bimbingan spiritual yang tidak hanya mengajarkan nilai-nilai spiritual klasik, tetapi juga mampu menjawab kompleksitas permasalahan hidup di era modern. Fungsi domain kesadaran pendidik dapat menumbuhkan dan menyadari dirinya atas keyakinan, kokoh dalam kekuatan pemahaman, mentalitas serta ketahanan diri dapat mempengaruhi perubahan sikap peserta didik. Landasan agama dalam diri peserta didik menjadi pedoman keberhasilan pendidikan.

Pembelajaran inovatif di era 5.0 mencakup perubahan pola pengembangan kecerdasan teknologi, kecerdasan buatan, khususnya pembelajaran mendalam, telah membuka babak baru dalam berbagai bidang kehidupan manusia. 2 Inovasi dalam bimbingan rohani Islam menjadi semakin relevan di era modern ini, di mana kebutuhan akan pemahaman dan pengamalan spiritual yang mendalam semakin mendesak. 3 Pendekatan pembelajaran mendalam, yang merupakan metode pembelajaran yang mendalam dan berlapis, menawarkan potensi yang signifikan untuk memperkaya pengalaman bimbingan rohani. Pembelajaran berbasis mindful learning mampu mendukung keseimbangan siswa antara kekuatan diri dengan penyesuaian pembelajaran dengan beradaptasi dengan situasi. Pendekatan pembelajaran mendalam yang baru mampu mengarahkan siswa berpikir kritis dan analitis secara mendalam, terjadi adanya reaksi antara apa yang dipikirkan dengan pemahaman, hal. Hal ini memberikan konsep bahwa kekuatan pikiran dan proses pencapaian pembelajaran pada siswa menjadi agen perkembangan dalam sistem pendidikan.

Pada masyarakat 4.0 sebelumnya, manusia akan mengakses layanan cloud (basis data) di dunia maya melalui Internet [21] Adapun perilaku positif peserta didik untuk meningkatkan perubahan diri dengan adanya pengembangan dan pola pikir produktif seperti memanfaatkan media online untuk belajar dan meningkatkan pengetahuan kognitif, menggunakan fitur e-learning dan media promosi pemasaran sebagai bisnis online. Perubahan perilaku positif menyumbangkan ilmu pengetahuan dan penghasilan di bidang tersebut secara komprehensif. Kesadaran akan hal inilah yang dapat memberikan perubahan positif. Manajemen kelas berbasis teknologi digital menjadi suatu kebutuhan yang tidak dapat dielakkan lagi, terutama dalam upaya peningkatan mutu pembelajaran dan pencapaian tujuan pendidikan yang lebih efektif [22]

Masyarakat 5.0 mencapai tingkat konvergensi yang tinggi antara ruang virtual dan ruang fisik nyata (real space). Pada masyarakat 4.0 sebelumnya, manusia akan mengakses layanan cloud (basis data) di dunia maya melalui internet [21] . Peserta didik pada program keahlian khusus dibekali dengan ilmu pengetahuan dan teknologi agar siap menghadapi dunia kerja setelah lulus sekolah. Kegiatan program keahlian ini tidak menjadi mata pelajaran di sekolah tetapi lebih kepada minat peserta didik dalam memilih keterampilan yang akan dilatihkan secara khusus, kegiatan pengembangan minat ini dapat diikuti dengan magang di beberapa industri yang telah bekerja sama dengan sekolah. Peserta didik dapat mengikuti program plus dalam jangka waktu tidak cukup lebih dari 3 bulan. Persiapan pembekalan praktik magang sebagai upaya guru dan sekolah membantu peserta didik agar dapat berkembang secara optimal sesuai bakat dan minat serta keterampilan yang dimiliki.

Model Perubahan Ilmu pengetahuan yang dikemukakan oleh Kuhn diawali dengan dominasi suatu paradigma tertentu sehingga terjadi akumulasi pengetahuan. Tahapan inilah yang disebut dengan ilmu pengetahuan normal, pada masa ini aktivitas pemecahan masalah berjalan dengan lancar berpedoman pada kaidah-kaidah paradigma tertentu. Ilmuwan pada masa normal ilmu pengetahuan tidak memerlukan sifat kritis karena bekerja tidak memerlukan tantangan-tantangan baru [23] . Tantangan pendidikan masa depan ada pada generasi yang lahir pada era pertumbuhan teknologi, untuk dapat mengimbangi perlu adanya pemerataan sehingga hal ini perlu ditingkatkan guna memahami permasalahan-permasalahan yang akan dihadapi di masa mendatang. Bentuk dari pendampingan dan pembelajaran yang sifatnya konvensional tidak ada inovasi dan kurangnya kreativitas dapat menyebabkan proses pengembangan pendidikan menjadi terhambat. Fokus dari tujuan pengajaran di Indonesia adalah seorang fasilitator yang mampu menyeimbangkan perubahan situasi dan menggunakan teknologi secara bijaksana. Pengajaran dan pembelajaran memerlukan, setidaknya dalam keadaan teknologi kita saat ini dimana Kecerdasan Buatan (AI) terbatas, guru dan siswa yang berinteraksi dalam tindakan yang berkesinambungan dan teratur untuk mentransfer pengetahuan, nilai-nilai dan keterampilan [24] .

Tantangan utama platform WFH atau School From Home (SFH) terletak pada kemauan pengguna untuk merangkul teknologi ini [6] . Perubahan dapat dirasakan secara masif oleh setiap siswa dan guru di lingkungan satuan Pendidikan, generasi digital (digital native). Generasi ini sangat dekat dengan teknologi digital. Teknologi digital menjadi bagian yang tidak terpisahkan dengan kehidupan mereka. Bahkan, perkembangan teknologi informasi dan komunikasi yang begitu pesat telah membuka ruang-ruang baru bagi mereka untuk berinteraksi dan melakukan berbagai hal. Dunia virtual telah menjadi ruang tanpa batas yang tidak dapat dipisahkan dengan generasi muda [25] . Kehadiran generasi internet tidak dapat dihindari tetapi dapat dikendalikan dengan cara yang bijaksana sehingga guru, orang tua, dan masyarakat mampu menyeimbangkan peran serta memanfaatkan teknologi.

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Awareness of PERMATA@Pintar Negara Centre Students about Bingo Game as Aid Tool in Teaching and Learning

Nur Shamim Hamzah[1], Ku Aqhlan Hafiey Ku Aznal Shahri[1] & Siti Munirah Mohd[2,3]

[1]*Pusat PERMATA@Pintar Negara, Universiti Kebangsaan Malaysia, 43600 Bandar Baru Bangi, Malaysia.*
[2]*Kolej PERMATA Insan, Universiti Sains Islam Malaysia, 71800, Bandar Baru Nilai, Negeri Sembilan, Malaysia*
[3]*Education & Advanced Sustainability Research Unit, Kolej PERMATA Insan, Universiti Sains Islam Malaysia, 71800, Bandar Baru Nilai, Negeri Sembilan*

Abstract

Gamification is an effective method for engaging students and sustaining their interest in learning. Educational games like Bingo incorporate elements like points and badges to enrich the learning experience. Playing Bingo can enhance cognitive function, communication skills, and critical thinking by encouraging active learning rather than passive memorization. This study aimed to evaluate students' awareness at the PERMATA@Pintar Negara Centre regarding using Bingo as a teaching tool. The research was conducted through purposive sampling, involving an online survey with students aged 12 to 17. The results indicate that while many students play Bingo, most are unaware of its educational potential. Therefore, it is recommended that the elements of Bingo games be introduced in teaching and learning.

Keywords: *bingo game; gamification; education* 4.0; *secondary school.*

1.0 Gamification in Teaching and Learning

Gamification in education has gained considerable attention in recent years, with studies conducted between 2020 and 2025 highlighting its potential to enhance student engagement, motivation, and learning outcomes. A thorough meta-analysis by [1] synthesised findings from 41 studies involving over 5,000 participants, revealing a significant positive effect of gamification on learning outcomes. Similarly, a study by [2] reported a moderately positive impact of gamification on students' academic performance. In the field of STEM education, a study by [3] showed that leaderboards used in gamification strategies significantly improved learning performance in university-level calculus courses. However, implementing gamification comes with its own set of challenges. Research by [4] identified some adverse effects associated with certain game design elements, noting that when gamification is not thoughtfully integrated, it can lead to decreased motivation and performance. These findings emphasise the importance of applying gamification in a deliberate and context-sensitive manner in educational settings to maximise benefits while mitigating potential drawbacks.

Harnessing the powerful benefits of gamification in education, the integration of active learning techniques through gamified approaches has emerged as a dynamic catalyst for elevating student engagement and learning outcomes. Active learning immerses students in the educational journey, compelling them to delve deep into the analysis, synthesis, and evaluation of information rather than simply absorbing it passively. By incorporating gamification elements such as points, badges, and competitive leaderboards, educators can create an engaging environment that inspires students to interact more meaningfully with the content. For instance, a study conducted by [5] revealed that the application of gamification within active learning settings at the collegiate level not only fostered significant skill development but also heightened student satisfaction, all while preserving rigorous academic performance. These compelling findings underscore the remarkable potential of merging gamification with active learning, paving the way for educational experiences that are not only more engaging but also profoundly productive.

One innovative application of gamified active learning is the incorporation of Bingo games within educational environments. This educational adaptation reimagines the classic Bingo game, aligning its structure and content with specific learning objectives to promote active student

involvement and reinforce the learning process. For instance, a study conducted by [6] focused on the use of activity-based Bingo games within a medical education context. The researchers meticulously evaluated the impact of this interactive approach on students' academic performance. Their findings revealed that participants who engaged in the Bingo activity showed a significant improvement in their post-test scores compared to their pre-test results. Furthermore, students expressed that the Bingo game not only deepened their comprehension of complex subject matter but also rendered the learning experience more enjoyable and engaging. Similarly, a study conducted by [7] detailed the implementation of an innovative strategy known as activity Bingo to boost student engagement during fieldwork experiences. This technique involved creating a Bingo card filled with various tasks and challenges related to the fieldwork, encouraging students to take an active role in their learning process. As they sought to complete their Bingo cards, students not only participated more eagerly but also took the time to reflect on their observations and experiences in the field. This thoughtful engagement ultimately led to enhanced learning outcomes, illustrating how such a game can transform traditional educational methods. By adopting this playful and interactive approach, educators can foster an environment that encourages active learning and critical thinking. The dynamic nature of activity Bingo not only revitalises the classroom atmosphere but also encourages collaboration among students, making the learning process more engaging and impactful. Through these engaging activities, educators can effectively facilitate a richer educational experience, leaving a lasting impression on their students.

2.0 Methodology

This study was conducted in three phases to investigate students' awareness of the Bingo game as an aid tool in teaching and learning based on Fig. 1.

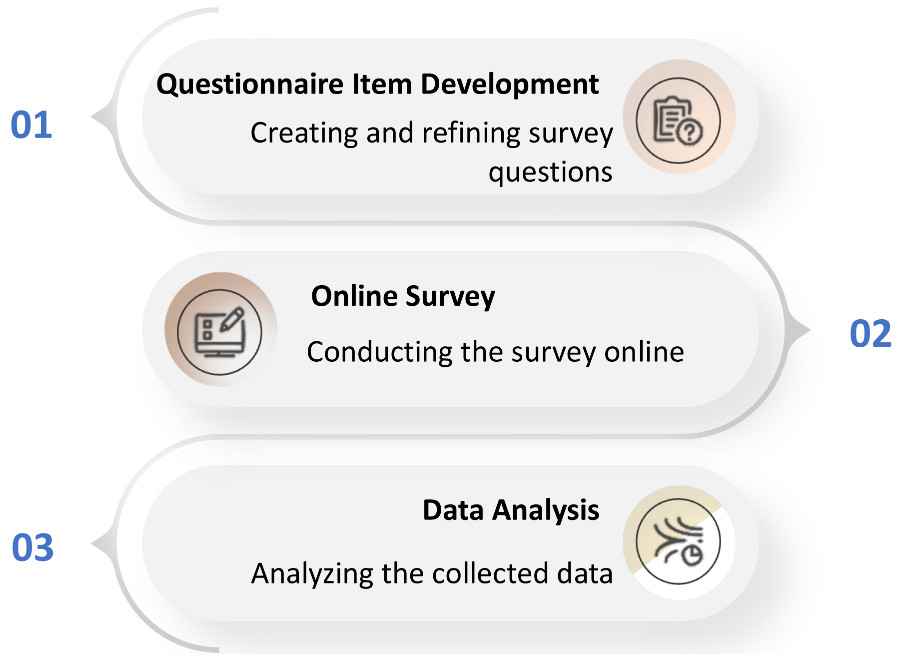

Fig. 1. Methodology

In the first phase, a questionnaire was developed to gather demographic data including age and gender.the questionnaire also include a specific element about the Bingo game. During the second phase, an online survey was distributed to students aged 12 to 17. Participation was voluntary, allowing students to share their thoughts about the Bingo game. In the third phase, the collected data was analyzed

using Microsoft Excel. Descriptive statistics, which are percentages, were calculated using basic Excel functions to identify trends and patterns in students' responses.

3.0 Results and Discussion

The age distribution of the 60 respondents shows a diverse range of student participants within the school in Fig.2. Most respondents are aged 14 (18 students) and 15 (17 students), indicating that early to mid-secondary school students are the most engaged in the survey. Following them are 12 students aged 13, which also demonstrates substantial participation from younger students. The groups of 16 year olds and 17 year olds, each represent a smaller portion, totalling 13 students. This variation in age suggests that the activity or survey appealed to a broad range of students but was particularly engaging for those in the middle secondary level.

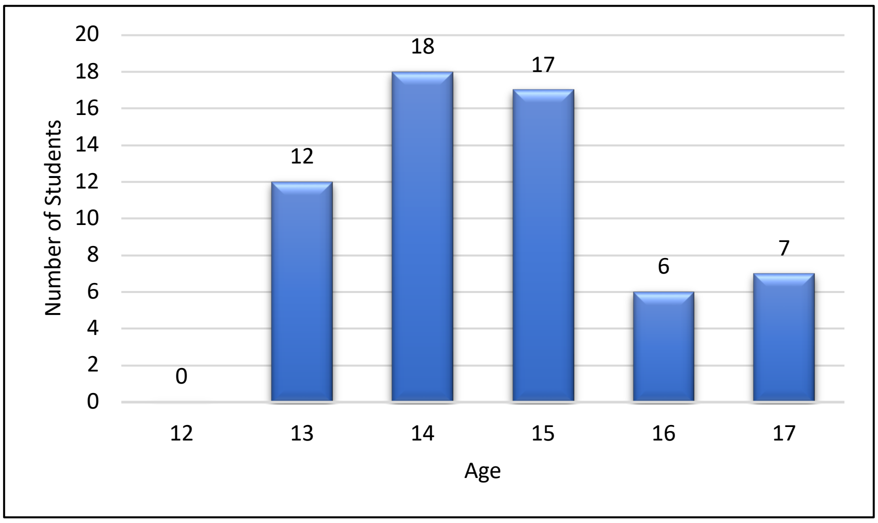

Fig. 2. Distribution of student participants according to age group ($n = 60$)

Regarding Fig. 3, based on the gender of students engaged, the survey indicates a significantly higher participation rate among female students (68%) than male students (32%). This gender gap may reflect differences in interest, availability, or engagement with the subject matter or platform used for the activity. The increased involvement of females may offer essential perspectives for upcoming planning, especially when it comes to customizing content, choosing themes, or creating follow-up activities that are engaging and accessible to both genders.

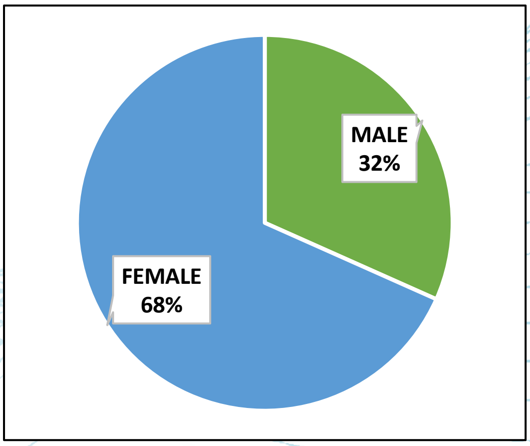

Fig. 3. Gender distribution of the students participants (n = 60)

Table 1 summarizes students' awareness, prior experience, and perceptions of Bingo games as a teaching tool. The data show that most respondents (93.3%, n = 56) are familiar with Bingo games and have prior experience playing them. The highest number of students indicated that Bingo is a popular game that students often play.

Table 1. Number of students' awareness, experience playing and perception as a teaching tool of Bingo games

Description	Yes	No
Awareness	56	4
Experience playing	56	4
Perception of Bingo as a teaching tool	21	39

However, despite this widespread awareness and experience, students' perceptions of Bingo as an educational tool are limited. Only 35% (n = 21) of respondents believe that Bingo can effectively support teaching and learning, while the majority (65%, n = 39) do not see it as such. This discrepancy highlights a significant gap between students' recreational engagement with the game and their recognition of its educational value. The findings suggest that while Bingo has the potential to be a familiar and interactive medium, further efforts are needed to help students understand how game based learning can enhance educational outcomes. Implementing structured Bingo based activities that align with curriculum content and learning objectives may increase students' acceptance of and appreciation for its academic relevance. Future research could examine the impact of such interventions on student engagement, motivation, and learning performance.

4.0 Conclusion

The findings of this study indicate a high level of student awareness and prior experience with Bingo games, demonstrating its potential as a familiar platform for engagement in educational settings. However, the relatively low perception of Bingo as a viable teaching tool underscores the need for targeted efforts to demonstrate its instructional value. Educators should consider integrating content-based Bingo activities that align with specific learning outcomes to enhance student engagement and understanding of concepts. Future efforts should focus on developing Bingo games and evaluating the effectiveness of these gamified approaches in various educational settings to encourage broader acceptance and maximize their impact on learning.

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Probabilistic Thinking of Undergraduate Male Mathematics Education Students in Solving Probability Problems Involving Binomial Distribution Based on Field-Independent Cognitive Styles

Supratman[1], I Ketut Budayasa[1] & Endah Budi Rahaju[1]

1Universitas Negeri Surabaya, 60231, Surabaya, East Java, Indonesia

Abstract

This study explores the probabilistic thinking of a male undergraduate mathematics education student characterized by a masculine gender trait and a field-independent (FI) cognitive style. The subject, referred to as MLI (Male, Field-Independent), was selected through purposive sampling based on gender traits, results from the Group Embedded Figures Test (GEFT), and mathematical ability assessed through UTBK SBMPTN questions. Most students tested were classified as having moderate mathematical ability, and the MLI subject was selected accordingly. Using a descriptive qualitative approach with a case study design, the study aimed to analyze the subject's approach to solving a probability problem involving binomial distribution. Data were gathered through a problem-solving task administered at the Faculty of Teacher Training and Education, Universitas Sembilanbelas November Kolaka. The data analysis process included data reduction, presentation, and conclusion drawing. Findings revealed that the MLI subject successfully applied Polya's four-step problem-solving model understanding the problem, devising a plan, carrying out the plan, and looking back. Although formulas were not explicitly written, the subject demonstrated clear logical structure and accurate reasoning. Reflective thinking was confirmed through interviews. These results highlight the need to develop probabilistic thinking in mathematics education to support effective teaching and real-world decision-making.

Keywords: *Probabilistic Thinking; Field-Independent Cognitive Style; Binomial Distribution; Probability Problem Solving; Male Undergraduate Students*

1.0 Introduction

In the Indonesian higher education curriculum, students enrolled in mathematics education program prospective mathematics teachers are systematically prepared to become professional educators in the field of mathematics. According to Law No. 14 of 2005 on Teachers and Lecturers, a mathematics teacher's professionalism comprises four core competencies: pedagogical, personal, social, and professional. These competencies are cultivated through academic supervision and structured coursework throughout the undergraduate program. Moreover, Law No. 12 of 2012 on Higher Education emphasizes the importance of facilitating the development of students' cognitive, affective, and psychomotor domains. To support this goal, Presidential Regulation No. 8 of 2012 on the Indonesian National Qualifications Framework (KKNI) was introduced to guide the formulation of learning outcomes at every level of education. For undergraduate students (S-1), learning outcomes are classified under KKNI Level 6, which includes the ability to apply specialized knowledge, utilize science and technology in solving problems, adapt to various situations, master both general and specific theoretical concepts, formulate procedural solutions, make informed decisions based on data analysis, and demonstrate responsibility in both individual and organizational contexts. These outcomes are aligned with the national standards for higher education in Indonesia [1]. At KKNI Level 6, the expected learning outcomes for mathematics education students include mastery of theoretical concepts in areas such as number theory, algebra, geometry and measurement, statistics and probability, trigonometry, and calculus, and the ability to formulate procedural solutions to problems. Teaching mathematics in general and instructing mathematics at junior schools in particular not only create favorable conditions for students to develop essential and core competencies but also help students enhance mathematical competencies as a foundation for a good study of the subject and promote essential skills for society, in which mathematical communication skill is an important one [2].

The topic of probability is addressed in the Mathematical Statistics I course in higher education. At this level, students are introduced to concepts such as combinatorics (including factorial, permutation, and combination), conditional probability, independent events, Bayes' theorem, discrete and continuous random variables, and probability distributions. These topics pose challenges for many students, particularly in solving probability-related problems. Solving such problems requires logical reasoning and the ability to provide sound arguments, explanations, and justifications, Success in problem-based learning requires both strong information literacy to search for, evaluate, and use information effectively, and argumentation skills to generate coherent arguments [3]. These skills are essential for students not only during their academic careers but also in their professional and everyday lives, enabling them to become critical thinkers and informed decision-makers. Consequently, it is crucial to revise the curriculum and instructional strategies used in teaching probability to undergraduate mathematics education students. This aligns with findings from Hokor and Hokor [4,5]. which suggest that educators should incorporate strategies that enhance probabilistic thinking, particularly because this type of thinking is essential in understanding probability and avoiding misconceptions. To foster probabilistic thinking among mathematics education students, problem-solving tasks rooted in real-life contexts should be emphasized in coursework. According to Pehkonen [6] states that "Problem solving has generally been accepted as a means for advancing thinking skills". In addition, [7-12]which concluded that in probabilistic thinking, students can develop their good probabilistic thinking intuitively, classically, and continuously, besides that students can also develop ideas.

According to Maxine & Constance [13] states that "probabilistic thinking is an inherently new way of processing information as the world view shifts from a deterministic view of reality". The quote explains that probabilistic thinking is a new way of processing information as the world view shifts from a deterministic view of reality. Lamprianou & Afantiti [14] stated that "probabilistic thinking is a mode of reasoning attempting to quantify uncertainty, as a tool for decision making". The quote explains that probabilistic thinking is a mode of reasoning attempting to quantify uncertainty, as a tool for decision making, while Biehler [15] states that there are several characteristics of probabilistic thinking as follows: (1) don't seek connection, (2) explaining and describing, (3) not a single data set, and (3) work with the model. The explanation of each characteristic is (1) in probabilistic thinking do not connect something in individual cases (special), but try to think on the regularity of repetition that may occur so that it is not just a guess but a certain calculation, (2) probabilistic thinking means explaining and describing variations of the probability model, (3) probabilistic thinking is not thinking of single data but the mechanism of generating an experiment that has several possibilities and (4) work with the "model" which is intended to work by making several possibilities, not with a fully known reality.), another case with Lau & Ranyard [16] probabilistic thinking as "the tendency to view the world in terms of uncertainty, the ascribing of different degrees of uncertainty either verbally or as a numerical probability". The quote explains that the tendency to describe the world in terms of uncertainty, ascribing different degrees of confidence either verbally or as a numerical probability. Based on the theoretical conjecture that the FI cognitive style of a masculine male in solving probability problems is interesting and important. Interesting because it can examine probabilistic thinking between subjects with FI cognitive style in solving probability problems. Important because it can provide scientific information in the field of cognitive psychology that the FI and FD cognitive styles of a student will also affect his probabilistic thinking in solving probability problems [17]. The importance of this research is done because probabilistic thinking as one of the thinking skills that must be owned by masculine male students who play a very important role and support student success in learning mathematics, then educators should know someone's probabilistic thinking in probability problems. Supratman, Budayasa & Rahaju [18] stated that quantitative analysis showed a significant role of probabilistic thinking and field-independent cognitive style in the probability problem-solving skills of feminine female undergraduate mathematics education students. Qualitative analysis, through interviews based on Polya's stages, provided deeper insights. During the interview, after completing the probability test, MPI struggled to apply the combination formula before using the binomial distribution. However, in the "looking back" stage, MPI successfully wrote the final answer. These findings highlight the need to develop probabilistic thinking.

2.0 Methodology

2.1 Research Design

This study employed a descriptive qualitative approach, as outlined by [19] to investigate the differences in probabilistic thinking among undergraduate mathematics education students with a field-independent cognitive style, specifically focusing on gender-based variations. In this case, the gender of interest was feminine. The study adopted a case study design, concentrating on a single subject to explore, in depth, the phenomenon of probabilistic thinking in solving probability problems by a female undergraduate mathematics education student with a field-independent cognitive style.

2.2 Participants and Data Collection

One male undergraduate mathematics education student with a masculine gender trait and a field-independent cognitive style was purposefully selected as the subject. The selection process incorporated a mathematical ability test using UTBK SBMPTN questions, which are standardized and credible assessment tools used in Indonesia's national university entrance examination. The student's mathematical ability was classified as moderate, based on the grading criteria of Universitas Sembilanbelas November Kolaka: A (high), B (moderate), and C (low). Purposive sampling was employed, focusing on students who had completed the Mathematical Statistics I course. The Grade Point Average (GPA) of sixth-semester students was also considered, with specific attention given to those categorized as having moderate ability. This selection was further supported by recommendations from lecturers who taught the Mathematical Statistics I course, which includes the topic of probability. The probability problem-solving task was administered in Room B4 of the Faculty of Teacher Training and Education at Universitas Sembilanbelas November Kolaka. Data were collected from the test responses of the selected male subject with a field-independent cognitive style. The data analysis process was conducted in three stages: data reduction, data presentation, and conclusion drawing. The specific probability problem-solving task given to the subject is shown in Fig. 1.

2. A circular dart target board has a small circular center called the target center (Bullseye), the target center in area 1 consists of 2 parts, namely the red inner part (Double Bull) and the green outer part (Bull) while 20 circular areas numbered 1 to 20 are located around the board. Each circular area is further divided into 3 parts, namely in area 2 includes the target boundary line which is assumed to be inside the circle and gets a double value of 3, in area 3 includes the target boundary line which is assumed to be inside the circle and gets a double value of 2, while in area 4 is the outermost area of the target board, so that if someone throws the dart and hits a certain number, then he gets a value equal to the number, twice the number, or three times the number, depending on which part of the hit area is successively on the outside, the center, and the inside which is assumed that the boundary between 2 adjacent curves is given an iron plate, so that the arrow cannot stick in the boundary line. If the chance of someone hitting the center of the target is 0.04, the chance of hitting double value 3 is 0.45, the chance of hitting double value 2 is 0.20, and the chance of hitting the outermost region of the target board is 0.03 which is illustrated in the following figure

Then determine that the probability that 15 dart throws result in:

a. Hit the center of the target exactly 5 times
b. Getting a double score at most 2 times
c. Scored double three more than 7 times
d. Hits the outermost area of the target board 4 times

Fig. 1. Probability problem-solving task

2.3 Research Instruments

The primary research instrument was a set of probability problem-solving tasks designed to explore the subject's probabilistic thinking in depth. These tasks included indicators of probabilistic thinking. Before conducting the research, a validation process was undertaken to ensure that the instruments effectively measured students' probabilistic thinking abilities, particularly in solving mathematical problems related to probability. The instruments used in the selection of subjects included a mathematical ability test and the Group Embedded Figures Test (GEFT). The mathematical ability test comprised general mathematics questions covering statistics, geometry, and algebrasourced from the UTBK SBMPTN. The GEFT was used to classify subjects according to their cognitive styles, specifically to identify those with a field-independent cognitive orientation.

2.4 Data Analysis

Following the categorization of probabilistic thinking data, analysis proceeded through three stages: data reduction, data presentation, and conclusion drawing. The objective was to examine how the selected subject a feminine female undergraduate mathematics education student with a field-independent cognitive style approached and solved probability problems.

3.0 Results and Discussion

The initial stage involved administering the probability problem-solving test to 15 undergraduate mathematics education students from the 2020 cohort. The mathematical ability test results showed that none of the students were in the high category; 8 students (53.34%) were classified as having moderate ability, and 7 students (46.67%) as having low ability. In the 2021 cohort, similarly, no students scored in the high category; 7 students (58.34%) were categorized as moderate, and 5 students (41.67%) as low.

The GEFT was administered to 15 students from the 2020 cohort. Results revealed that 8 students exhibited a field-dependent (FD) cognitive style, consisting of 1 masculine male and 7 feminine females. The remaining 7 students demonstrated a field-independent (FI) cognitive style, comprising 1 masculine male and 6 feminine females. For the 2021 cohort, 5 students were identified as field-dependent (1 masculine male and 4 feminine females), while 7 were feminine females with a field-independent cognitive style. Based on purposive sampling, considering the mathematical ability and GEFT results, the study focused on one subject: a masculine male student from the 2020 cohort with a field-independent cognitive style, coded as MLI. This subject was recommended by the course instructor for Mathematical Statistics I and met the medium-level ability criterion. A detailed analysis of the MLI subject's responses to the probability problem-solving task (see Fig. 2) yielded the following insights:

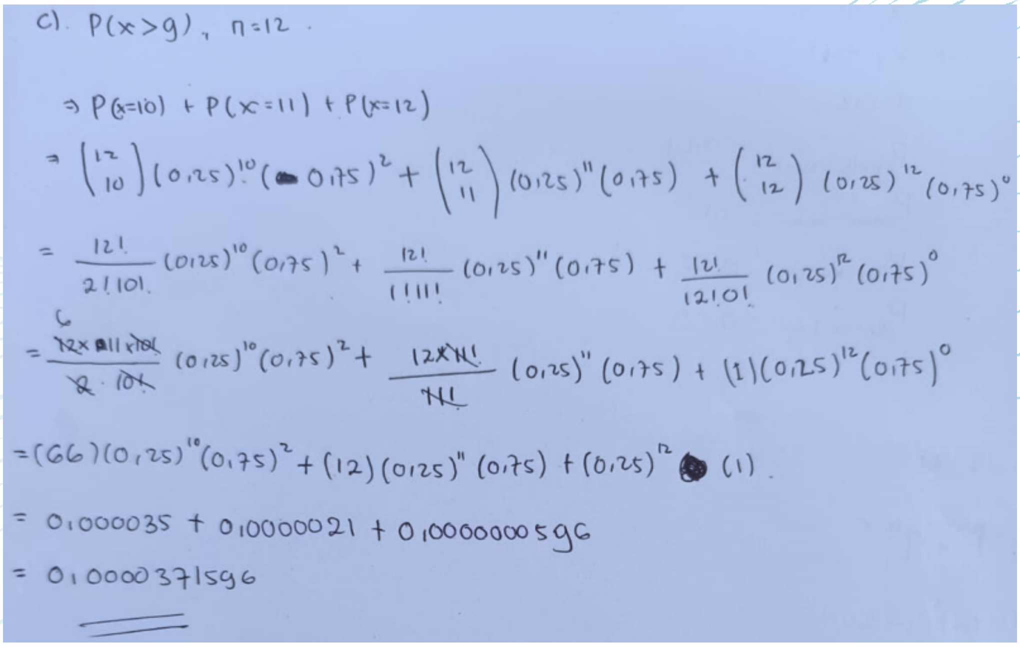

Fig. 2. results of MLI subject's probability problem solving answers

The MLI subject demonstrated competence in solving the probability problem by successfully applying all four stages of Polya's problem-solving process. In the Understand the Problem stage, the subject was able to identify and extract relevant information from the given problem, particularly recognizing that the probability in question involved obtaining a double value of 3 in more than 9 attempts out of a total of 12 dart throws. He correctly interpreted this to mean the event occurring in exactly 10, 11, or 12 throws. Moving on to the Devising a Plan stage, the subject immediately implemented a solution strategy by applying the principles of the binomial distribution. Although he did not explicitly write the formulas for the binomial distribution or combinations, his solution was systematically structured and reflected a sound conceptual understanding of the underlying mathematical processes. In the Carrying Out the Plan stage, the subject executed the solution with a high degree of accuracy and fluency. He organized the steps logically and presented calculations in a clear and structured manner, ultimately arriving at an appropriate and correct final answer. Finally, during the Looking Back stage, although the subject did not document a written review of his work, follow-up interviews revealed that he had mentally retraced his entire problem-solving process. He revisited the known and unknown elements of the problem, reflected on the steps taken, and verified the correctness of the solution. This demonstrated his ability to engage in reflective thinking, an essential component of effective problem solving.

The findings indicate that the MLI subject successfully demonstrated all four stages of Polya's problem-solving model in addressing the probability task. In the Understand the Problem stage, the subject accurately interpreted the scenario and extracted the essential information needed to approach the solution, although the specific question posed in the problem was not explicitly restated in the written response. In the Devising a Plan stage, the subject did not provide the explicit formulas for the binomial distribution or combinations; however, he applied the binomial distribution strategy correctly, reflecting a solid understanding of the appropriate problem-solving method. During the Carrying Out the Plan stage, the subject executed the strategy competently, presenting the solution through a series of logical and systematically organized steps that led to a valid and appropriate conclusion. At the Looking Back stage, although the subject did not include a written review of the problem-solving process, data obtained through interviews confirmed that he had mentally reviewed and verified the accuracy of his solution. These results are consistent with findings from prior studies. For instance, Lin & Davidson-Shivers [20] found that individuals with a field-independent cognitive style are typically more engaged in learning activities, enabling them to independently analyze, reconstruct, and resolve problems. Furthermore Yazici & Ertekin [21] reported notable gender-based differences in mathematics-related beliefs and confidence levels. Their study found that male pre-service teachers tend to exhibit higher levels of confidence in teaching mathematics, while their female counterparts are more likely to experience anxiety. Similarly, Li [22] identified significant gender differences in both students' and teachers' beliefs regarding the importance and difficulty of mathematical topics, with male teachers generally perceiving mathematics topics as more important than female teachers.

4.0 Conclusion

Based on the findings and discussion, it can be concluded that the MLI subject demonstrated the ability to solve probability problems effectively by following Polya's four-step problem-solving process. At the Understand the Problem stage, the subject successfully identified and documented the essential information provided in the problem. During the Devising a Plan stage, the subject proceeded directly to apply the binomial distribution approach, although he did not explicitly write out the relevant formulas, including those for combinations. Nonetheless, the structure and coherence of his solution indicated that he understood the strategy required to solve the problem accurately. At the Carrying Out the Plan stage, the MLI subject displayed a high level of skill and accuracy, presenting a well-organized sequence of calculations that led to the correct final answer. In the Looking Back stage, although the subject did not include a written review of his solution, interviews revealed that he had mentally revisited the entire process from identifying the known and unknown elements to formulating and solving the problem demonstrating a thorough and reflective approach. These findings reinforce the importance of developing probabilistic thinking in higher education as a fundamental cognitive skill. Probabilistic thinking is a crucial component of the learning outcomes expected at the undergraduate level, as it supports students in applying mathematical knowledge and leveraging science and technology to solve real-world problems. Furthermore, it cultivates students' ability to adapt to diverse situations, make data-driven decisions, and master both general and specialized theoretical concepts in mathematics.

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SCIENCE
&
TECHNOLOGY

Entanglement Classification Operator Model Development of SU(2)

Amirul Asyraf Zhahir[1], Siti Munirah Mohd[2,3,7,*], Mohd Ilias M Shuhud[1,7], Bahari Idrus[4], Hishamuddin Zainuddin[5], Nurhidaya Mohd Jan[2,3], & Mohamed Ridza Wahiddin[6]

[1]*Faculty of Science and Technology, Universiti Sains Islam Malaysia, Negeri Sembilan, Malaysia*
[2]*Kolej PERMATA Insan, Universiti Sains Islam Malaysia, Negeri Sembilan, Malaysia*
[3]*Education & Advance Sustainability (EdAS), Kolej PERMATA Insan, Universiti Sains Islam Malaysia, Negeri Sembilan, Malaysia*
[4]*Center for Artificial Intelligence Technology (CAIT), Faculty of Information Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia*
[5]*1133, Jalan S2 A33, Central Park, Seremban 2, 70300 Seremban, Negeri Sembilan, Malaysia*
[6]*Tahmidi Centre, Universiti Sains Islam Malaysia, Nilai, Negeri Sembilan, Malaysia*
[7]*Cybersecurity and Systems Research Unit, Faculty of Science and Technology, Universiti Sains Islam Malaysia, Negeri Sembilan, Malaysia*

Abstract

The study presents the development of the $SU(2)$ operator model for entanglement classification within the Local Unitary (LU) protocol. The operator model was systematically designed, specifically tailored for the pure three-qubit quantum system to accurately identify the distinct classes of entanglement. By leveraging the special unitary group, $SU(2)$, this operator model development benefits researchers to gain a better understanding of the essence of entangled states, assisting researchers in effectively harnessing them to numerous potential applications in quantum computing, quantum cryptography, quantum teleportation and other respective fields. Hence, the study contributes significantly to advancing quantum information science. Furthermore, the foundation of this study establishes a broad pathway for advancements and future innovation in quantum information science and technologies.

Keywords: *Special unitary group; Local Unitary; LU; Entanglement classification.*

1.0. Introduction

Quantum entanglement is regarded amongst the most important phenomenon in quantum information science. It describes a phenomenon where multiple particles carrying vital information are somehow correlated with each other regardless the distance between them. The principal concept of quantum entanglement has attracted researchers, innovators and others from various science, technology and engineering fields. Over the past several decades, quantum entanglement has enabled numerous scientific breakthroughs to have been made namely in quantum computing, quantum cryptography and quantum teleportation [1-9].

The utilization of quantum entanglement in various quantum fields, particularly quantum computing is extremely crucial in order to successfully implement its complex programs. To fully utilize the quantum entanglement, a vital process to differentiate types of entanglement is essential. Entanglement classification as the name suggests, is a process of classifying different types of entanglement [4,10]. The classification of entangled states is needed to fully understand the nature of quantum entanglement and its application. By classifying entangled states, the most suitable quantum states for specific quantum tasks can be allocated effectively and efficiently. Some existing key protocols for entanglement classification are namely, Local Unitary (LU), Local Operations and Classical Communication (LOCC), and Stochastic Local Operations and Classical Communication (SLOCC) [11]. These protocols basically suggest that quantum states can be manipulated using local operations and classical communication between different part of its subsystems.

This study considered entanglement of multiqubit quantum systems under the LU protocol, specifically three-qubit pure quantum system, which is integral to many practical quantum applications.

LU operations are a transformation applied to quantum states, and the protocol preserves the overall structure and entanglement properties of quantum states. Additionally, LU protocol does not require any communication or interaction between quantum subsystems, which is a key feature that preserves the independence of local operations. For a three-qubit quantum systems, there exist six entanglement classes under Local Unitary (LU) which include separable ($A-B-C$), bi-separable ($A-BC$, $B-AC$ and $C-AB$) and genuinely entangled states (W and GHZ) [10-13].

The main goal of this study is to design and develop an operator model, SU(2), under the LU protocol for entanglement classification of a three-qubit pure quantum system. This work aims to bridge theoretical concepts with practical applications, thereby enhancing the understanding and utilization of entangled states. The remainder of this study is organized as follows: Section 2 describes the methodology followed by section 3 which presents the result and finally, section 4 concludes the study.

2.0 Research Methods

The SU(2) operator model was developed through a systematic process, using three sets of 2×2 matrices to serve as generators, after appropriate sets of generators were determined. As part of the development process, suitable sets of parameters were selected to ensure an accurate and adaptable operator model was developed. It was then proceeded to the full development phase from the generated matrix produced. The selection of appropriate parameters was crucial for achieving accuracy during the development.

It is important to develop a precise operator model, so that the operator model is able to be further extended as the SU(2) represents a single-qubit quantum system. It is greatly convenient if it is capable of extending to a multiqubit quantum system. Validation of the operator model was conducted to ensure its reliability and accuracy. The developed model was benchmarked against previous studies, with experimental comparisons conducted to evaluate its performance. Fig. 1 provides an overview of the modelling process of SU(2), highlighting key steps from the initial parameter selection to the final validation phase.

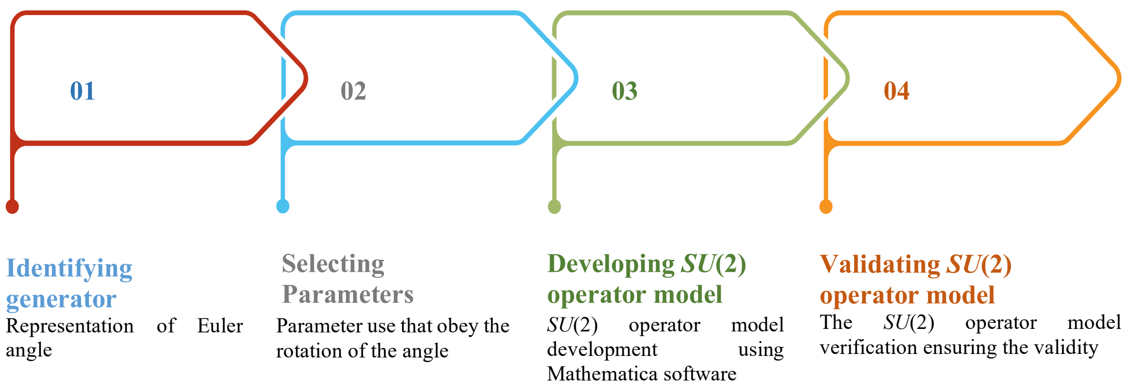

Fig. 1. Modelling process of $SU(2)$

3.0 Results

The $SU(2)$ operator model was successfully developed and validated for entanglement classification. Fig. 2 illustrates the $SU(2)$ operator model successfully developed derived on equation (1). The operator model demonstrated robust classification capabilities, aligning with the theoretical framework and outperforming some existing approaches in terms of precision and scalability.

$$SU(2)=e^{i\sigma_3\beta_1}e^{i\sigma_2\beta_2}e^{i\sigma_3\beta_3} \quad (1)$$

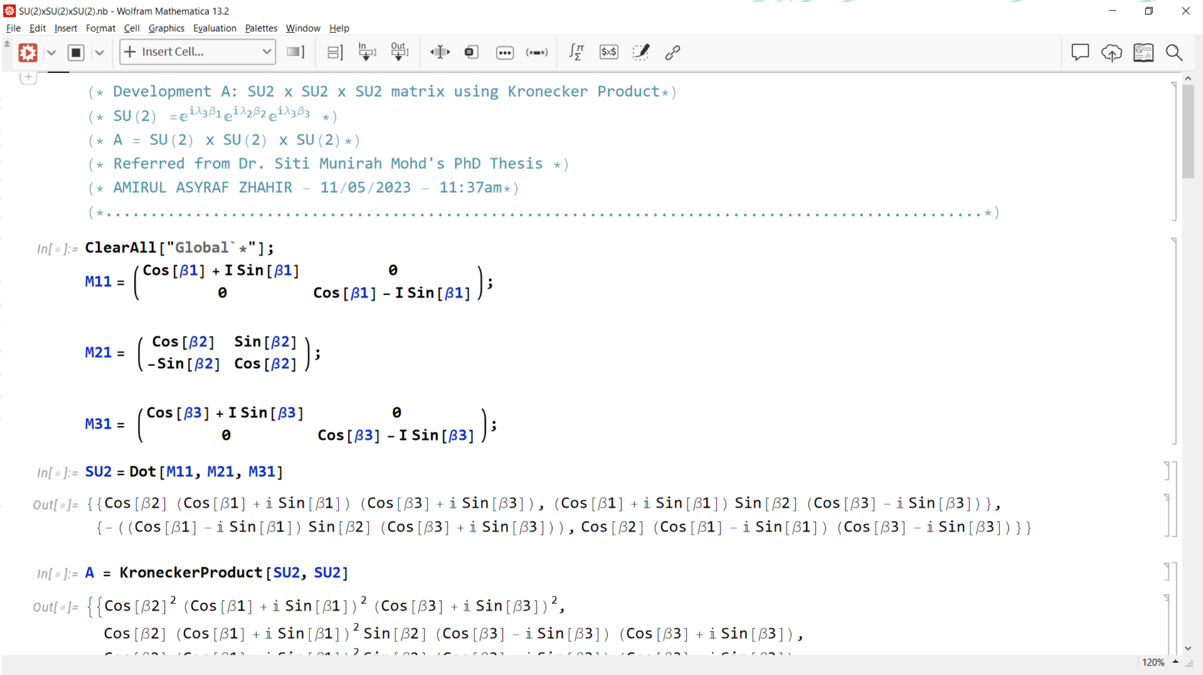

Fig. 2. Development of $SU(2)$

4.0 Conclusion

This study presents the design and development of a novel *SU*(2) operator model, tailored to entanglement classification of a pure three-qubit quantum system utilizing the special unitary group *SU*(2), within the LU protocol. The developed model not only advances the theoretical understanding of entangled states but also serves as a practical tool for precise entanglement classification in applications where accuracy is critical.

By leveraging the properties of the special unitary group *SU*(2), this work contributes to the growing body of knowledge in quantum information science. The developed operator model offers significant potential for future work, extending its developments and applications to multiqubit or even a higher-dimensional quantum systems, paving the way for future advancements in quantum computing, quantum cryptography, quantum teleportation and beyond.

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Experimental Study of Surface Integrity During Turning of Aluminium Metal Matrix Composite

Theebenraj Rajosagran [1], Fauzi Ab Ghafar & Victor Amirtham [3]

[1]*Politeknik Ungku Omar, 31400, Ipoh, Perak, Malaysia*

Abstract

Metal matrix composite (MMC) has many advanced mechanical properties such as high wear resistance, less weight, high strength and stiffness, lower coefficient of thermal expansion and high thermal conductivity, which are widely used in the automotive, railway and aerospace industries. The main limitation in MMC application is difficult to machine, which leads to low production volumes and high machining costs. This study aims to investigate the surface integrity of metal matrix composites through the high-speed turning experiments. High cutting velocity with low feed rate were the dominant parameter associated with the surface roughness. Surface roughness as low as 0.20 micron was achieved at low feed rate of 0.10 mm/rev with high cutting velocity of 175 m/min on Al 6061/SiC_p by solid coated (TiAlN) cemented carbide tool. Conversely, the lowest microhardness of 102 HV are obtained at high velocity of 200 m/min with feed rate of 0.10 mm/rev. The study concludes that high cutting velocity can effectively reduce surface roughness when machining difficult-to-cut materials. However, it is important to consider that reducing the feed rate can significantly increase the turning time. Additionally, flank wear and chip formation must be considered when selecting cutting parameters. Continuous and long chips that wrap around the machined surface can cause surface damage. This research demonstrates that hard turning is a viable alternative to grinding for achieving low surface roughness in MMCs, provided that the appropriate operating parameters are carefully selected.

Keywords: *Metal matrix composite; surface roughness; heat affected zone; built-up edge*

1.0 Introduction

In recent years, a new generation of materials known as metal matrix composites (MMCs) has emerged, owing to their significant scientific, technological, and commercial potential. MMCs have attracted considerable attention in the automotive and aerospace industries due to their outstanding properties, such as high strength, low weight, high modulus, low ductility, excellent wear resistance, high thermal conductivity, and low thermal expansion [1, 2]. These composites can be manufactured using a variety of cost-effective technologies. However, their poor machinability remains a major challenge, necessitating improvements in cutting tool materials and machining strategies [3].

Among various MMCs, aluminium-based metal matrix composites (Al-MMCs) are being increasingly adopted as substitutes for conventional aluminium alloys in diverse engineering applications due to their enhanced mechanical and thermal performance [4]. From the perspective of metal cutting theory, analyzing surface integrity is one of the most effective approaches to understanding the machining behaviour of materials [5]. Surface integrity directly influences the functional performance of machined components, including their fatigue life, tribological characteristics, and mechanical compatibility [6]. It consists of two critical aspects: surface texture and microhardness.

Surface texture primarily refers to surface roughness, which represents the fine irregularities on a surface caused by machining. These are influenced by the tool geometry, cutting speed, feed rate, and cutting environment [7]. On the other hand, microhardness refers to the material's hardness on a microscopic scale, typically evaluated using indentation methods. The measured impression dimensions under a known load provide a quantitative hardness value, which reflects the surface's mechanical integrity and can be used to infer service performance [8].

To enhance tool life and performance during the machining of difficult-to-cut materials such as Al-MMCs, cemented carbide cutting tools are often used with coatings like titanium carbide (TiC), titanium nitride (TiN), and hafnium nitride (HfN). These coatings, generally 5–8 µm thick, are deposited over a tungsten carbide (WC) substrate and offer superior wear resistance and thermal stability, especially under high-speed machining conditions [9].

Although milling and turning are conceptually distinct operations, they share the fundamental principle of material removal through chip formation. Both aim to shape a workpiece to specified dimensions and tolerances [10].

The objective of the present study is to investigate the machinability of Al-MMCs using coated cermet carbide inserts, with a focus on evaluating the influence of various cutting conditions on surface quality and subsurface damage. The study aims to offer insights into the optimal machining parameters for improved surface integrity, which is critical for ensuring component performance in demanding applications.

2.0 Materials and Methods

The workpiece material used in this study is Al 6061 reinforced with SiC particles of metal matrix composite. As the matrix element, aluminium, titanium and magnesium alloy are used, while the popular reinforcements are silicon carbide (SiC) and alumina (Al_2O_3). Aluminium-based SiC particle reinforced MMC materials have become useful engineering materials due to their properties such as low weight, heat resistant, wear resistant and low cost.

Table 1. Chemical Composition of Al 6061/SiC_p

Element	Wt. %
Silicon (Si)	0.59
Magnesium (Mg)	1.04
Carbon (C)	0.001
Chromium (Cr)	0.09
Copper (Cu)	0.27
Iron (Fe)	0.15
Manganese (Mn)	0.004
Zink (Zn)	0.002
Nickel (Ni)	0.001
Titanium (Ti)	0.006
Aluminium (Al)	97.846

The requirements for any cutting tool material used for machining aluminium-based metal matrix composites should include wear resistance, high hot hardness, high strength and toughness, good thermal shock properties and adequate chemical stability at elevated temperature. Usually the cutting tool materials that used for machining are:

- Plain carbon and low alloy steels
- Cast cobalt alloy
- Carbon tool steel
- High speed steel (HSS)

- Cemented carbides
- Cermet
- Coated carbides
- Ceramics
- Synthetic diamond
- Cubic Boron Nitrides (CBN)

Cemented carbide tools are still largely used for machining the aluminium-based metal matrix composites. Over the years, the use of carbides for cutting tools has been established. However, with the increasing demand to achieve fast material removal and better surface quality, high speed machining was introduced and the use of the cemented carbide tools has become more problematic [6,7]. For metal matrix composite, the concept of high-speed machining refers to speeds over 50 m/min approximately. In order to achieve higher cutting speeds, coated cemented carbides have been developed.

Turning is a complex machining process influenced by multiple parameters, including cutting speed, feed rate, depth of cut, and tool geometry. In this study, a series of controlled experiments were conducted to identify the most significant factors affecting surface finish during the turning of aluminium-based metal matrix composites. The key parameters considered for the experimental investigation were cutting speed, feed rate, and depth of cut [9,10]. All experiments were performed under dry cutting conditions to eliminate the effects of lubrication and better reflect industrial practices. The specific cutting conditions and levels for each parameter are presented in Table 2.

Table 2. Process parameters and their levels

Levels	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)
1	100	0.10	0.2
2	100	0.20	0.2
3	100	0.30	0.2
4	125	0.10	0.2
5	125	0.20	0.2
6	125	0.30	0.2
7	150	0.10	0.2
8	150	0.20	0.2
9	150	0.30	0.2
10	175	0.10	0.2
11	175	0.20	0.2
12	175	0.30	0.2
13	200	0.10	0.2
14	200	0.20	0.2
15	200	0.30	0.2

A high-precision numerically controlled (NC) turning machine was employed for the experimental investigations. The cutting tools used were solid TiAlN-coated carbide inserts with two cutting edges. A total of ten inserts were utilized, with each tool being used for four separate machining trials to ensure consistency and minimize tool wear influence across tests. Surface roughness measurements were performed using a calibrated surface roughness tester. For each specimen, measurements were taken at four equally spaced locations (90° apart) along the face of the machined surface. At each location, two readings were recorded, and the average of all eight readings was calculated and reported as the representative surface roughness value.

Microhardness measurements were performed using a Vickers microhardness tester with a constant applied load of 20 N. Indentations were made on the machined surface, and the corresponding diagonal lengths were measured microscopically to determine the hardness values. These measurements provided insights into potential subsurface alterations due to different cutting conditions.

3.0 Results & Discussions

3.1 Surface Roughness

Surface roughness (Ra) is a widely used colloquial term to describe the general quality of a machined surface [3]. While "surface finish" is a broader term not necessarily tied to surface texture or pattern, a lower surface roughness value typically implies a better surface finish [5]. Surface roughness is of particular interest in manufacturing because it directly affects the friction between contacting surfaces. It influences not only how a surface feels and appears but also its behaviour during contact, coating, or sealing operations.

Surface roughness is a key performance measure in machining processes, especially in finish turning. Figure 5 illustrates the measured surface roughness values at cutting speeds of 100, 125, 150, 175, and 200 m/min with a feed rate of 0.10 mm/rev for a 100 mm length of cut (referred to as Trial 1). At a cutting speed of 100 m/min, the surface roughness was initially 0.43 µm. This low value can be attributed to the sharp, unworn cutting edge. As the cutting speed increased to 125 m/min and 150 m/min, the roughness values were 0.52 µm and 0.34 µm, respectively. These differences though relatively small (0.18 µm) show a general trend of decreasing roughness. At 175 m/min and 200 m/min, the surface roughness further decreased to 0.20 µm and then increased slightly to 0.29 µm.

Previous studies have shown that surface roughness tends to improve (i.e., decrease) with increasing cutting speed, up to a certain point [5,6]. Beyond this optimal range, further increases in cutting speed can cause deterioration in surface finish due to tool wear and thermal effects [8]. Surface roughness is affected by several factors, including machining parameters, tool geometry, workpiece material, and tool wear [9]. Manufacturing engineers must also consider cutting time when selecting parameters. While a lower feed rate generally produces a smoother surface, it also results in significantly longer machining times.

The experiment continued at a higher feed rate of 0.20 mm/rev with the same cutting speeds. The surface roughness values for this trial were 1.06, 1.08, 1.02, 0.90, and 0.81 µm at 100, 125, 150, 175, and 200 m/min respectively. At a feed rate of 0.30 mm/rev, the roughness values increased further to 2.50, 2.42, 2.33, 2.23, and 2.03 µm, respectively, at the same cutting speeds.

Researchers who studied machining of Aluminium Metal Matrix Composites (MMCs) using different cutting tool materials observed that rough surfaces were often caused by flank and crater wear [4,6,7]. Low feed rates at high cutting speeds tend to result in lower surface roughness. However, high cutting speeds also generate elevated temperatures at the tool-workpiece interface, which can soften the tool material and worsen the surface finish. This behaviour explains the slightly increased values of surface roughness in trial 2.

As both feed rate and cutting speed increased, surface roughness tended to increase. Built-up edge (BUE) formation also significantly influenced surface finish [10]. At higher cutting speeds, the increased temperature can reduce material adhesion, potentially eliminating the BUE. However, when BUE detaches, it can remove parts of the tool material, leading to cutting edge chipping and deteriorated surface quality.

Ultimately, high cutting speed combined with low feed rate emerged as the most effective combination for achieving superior surface finish. An average surface roughness as low as 0.20 µm was achieved at 175 m/min and 0.10 mm/rev feed rate. However, it's important to balance this with machining efficiency, as lower feed rates significantly increase cycle time. Additionally, flank wear and chip formation patterns (especially continuous chips that may wrap around the tool or workpiece) must also be considered when selecting parameters. Improper chip control can damage the machined surface.

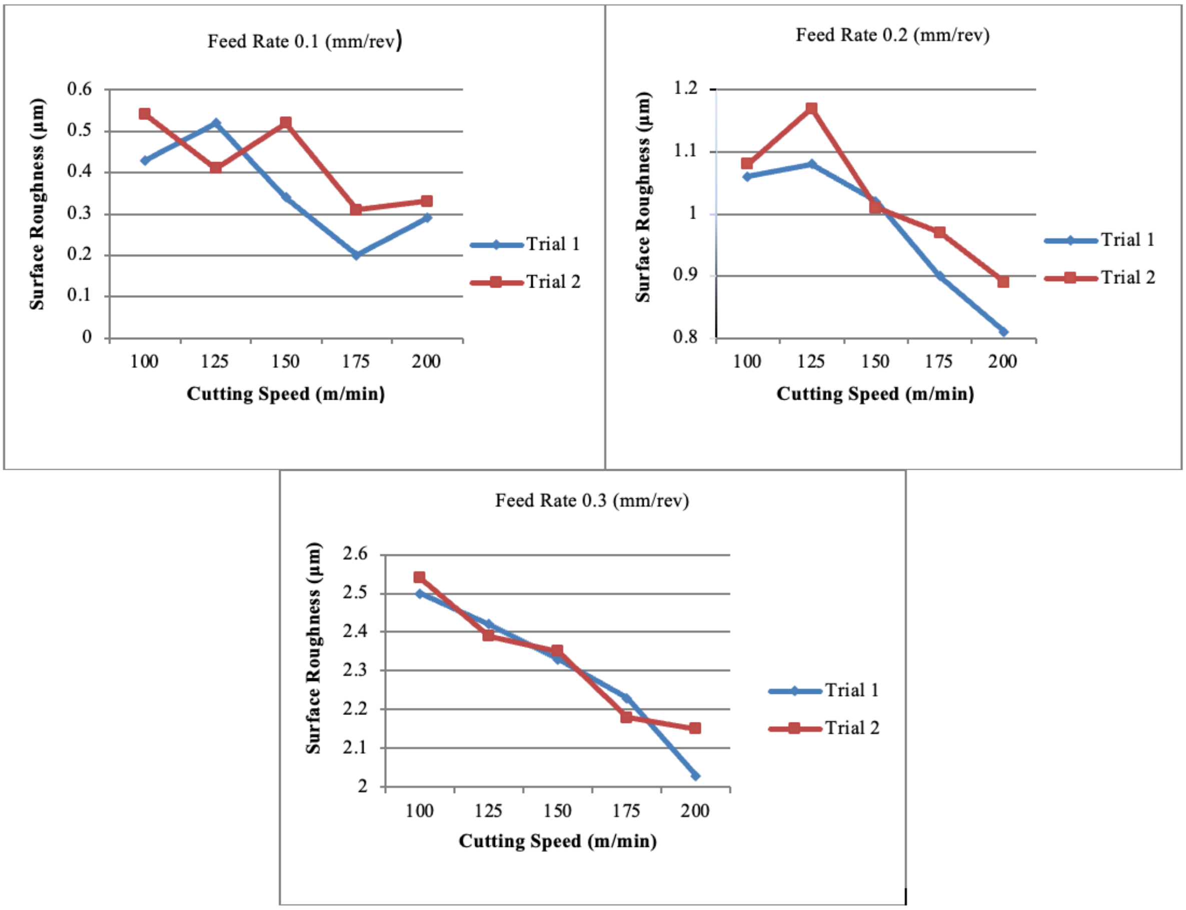

Fig 1. Effect of cutting speed at feed rate of 0.1mm/rev;0.2mm/rev and 0.3mm/rev on surface roughness.

3.2 Microhardness

Microhardness, as a key physical parameter of surface integrity, is influenced by a variety of factors, including technological parameters, the stereometrics and micro-geometry of the cutting edge, and others [4]. Among these, the cutting speed plays a particularly significant role during the surface layer formation process [1]. It directly affects the amount and rate of heat generated in the machining zone. This heat, in turn, penetrates the subsurface layers of the workpiece material, potentially altering its microstructural and mechanical properties, including microhardness. Given this, the functionality of the machined surface which is closely tied to microhardness can be substantially affected by thermal and mechanical loads induced during turning [7].

From Figure 6 it can be seen that as cutting speed is increased the chip microhardness is decreased. It is found that the lowest values of chip micro-hardness were at the highest values of cutting speed mean at level 200 m/min. This was because, as cutting speed is increased the cutting forces are decreased thus lowering the amount of heat generation and as a result the rate of strain hardening is decreased. Also, at high cutting speed and the time allowed to machine the surface is shorter meaning that the time during which the tool is in contact with the work piece is short, so heat generation due to the mechanism of cutting and friction which is a function of rubbing between tool and work piece as of a small amount [2,5]. A small quantity of heat which is transferred to the chip does not result microstructure change of the chip and strain hardening is of negligible effect compared with lower cutting speed [10]. In Figure 6, feed rate is shown to have its effect on chip microhardness. However, as feed rate is increased the chip microhardness is increased relatively up to the highest feed rate at level 0.3mm/rev. Thus, as feed rate is increased, a large amount of metal removed is subjected to higher temperature and plastic deformation because of an increase in cutting force and normal force which result in temperature increase of the chip and plastic deformation which results hardening of the chip especially at the interface between the chip and tool [10]. At the slow cutting speed, the heat input to the material was high and it resulted in wider HAZ, whereas, at a faster cutting speed, the heat input was lower and a correspondingly narrower HAZ was obtained [9].

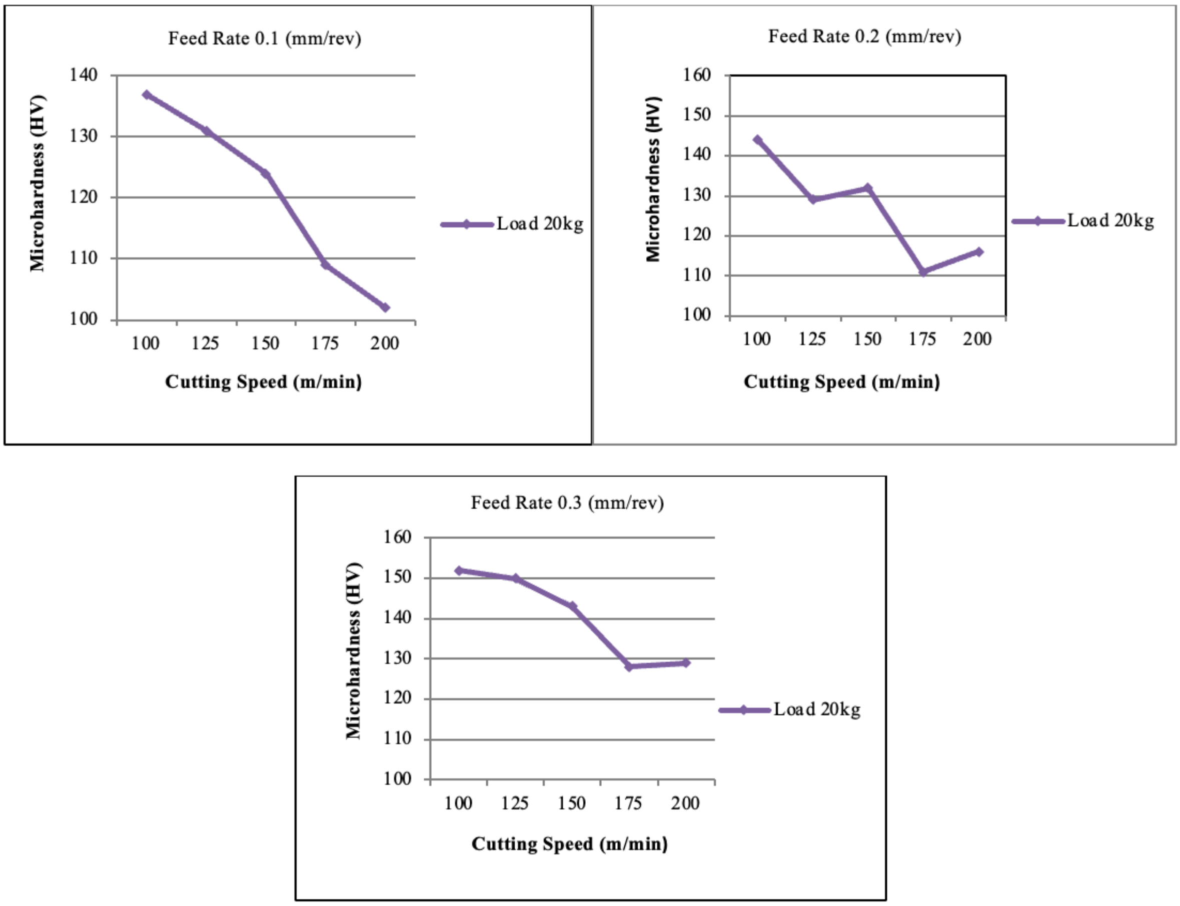

Fig 2. Effect of cutting speed at feed rate of 0.1mm/rev;0.2mm/rev and 0.3mm/rev on microhardness.

4.0 Conclusion

Building on the foundation of earlier studies conducted primarily in industrialized nations, this research aims to enhance the understanding and performance of turning processes applied to metal matrix composites (MMCs). By identifying and optimizing machining parameters, the productivity and cost-effectiveness of machining MMCs can be significantly improved. Prior research has already established the viability of machining MMCs using appropriate tool materials and cutting conditions [1,3]. This study further emphasizes that proper selection of parameters such as cutting speed, feed rate, and tool material can make the machining process more efficient and economically viable across various industrial applications.

The surface roughness of MMCs during turning operations is predominantly affected by cutting speed. Higher cutting speeds generally lead to better surface finishes. However, increasing the cutting speed also raises the temperature in the cutting zone, potentially causing softening of the tool material [3]. Feed rate also plays a critical role where bigger feed rates tend to degrade surface quality by producing rougher surfaces [4]. At constant depth of cut, higher cutting speed with lower feed rate initially improves surface finish for hard to machine MMCs, but this improvement plateaus or reverses at very high speeds due to thermal effects and tool wear.

Among the examined parameters, cutting speed and feed rate were the most influential in determining surface finish. Additionally, tool wear directly impacts surface roughness and often serves as the trigger for tool replacement in finish turning applications [5].
The machinability tests indicated that tool wear is a critical factor in the turning of Al/SiC MMCs. Two common wear types were identified: flank wear and crater wear, with flank wear being dominant. Abrasive wear was the primary mechanism, with no significant evidence of chemical wear. Cutting speed emerged as the most influential parameter, with increased speeds accelerating wear rates. Feed rate was the second most significant factor where higher feeds produced increased tool wear [2,5].
Interestingly, flank wear was more sensitive to cutting speed than to feed rate. At lower cutting speeds, increased cutting forces and the formation of built-up edge (BUE) accelerated wear. Based on these findings, for rough or medium turning, it is recommended to use low cutting speeds with high feed rates and depths of cut in combination with coated carbide tools to maximize tool life. For finish machining, high cutting speeds with low feed rates yield superior surface finishes when using coated cutting tools [7].

Another observed phenomenon was the variation in chip microhardness. The lowest chip microhardness values were found at the highest cutting speeds, while the highest micro-hardness was recorded at elevated feed rates. Increased cutting speeds reduce cutting forces and heat generation, thereby lowering strain hardening effects due to shorter contact time between the tool and workpiece [10].

Conversely, higher feed rates produce more significant deformation and heat at the tool chip interface, resulting in increased chip hardness. At low cutting speeds, the heat input is greater, leading to a wider heat-affected zone (HAZ). In contrast, higher cutting speeds result in lower heat input and narrower HAZ, minimizing thermal damage to the workpiece surface [9].
The machinability of MMCs in turning operations is strongly dependent on cutting parameters. Surface roughness is best minimized through high cutting speeds and low feed rates, while tool life is extended under lower speeds and higher feeds. Tool wear, particularly flank wear due to abrasion, is a critical limitation in MMC machining and must be factored into process planning. Optimizing these parameters not only improves surface finish and productivity but also enhances the economic feasibility of hard turning as an alternative to grinding for difficult to machine materials.

While reaching all the initially proposed goals, this dissertation is still far from answering all the questions raised by the complex phenomenon occurring in hard turning. Several future directions of investigations are proposed in relation with completed work.

(i) Surface roughness -Turning the material using different nose radius tool with fine feed rate and high speed turning.

(ii) Chip formation -The generated chips should be investigated through SEM as a function of cutting conditions and tool wear, the physical cause for chip segmentation should be determined. Measurement of temperatures at various operating parameters can be studied.

(iii) Tool wear -Tool life may be investigated based on operating parameters of the cutting regime as variation factors. The effect of chemical reactions between the tool and work material should be investigated from the view point of chemical wear and white layer formation on chips

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Study of Narrow Energy Band Gap Polymer Matrix for Organic Field-Effect Transistor-based Biosensor

Irfan Danial Ismadi[1], Muhammad Fakhrullah Mohamad Azmi[1], Muhammad Fadzlisyam Redzuan[1], Izzah Afifah Ibrahim[1], Mohd Ifwat Mohd Ghazali[1], Nizam Tamchek[2], Nurul Azmawati Mohamed[3], Shahino Mah Abdullah[1*]

1Faculty of Science and Technology, Universiti Sains Islam Malaysia, Bandar Baru Nilai, Nilai 71800, Negeri Sembilan, Malaysia
2Faculty of Science, Universiti Putra Malaysia, 43400, UPM Serdang, Selangor Darul Ehsan, Malaysia
3Faculty of Medicine and Health Sciences, Universiti Sains Islam Malaysia, Bandar Baru Nilai 71800, Negeri Sembilan, Malaysia

Abstract

In this project, triisopropylsilylethynyl-pentacene (TIPS-pentacene) will be utilized as a semiconducting polymer matrix for the preparation of biosensors based on organic field-effect transistor (OFET) structure. A thin layer of TIPS-pentacene can be easily formed on a silicon substrate through solution processable technique. Through polymer blend method which allows synergistic combinations of stacking configurations of multiple polymers energy levels which will enhance overall charge transport. Novel pentacene derivatives will also be proposed using machine learning method and computational study for synthesizing new narrow energy band gap polymer matrix. Analytical techniques, such as ultraviolet-visible (UV-Vis) spectroscopy will be used in the characterization of the materials properties. The proposed biosensor based on integration of biological compound into OFET will facilitate the government.

Keywords: *Triisopropylsilylethynyl-pentacene; organic field-effect transistor; semiconducting polymer matrix; biosensor.*

1.0 Introduction

Previous research has demonstrated the potential of OFET-based biosensors for detecting the various disease by the presence and amount of biological compound [1,2,3]. But, due to lack of charge mobility, stability and reproducibility, OFET devices eventually has limitation to their performance and affect sensor detection [4,5]. Moreover, further research is needed to maximize its practicality for the use in medical environments. There are several strategies to improve the functionality of OFET to detect infectious diseases more accurate. One of the methods is via blend strategy [6]. The electrical performance of an OFET device with common material such as pentacene for instance which can be enhanced by blending with other semiconductor materials whether small molecules or polymers [7].

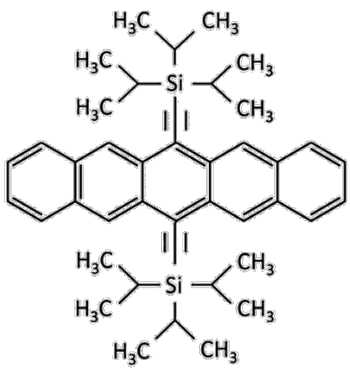

Fig. 1. TIPS-pentacene molecular structure

In this project, 6,13-bis(triisopropylsilylethynyl)pentacene or TIPS-pentacene will act as polymer matrix for the preparation of OFET-based biosensor. It was selected as a main polymer matric due to its excellent solubility in many organic solvents, make it easier to be utilized in many solution-process methods for large area and low-cost electronic devices [8,9,10,11]. As Fig.1 shows the molecular structure of TIPS-pentacene, it also can use the same solvent that be dissolved by other semiconductor materials, it can mix and allows its electrical parameter such as energy band gap to be tuned [12,13,14,15]. It is expected that by reducing the energy band gap, it can help to increase the mobility [16,17].

A composite can be obtained by blending two different conjugated polymers with different band gaps and tunable band gap could be adjusted by changing the blending ratio of the two polymers. The best methods for tuning the band gap of OFETs is by interpenetrating polymer networks and polymer blending which allowing for the control of the band gap and the improvement device performance [18,19,20,21]. Furthermore, TIPS-pentacene also have the highest hole mobility at the room temperature that made an optimum option among the organic materials and polycrystalline. Its application is much as like Polyacene and Anthracene single crystals and thin films of Tetracene, Anthracene as well as thin film structures are also investigated. The latest material including P3HT poly (3-hexylthiophene), TIPS-pentacene are P-type because the contact metal Fermi level is very close to the highest occupied molecular orbital (HOMO) level instead of lowest unoccupied molecular orbital level (LUMO): hence on the basis of this the P-type semiconducting materials are well developed and more stable in atmosphere than the N-type materials.
Moreover, a high annealing process is required to prepare materials with a high dielectric constant, which is impossible in plastic. Several applications use organic field-effect transistors (OFETs), which are active layers in matrix displays, biological sensing, chemicals, radio frequency identification (RFID) tags, and flexible electronics [22].

2.0 Methodology

2.1. Synthesis of narrow the energy band gap of pentacene derivatives

A conjugated polymer, TIPS-pentacene, was dissolved using two different solvents, namely chloroform and dimethylformamide (DMF). Both solutions were constantly stirred for 1 hour using magnetic stirring to obtain a uniform solution. In this process, there were only two reference samples on two different substrates. The samples were run under UV-Vis. A new solution of co-polymer materials was prepared for creating interpenetrating polymer networks (IPN).

2.2. Fabrication of organic field-effect transistor

The ITO glass substrate was used for OFET and Sensing as shown in Fig. 2, which has been designed to enable the fabrication and characterization of transistors and sensing devices without the need for vacuum evaporations or probe stations. This is to make a system ideal for reducing the costs of material screening experiments, but allows devices to be produced and tested with significantly increased simplicity.

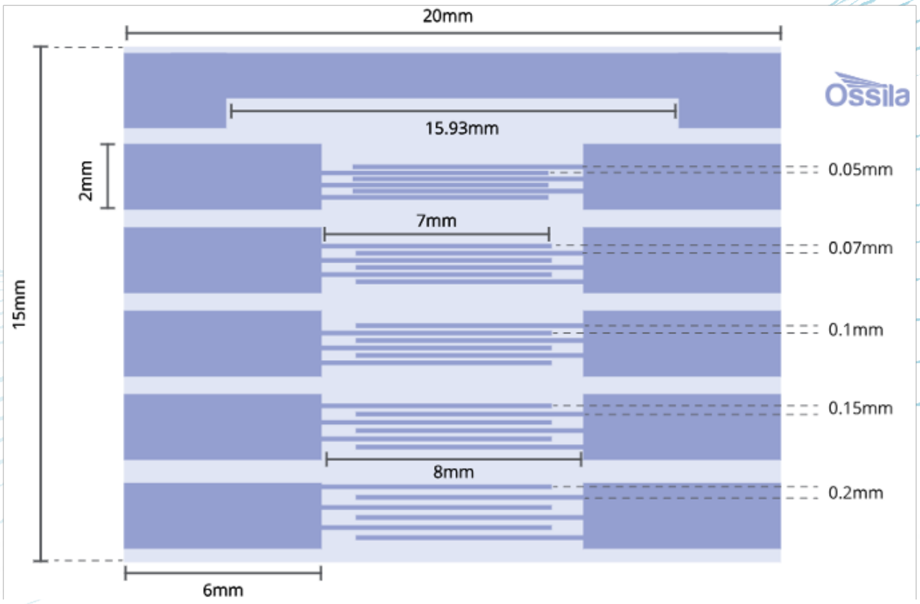

Fig. 2. Ossila ITO OFET substrate variable schematic. The Gate channel length is 20mm. The Drain and Source channel lengths are 6mm and 8mm apart from each other

By simply depositing an organic semiconductor, gate insulator, and gate on the substrates, the transistor can be fabricated. By using a synthetic metal such as PEDOT; PSS, deposited from solution for the gate, it is possible to make a fully functioning OFET with solution processing alone, eliminating vacuum evaporation processes. The substrates were also designed to work with a wide variety of different material systems and deposition techniques, while all solution-based processing allows transistors to be fabricated in a matter of minutes.

2.3. Optimization of biosensor

By using a combination of other polymer materials, it can achieve optimized interpenetrating polymer networks (IPN). The TIPS pentacene will be added to this co-polymer solution to tune its energy band gap. The same process of phase 2 was used to fabricate the same OFET sensor devices but with a different combination of co-polymer IPN. The process will be continued to optimize the OFET sensor by fabricating the same OFET biosensor devices on the ITO-coated PET film with pre-patterned source-drain channels. The pre-patterned source-drain channels are formed using the photolithography technique before the deposition of the mixed TIPS pentacene and co-polymer solution. These OFET biosensors will also be characterized using SMU to obtain current-voltage characteristics for saturation and transfer curves.

2.4. Collecting real data and analyze

The fabricated organic field-effect transistor (OFET) biosensor was connected to a microcontroller unit (MCU) and an Analog Devices M1K ADALM1000, which were used to collect data based on changes in electrical signals when the sensor detected the presence of a target substance. The acquired data were analyzed using the Tauc plot method to determine the optical band gap energy (Eg). The optical band gap energy (Eg) of a semiconductor was a crucial parameter that defined the minimum photon energy required to excite an electron from the valence band to the conduction band [23]. According to Eq. (1), the optical absorption coefficient (α) of a semiconductor was energy-dependent and followed the relation:

$$(ahv)^{\frac{1}{n}} = A\ (hv - Eg) \quad (1)$$

where h is the Planck constant, ν is photon's frequency, Eg is bandgap energy, C is a constant, and α is the absorption coefficient which describes how much light of a given colour is absorbed by a material of given thickness. Depends on the nature of electron transition, the n is numerically equal to o 1/2, 3/2, 2 or 3 for direct allowed, direct forbidden, indirect allowed, or indirect forbidden transitions, respectively. By analysing the Tauc plot, we can gain deeper insights into the electronic and optical properties of the semiconductor material used in the biosensor.

3.0 Results and discussion

The electrical properties of an organic semiconductor are studied to measure the current-voltage characteristics. The main electrical characteristics in the organic field-effect transistor is determined by the charge carrier transport in the polymer material across a gap between the Source and Drain terminals. The terminal that majority charge carrier enter the FET is called Source, while the terminal that majority charge carrier exit the FET is called Drain. The charger carrier mobility in polymer are limited to hopping mechanisms across the band gap between the interfaces of Source/conjugated molecules/Drain. The result is obtained from the UV-vis spectroscopy which can calculate material's light absorption in solution form.

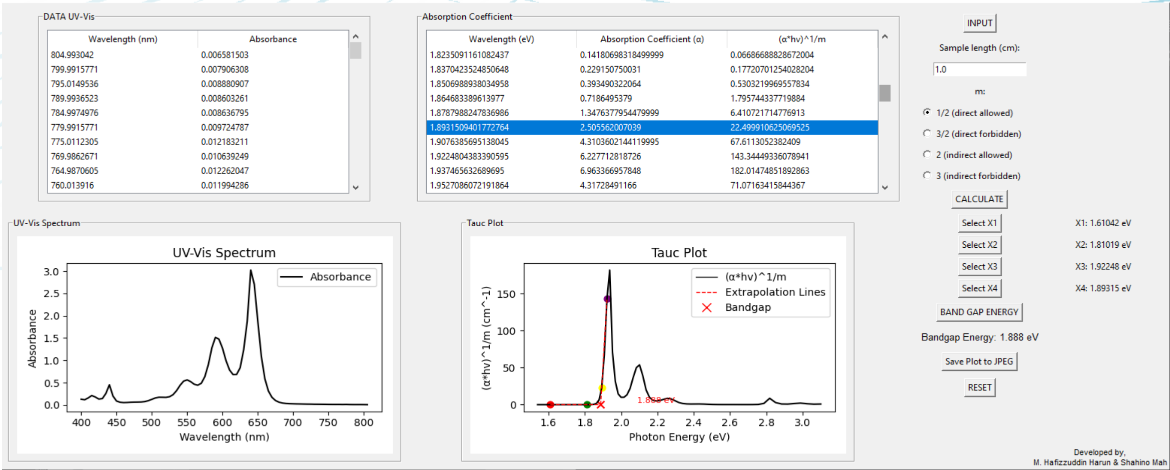

Fig. 3. The plotted graph of TIPS-pentacene solvent with chloroform

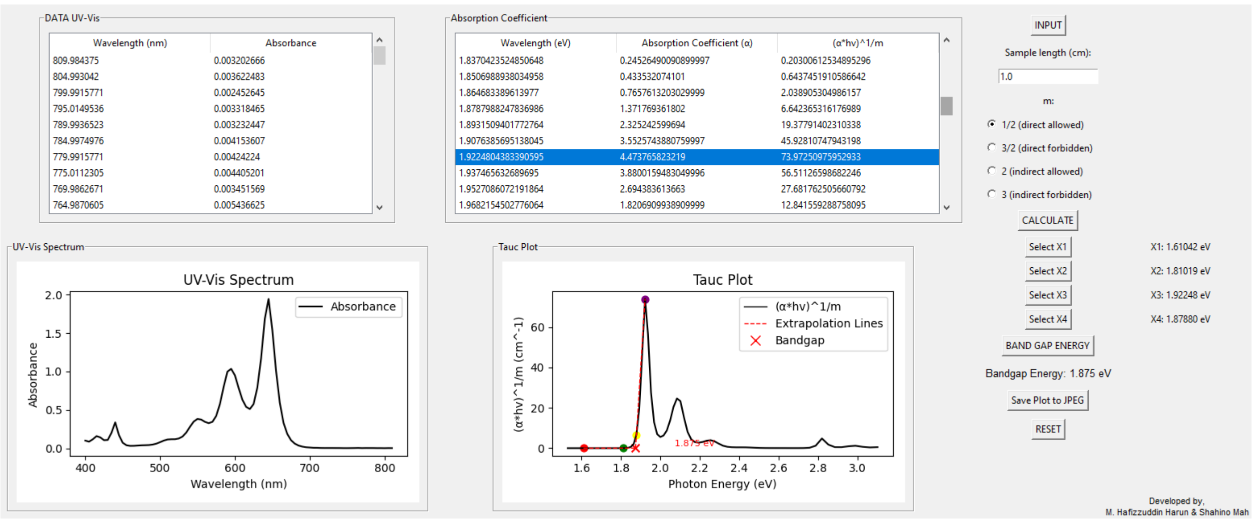

Fig. 4. The plotted graph of TIPS-pentacene solvent with dimethylformamide

From Fig.3, the data were inserted into a software, and it calculates the energy band gap. The Tauc Plot is used to determine the optical bandgap of either disordered or amorphous semiconductors. The optical band gap of TIPS-pentacene, ranging from 1.6 eV to 1.87 eV in thin film form, is commonly reported to be around 1.72 eV. In this work, the value of the optical bandgap was found to be 1.888 eV when dissolved in chloroform. While for the UV-vis spectrum shows the absorbance vs wavelength (nm). The curve for this graph is the same curve of blue colour wavelength, which peaks between 600 nm to 700 nm. Then, for Fig.4, the value of bandgap energy obtained was 1.875 eV when dissolved in DMF. While for the UV-vis spectrum shows the same curve as Fig.3, which is a peak between 600 nm to 700 nm. The reason both consist of the same UV-vis spectrum curve is that each solution is a dye in blue colour.

The difference between the optical bandgap energies of TIPS-pentacene dissolved with chloroform (1.888 eV) and dimethylformamide (1.875 eV), observed as such, is due to the influence of the solvent and not measurement error. This is because all the experimental conditions, like polymer concentration, stirring rate, substrate type, sample preparation, and measurement configurations, remained consistent to eliminate variability. Further, the readings were consistent with replicable values being taken from repeated experimentation, indicative of systematic rather than random error. Even the small variance of 0.013 eV, although small, lies outside the normal error range for UV-Vis spectroscopy and must therefore be considered significant. The deviation can be accounted for by the differing interactions of the solvents with the TIPS-pentacene molecules. The non-polar solvent chloroform and the polar solvent dimethylformamide (DMF) influence the molecular conformation of the polymer, chain packing, and film morphology in various ways when dissolving and casting into films. The electronic structure, particularly the π-π stacking, is influenced by these alterations, inducing slight alterations in the optical bandgap. Parallel solvent-dependent behaviour was shown by conjugated polymers according to the literature, so the conclusion based on this that the observed difference is due to solvent effect rather than instrumental or reading error is supported further.

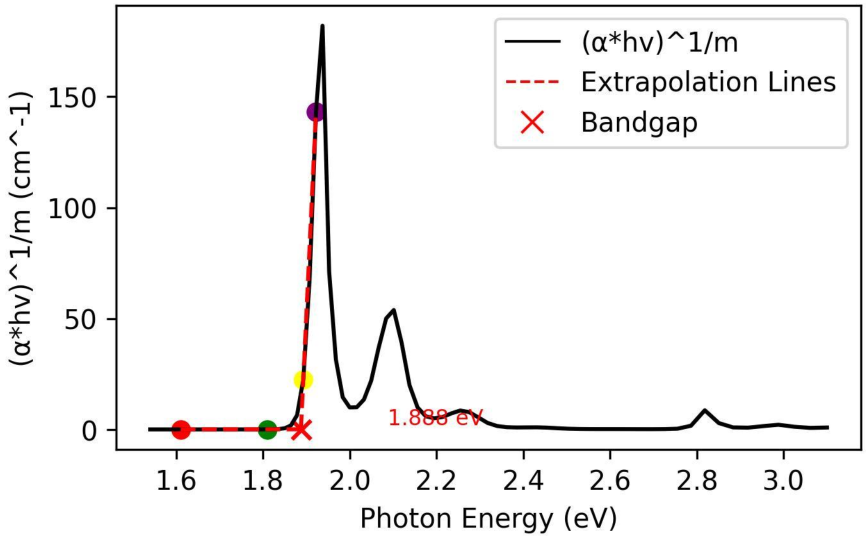

Fig. 5. Tauc Plot of TIPS-pentacene diluted with chloroform

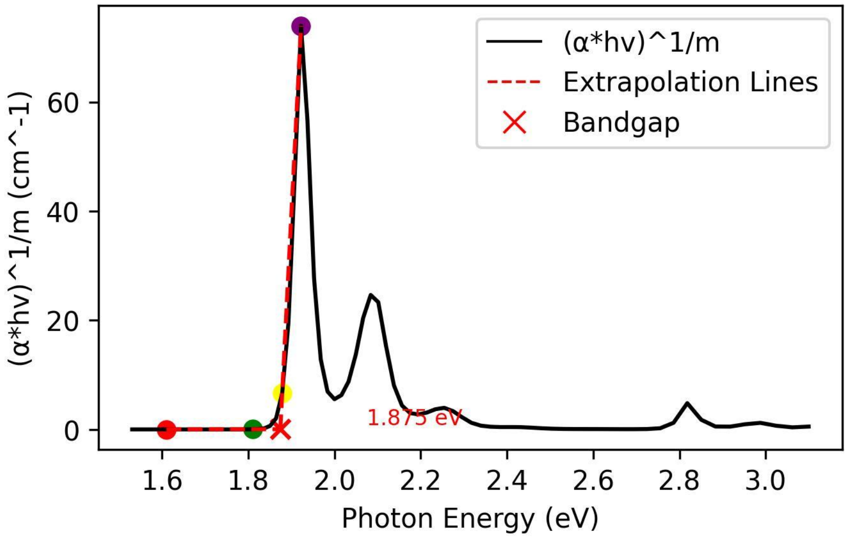

Fig. 6. Tauc Plot of TIPS-pentacene diluted with dimethylformamide

4.0 Conclusion

The solution of TIPS-Pentacene dissolved in both DMF and chloroform has been prepared to determine the optical energy band gap. This measure will be very helpful for the fabrication of OFET-based biosensors. By comparing the results between two solvents, DMF has a slightly better, negligible bandgap energy, which is 1.875 eV, while for the solvent chloroform, it is 1.888 eV. The bandgap energy represents the minimum energy that is required to excite an electron up to a state in the conduction band where it can participate in conduction [25]. The solvents that have higher boiling points result in larger grain size and can improve crystallinity [26]. By combining both lower bandgap blended polymer matrix and an increase in Gate applied voltage which make detection rate will significantly increase. A decrease in bandgap in a polymer material means a lower amount of energy required to excite electrons from the valence band to the conduction band, so more charge carrier generation occurs upon light or analyte exposure. Enhanced carrier density enhances the conductivity and sensitivity of the organic field-effect transistor (OFET) channel. It can be a potential candidate for the biomedical sensor to rapidly detect infectious diseases because of has better internal charge carriers. When rapid and accurate detection of the disease can be carried out within a short time, it can provide immediate information to curb the spread of infection and save more lives.

Acknowledgements

This research was supported by Universiti Sains Islam Malaysia under USIM Research Grant (PPPI/USIM/FST/USIM/112623). The research was also funded by the Ministry of Higher Education, Malaysia under the Fundamental Research Grant Scheme (FRGS/1/2024/STG07/USIM/02/1).

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Fabrication of 3D-Printed Flow Cell Biosensor for Pathogenic Escherichia Coli Bacteria Detection

Muhammad Fadzlisyam Redzuan[1], Irfan Danial Ismadi[1], Muhammad Fakhrullah Mohamad Azmi[1], Izzah Afifah Ibrahim[1], Mohd Ifwat Mohd Ghazali[1], Nurul Azmawati Mohamed[2], Nizam Tamchek[3], & Shahino Mah Abdullah[1*]

[1]*Faculty Science and Technology, Universiti Sains Islam Malaysia, 71800, Nilai, Negeri Sembilan, Malaysia*

[2]*Faculty of Medicine & Health Sciences, Universiti Sains Islam Malaysia, 71800, Nilai, Negeri Sembilan, Malaysia*

[3]*Department of Physics, Universiti Putra Malaysia, 43400, Serdang, Selangor, Malaysia*

Abstract
This research seeks to develop an innovative 3D-printed biosensor for the rapid and accurate detection of Escherichia coli (E. coli) bacteria in water samples. The proposed biosensor will incorporate a flow cell design, which allows continuous monitoring and efficient detection of E. coli in real-time. The sensor will be fabricated using conductive polymer-based materials integrated with specific biological recognition elements to ensure high sensitivity and specificity. The 3D printing technology will be utilized to create a precise and reproducible flow cell structure, optimizing the sensor's functionality and scalability. The research will proceed through several key phases: designing and simulating the flow cell structure, selecting and functionalizing the sensing materials, fabricating the biosensor using 3D printing techniques, and conducting extensive testing with water samples containing various concentrations of E. coli. This research will establish a foundation for future advancements in portable and effective biosensing devices for early detection of bacterial contamination.

Keywords: *Escherichia Coli; Biosensor; Flow Cell; 3D printing*

1.0 Introduction

Traditional methods for detecting E. coli contamination, such as culture-based techniques and polymerase chain reaction (PCR), while effective, are time-consuming, labor-intensive, and require specialized laboratory equipment. These limitations create a demand for more efficient, portable, and real-time detection methods. Biosensors offer a promising solution, providing the capability to detect E. coli rapidly and accurately without the need for extensive sample preparation or sophisticated instrumentation. The development of biosensors for E. coli detection addresses several critical needs involving speed, portability, sensitivity, and cost-effectiveness [1]. In this case, rapid detection can prevent the spread of contamination and enable timely interventions. Field-deployable sensors allow on-site testing in various environments, from food processing plants to remote water sources. High sensitivity ensures the detection of low bacterial concentrations, while specificity ensures that the sensor targets E. coli strains accurately without cross-reacting with other microorganisms.

Flow cell biosensors based on electrochemical structure have emerged as a superior design for detecting bacterial contamination Fig. 1. The flow cell structure offers several advantages that include continuous monitoring, enhanced sensitivity, improved response time, and reduced fouling [2,3]. The flow cell design allows for the continuous flow of samples through the sensor, enabling real-time monitoring and immediate detection of contaminants [4]. The continuous flow ensures that fresh samples are constantly exposed to the sensing elements, increasing the likelihood of detecting bacteria even at low concentrations.

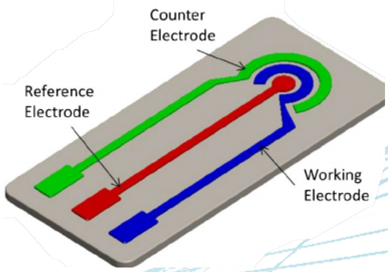

Fig. 1. Basic construction of electrochemical flow cell sensor

This research will leverage 3D printing technology in biosensor production Fig. 2. 3D printing allows for the precise and reproducible creation of complex sensor structures that would be challenging to produce using traditional manufacturing methods [5]. Key benefits of using 3D printing for biosensor production include customization, scalability, precision, and material versatility. In this case, 3D printing enables the design and production of biosensors tailored to specific applications and requirements. 3D printing supports a wide range of materials, including biocompatible polymers and conductive materials, essential for the construction of functional biosensors.

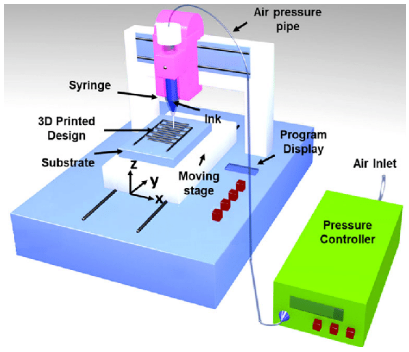

Fig. 2. Sensor fabrication via 3D printing technique

Potassium chloride (KCl) is the most widely used supporting electrolyte solution for application in cyclic voltammetry (CV) experiments because of high aqueous solubility and good conductor [6], providing optimum ionic strength and enhancing solution conductivity. This minimizes uncompensated resistance and leads to greater accuracy and reproducibility in electrochemical measurement. In addition to that, chloride ions in KCl are able to stabilize some metal cations via complex formation, influencing their electrochemical reactions.

Nickel (II) phthalocyanine-tetrasulfonic acid tetrasodium salt (NiTsPc) is a water-soluble chemical having a stable planar structure Fig. 3. Its four sulfonate groups allow it to dissolve in water, making it suitable for a variety of applications. NiTsPc is commonly used to construct nanostructures such as thin films with layer-by-layer (LbL) assembly. This experiment will utilize a combined solution of Potassium Chloride (KCl) and nickel (II) phthalocyanine-tetrasulfonic acid tetrasodium salt (NiTsPc) as the water sample for cyclic voltammetry (CV) experiments and biosensor testing.

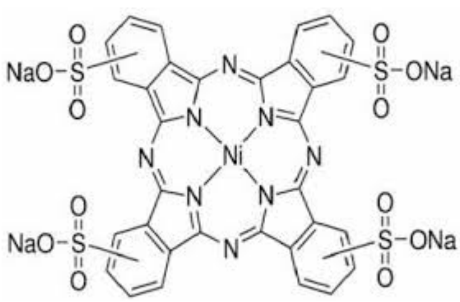

Fig. 3. Molecular structures of NiTsPc

2.0 Methodology

2.1 Design and selection of sensing materials

The initial phase of the research involves the conceptualization and optimization of the 3D-printed flow cell biosensor's design. This begins with an extensive literature review to understand the current advancements and limitations in biosensor technology, particularly focusing on flow cell designs. Using computer-aided design (CAD) software, detailed models of the flow cell structure will be created, incorporating microfluidic channels and sensor integration points to facilitate optimal fluid dynamics and bacterial interaction Fig. 4 [7,8].

The second phase focuses on the selection and functionalization of conductive polymer-based materials to be used in the biosensor. The process begins by identifying and testing various conductive polymers suitable for 3D printing and biosensing applications. Fluid dynamics simulations will be conducted to analyse and refine the flow patterns, shear stress, and bacteria transport mechanisms within the flow cell. Initial prototypes will be fabricated using 3D printing technology to test the feasibility and practicality of the design. The outcome of this phase will be a validated and optimized flow cell structure that ensures efficient fluid dynamics, setting a solid foundation for the subsequent phases of biosensor development.

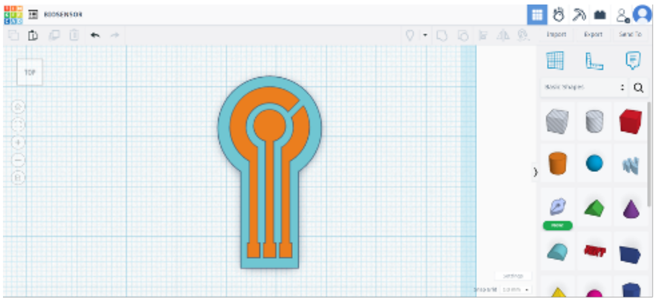

Fig. 4. Schematic of the 3D-printed flow cell biosensor's design

2.2 Setup for the cyclic voltammetry (CV) testing

This phase began with the preparation of the cyclic voltammetry (CV) setup to evaluate its performance on the water samples Fig. 5. The Analog Device ADALM1000 was used to demonstrate the relationship between current, voltage, and impedance (including resistance, inductance, and capacitance). When connected to a laptop or tablet, the ADALM1000 functioned as a personal portable laboratory [9]. Pixelpulse2, an open-source program, provided a user interface for visualizing and adjusting signals while analyzing systems connected to the device.

The CV setup included three different electrode materials: 1) platinum (Pt) as the counter electrode, which was connected to the GND of the ADALM1000, 2) graphite (Gr) as the working electrode, which was connected to the CHA of the ADALM1000, and 3) silver chloride (AgCl) as the reference electrode, which was connected to the CHB of the ADALM1000. For the preparation of the water sample used to systematically evaluate the CV's performance, the experiment utilized two solutions consisting of: 1) 40 mL of 3M KCl combined with 3 mL of 0.1M KCl + 0.5 mg/mL of NiTsPc, and 2) 40 mL of 3M KCl combined with 6 mL of 0.1M KCl + 0.5 mg/mL of NiTsPc.

The CV measurements were conducted over 3 complete cycles to ensure consistency and repeatability of the electrochemical response. No specific scan rate was defined during the experiment, as the ADALM1000 and Pixelpulse2 interface operated based on time-domain sampling rather than conventional potentiostat scan rate settings. The sampling rate was set to 1000 samples per second to capture detailed current and voltage fluctuations during each cycle. These parameters were chosen to balance data resolution with system stability and processing efficiency.

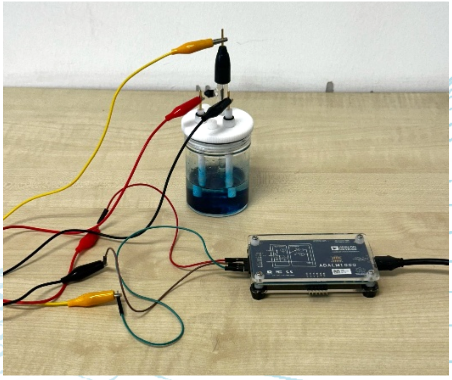

Fig. 5. Setup for the cyclic voltammetry (CV) testing

2.3 ***Setup for the 3D-printed flow cell biosensor testing***

The experiment continued with the preparation of the 3D-printed flow cell biosensor setup to evaluate its performance on the water samples Fig. 6. In this phase, only the CV component was replaced with the biosensor, while the other devices remained the same for data evaluation.

The biosensor also contained three different electrodes: 1) the counter electrode was connected to the GND of the ADALM1000, 2) the working electrode was connected to the CHA of the ADALM1000, and 3) the reference electrode was connected to the CHB of the ADALM1000. The biosensor was tested by before and after applying a solution of 0.1M KCl + 0.5 mg/mL of NiTsPc onto its conductive surface to obtain the readings.

The biosensor's performance was rigorously compared with conventional detection methods to validate its effectiveness and highlight its advantages. This phase aimed to generate comprehensive data demonstrating the biosensor's high sensitivity, specificity, and reliability in detecting E. coli.

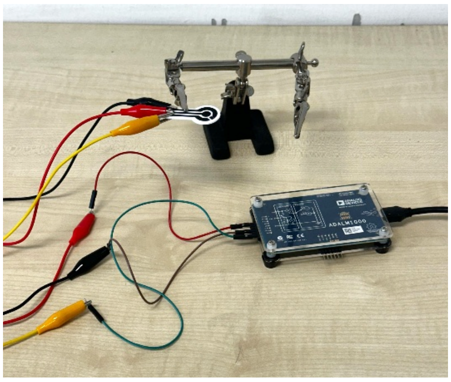

Fig. 6. Setup for the 3D-printed flow cell biosensor testing

3.0 Result and discussion

3.1 Fabrication of the biosensor using 3D printing

The research is centered on the actual fabrication of the 3D-printed flow cell biosensor using advanced 3D printing techniques Fig. 7 [10]. High-resolution Bambu Lab A1 mini 3D printers will be employed to fabricate the optimized flow cell structure, ensuring precise replication of the design developed in the first phase [11]. The integration of the functionalized sensing materials into the 3D-printed flow cell structure is a critical step, requiring precise alignment and secure attachment to maintain the sensor's functionality [12]. The complete assembly of the biosensor will also include necessary electronic components for signal transduction and data acquisition. Throughout this process, rigorous quality control tests will be conducted to verify the structural integrity and functionality of the biosensor components. This phase will culminate in a fully assembled and functional 3D-printed flow cell biosensor, poised for performance evaluation and testing. The use of 3D printing technology not only ensures high precision and customization but also offers a cost-effective and scalable approach to biosensor production [13].

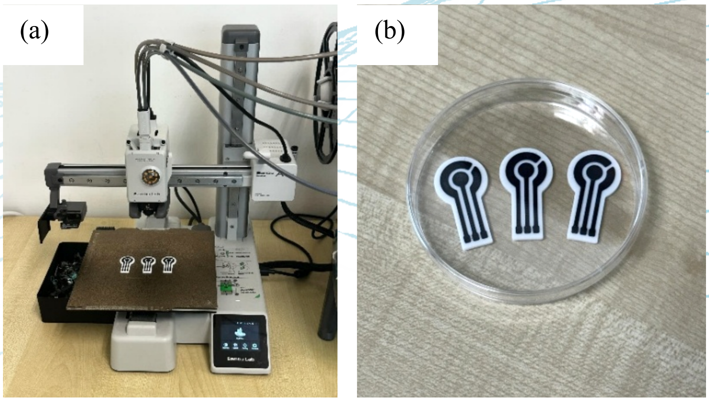

Fig. 7. (a) The advanced 3D printing techniques; (b) the actual fabrication of the 3D-printed flow cell biosensor

3.2 Testing on the cyclic voltammetry (CV)

The CV graph illustrated the response of how the current changed as the voltage was scanned in both the forward and reverse directions Fig. 8. The solution for this experiment was prepared using 40 mL of 3M KCl combined with 3 mL of 0.1M KCl + 0.5 mg/mL of NiTsPc. The results indicated variations in current as the voltage was applied in both directions. It showed that there were no clear peaks of oxidation and reduction available because the electrolyte solution might be insufficient at low concentration. Despite these fluctuations, the graph demonstrated the ability to form a distinguishable cyclic voltammetry. The current (A) ranged from approximately -0.035 to 0.04 A, while the voltage (V) varied between 0 and 3 V.

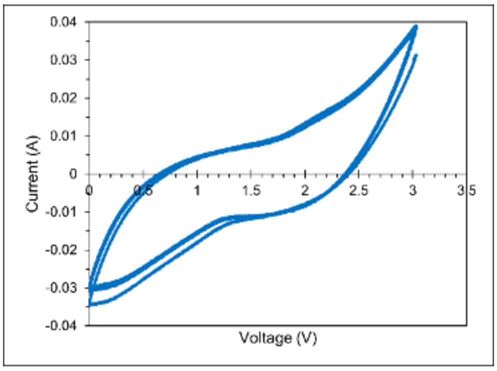

Fig. 8. CV's graph of 40 mL of 3M KCl with 3 mL of 0.1M KCl + 0.5 mg/mL of NiTsPc

This part showed the typical shape with an oxidation (anodic) and reduction (cathodic) peak illustrating the electroactivity of the system Fig. 9. Red lines showed the slope of different regions with response to the change in the current, and green arrows showed the voltage readings for oxidation was 2.2 V and reduction was 0.9 V. The solution for this experiment was prepared with 40 mL of 3M KCl with 6 mL of 0.1M KCl + 0.5 mg/mL of NiTsPc, and this could have impacted the electron transfer process and enhanced the electroactivity of the sensor. The current (A) ranged from approximately -0.027 to 0.03 A, while the voltage (V) varied between 0 and 3 V. The shape of the cyclic voltammetry showed excellent electron transfer characteristics, as reflected by the relatively symmetrical oxidation and reduction peaks.

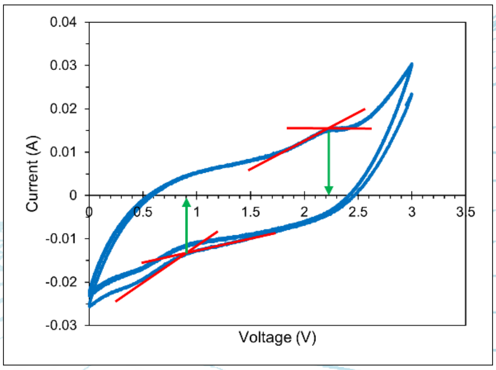

Fig. 9. CV's graph of 40 mL of 3M KCl with 6 mL of 0.1M KCl + 0.5 mg/mL of NiTsPc

To clearly compare the performance under both conditions, Table 1 summarizes the key observations from each CV test:

Solution Composition	Current Range (A)	Voltage Range (V)	Redox Peaks
40 mL 3M KCl + 3 mL 0.1M KCl + 0.5 mg/mL NiTsPc	-0.035 to 0.04	0 – 3	Not clearly visible
40 mL 3M KCl + 6 mL 0.1M KCl + 0.5 mg/mL NiTsPc	-0.027 to 0.03	0 – 3	Oxidation at 2.2 V, Reduction at 0.9 V

This comparison reinforces the importance of optimal electrolyte concentration in achieving effective redox activity and highlights the potential of the CV setup in future electrochemical sensing applications.

3.3 Testing on the 3D-printed flow cell biosensor

As stated in the method, the 3D-printed flow cell biosensor was tested before and after the electrolyte solution was applied. Fig. 10 displayed the graph obtained when the biosensor was tested without any solution. The result showed that the voltage (V) ranged from 0 to 0.5 V, remaining nearly constant at Channel B across each cycle.

Fig. 10. Biosensor's graph without any solution

Next, the solution for this experiment was prepared using 0.1M KCl + 0.5 mg/mL of NiTsPc, then applied to the biosensor to obtain the graph Fig. 11. The results showed that the voltage (V) ranged from 0 to 1.4 V. A clear change was detected as the peaks increased, indicating that the biosensor exhibited conductive capability in detecting the solution.

Fig. 11. Biosensor’s graph with the solution of 0.1M KCl + 0.5 mg/mL of NiTsPc

To provide a clearer comparison of performance, Table 2 summarizes the key voltage responses observed before and after the electrolyte solution was introduced:

Condition	Voltage Range (V)	Peak Presence	Conductive Response
Before solution application	0 – 0.5	No peaks	Minimal
After solution application	0 – 1.4	Clear peaks	Significant

This comparison highlights the sensitivity of the 3D-printed biosensor to the electrolyte solution, suggesting its potential applicability in detecting analytes such as E. coli in future work.

4.0 Conclusion

The CV experiment achieved voltage readings of 2.2 V for oxidation and 0.9 V for reduction. The results indicated that the minimum electrolyte concentration required to obtain distinct oxidation and reduction peaks were 40 mL of 3M KCl mixed with 6 mL of 0.1M KCl + 0.5 mg/mL of NiTsPc. When a lower concentration was used, no significant reaction was observed. In the biosensing experiment, the results demonstrated that the fabricated 3D-printed biosensor generated a response upon contact with electrolyte solutions. It could be concluded that the fabrication of the 3D-printed flow cell biosensor using advanced 3D printing techniques achieved early success, as it was a low-cost, biodegradable, and mass-producible alternative to conventional methods. This suggests that the biosensor could serve as a practical alternative for detecting various water samples in real-life applications such as detecting E. coli or any bacterial disease. Although direct testing with E. coli samples has not yet been conducted, the experimental methods and preliminary results confirm the biosensor's functional responsiveness to electrolytic changes, indicating strong potential for bacterial detection. These findings lay the groundwork for future studies, where the biosensor will be further validated using real E. coli samples to confirm its specificity and sensitivity. Therefore, the current experiments provide a solid foundational approach toward developing an effective tool for microbial water quality monitoring.

Acknowledgement

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Study of biophysical mechanisms of aptamer-based biosensor for detection of Escherichia coli O157:H7

Muhammad Fakhrullah Mohamad Azmi[1], Wan Mardhiyana Wan Ayub[1], Muhammad Fadzlisyam Redzuan[1], Irfan Danial Ismadi[1], Mohd Ifwat Mohd Ghazali[1], Muhamad Arif Mohamad Jamali[1], Liyana Azmi[2], Nur Zaireena Zainal[2], Nazefah Abdul Hamid[2], Shahino Mah Abdullah[1*]

[1]*Faculty of Science and Technology, Universiti Sains Islam Malaysia, Bandar Baru Nilai, Nilai 71800, Negeri Sembilan, Malaysia*

[2]*Faculty of Medicine and Health Sciences, Universiti Sains Islam Malaysia, Bandar Baru Nilai, Nilai 71800, Negeri Sembilan, Malaysia*

Abstract

The increasing prevalence of pathogenic Escherichia coli (E. coli) in water and food sources poses a significant threat to public health, necessitating the development of rapid and accurate biosensor detection methods such as aptamer-based biosensors due to their high specificity and sensitivity. Aptamers are nucleic acids that can bind with high affinity and specificity to a range of target molecules. In this study, 1,000 shuffled variants of a known aptamer (PDB ID: 2AU4) were generated and evaluated for stability using RNAfold and RNALfoldz based on minimum free energy (MFE). The five most stable sequences were selected and analyzed for their secondary and tertiary structures using RNAComposer. The target protein, Shiga toxin (Stx, PDB ID: 1C48), was modeled with AlphaFold 3 and validated through Ramachandran plot analysis. Molecular docking using the HDOCK server revealed aptamer-protein binding interactions, offering insights into the structural features that influence binding specificity and stability. In conclusion, this research bridges theory for future applications, thereby establishing a theoretical framework to support the future development of aptamer-based biosensors targeting E. coli O157:H7.

Keywords: *Escherichia Coli; Aptamer; Protein; Molecular free energy; Molecular docking*

1.0 Introduction

Escherichia coli (E. coli) is a diverse group of bacteria found in the environment, foods, and intestines of humans and animals [1]. Enterohemorrhagic E. coli (EHEC), including the notorious O157:H7 strain can cause severe foodborne disease, leading to bloody diarrhea and potentially life-threatening conditions such as hemolytic uremic syndrome (HUS) [2,3]. Thus, the increasing prevalence of pathogenic E. coli in water and food sources poses a significant threat to public health, necessitating the development of rapid and accurate detection methods. Aptamer-based biosensors have emerged as a promising tool for pathogen detection due to their high specificity, sensitivity, and stability [4]. However, a comprehensive understanding of the structural dynamics underlying aptamer-target interactions remains limited. This study helps bridge that gap by using computational biophysical simulations to find stable aptamer candidates and predict how well they bind to E. coli Shiga toxin, bringing us a step closer to developing more effective next-generation biosensors.

This study will employ docking simulation to elucidate the interaction dynamics between specific aptamers and their target molecules which in this case is protein E. coli [5]. Docking simulations are very popular approaches able to assess the capacity of a given ligand to interact with a target. The goal of ligand-protein docking is to predict how a protein interacts with ligands of known three-dimensional structure [6]. There are three docking methods that can be classified: protein-small molecule docking, protein-nucleic acid docking, and protein-protein docking [7]. To evaluate a good docking process, a docking score will be calculated and analysed. Docking score is an algorithm designed to compute the binding affinity of a protein-ligand complex [8]. By simulating the binding processes at an atomic level, we will gain insights into the conformational changes and binding affinities of the aptamer that govern the selectivity and sensitivity of these biosensors [9].

Aptamer binding often indu Aptamer binding often induces conformational changes in both the aptamer and the target protein [10]. Aptamers are single-stranded oligonucleotides that fold into defined architectures and bind to targets such as proteins with high affinity and specificity [11]. Aptamer is built with three structures: primary, secondary and tertiary structures. Primary structures are built with a long sequence of nucleotides (A, T/U, C, G). The primary structures are fundamental for the secondary and tertiary structures. Secondary structures, generally a two-dimensional structure can form various secondary structures like hairpins, loops, bulges, and G-quadruplexes, which contribute to their overall 3D shape and binding capabilities. The evaluation stability of these structures is according to their molecular free energy (MFE) value. The lowest MFE value (negative MFE) determines the stability of that aptamer structure [12]. Tertiary structure or commonly known as three-dimensional structure enables aptamers to recognize and bind to their specific targets in molecular docking and molecular dynamic simulation [13].

2.0 Methodology

2.1. Software workflow

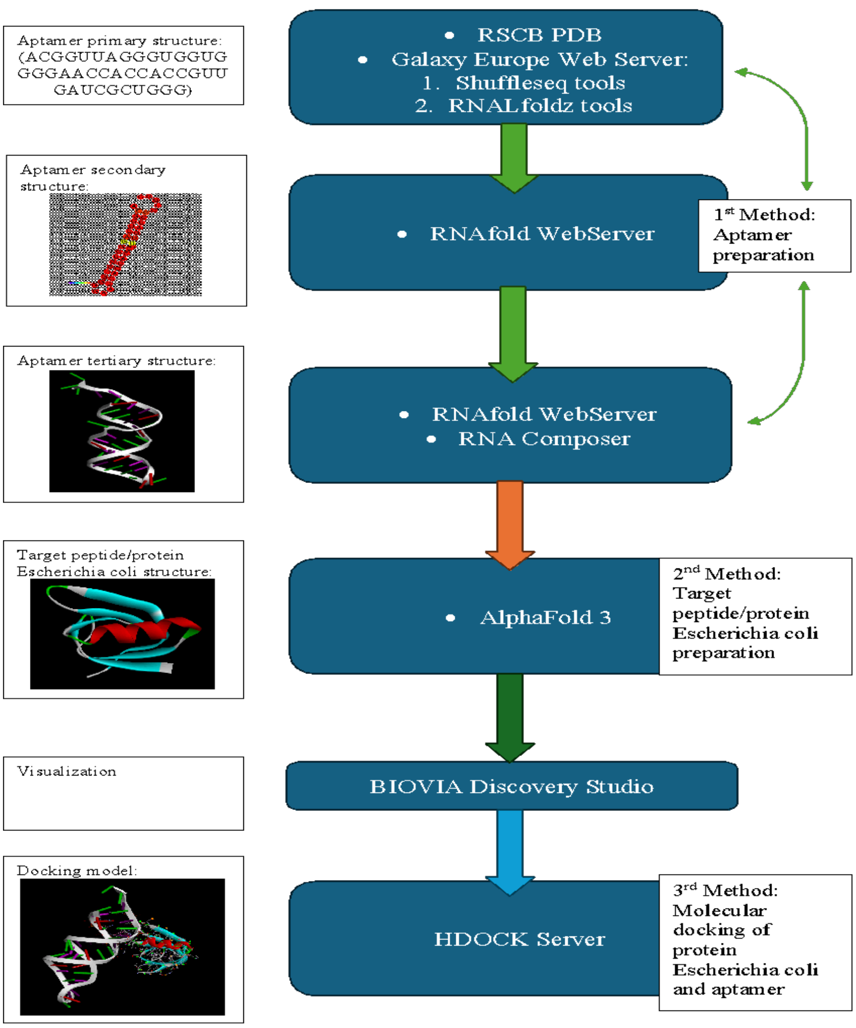

Fig. 1. Software workflow starting from aptamer structure, peptide structure and docking model

2.2. Aptamer preparation

The structure of aptamer was retrieved from Protein Data Bank with PDB code: 2AU4 as shown in Fig. 2.

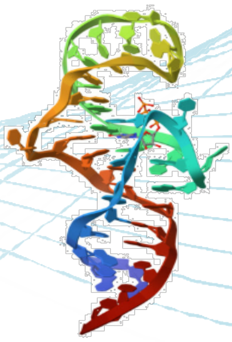

Fig. 2. 2AU4 Aptamer

The structure from PDB was exported in FASTA Sequence format because then the structure sequence needs to be shuffled to produce other clones of 2AU4 aptamer sequences. The shuffle process was using shuffleseq tools from usegalaxy.eu web server with 1000 number of shuffles. As a result, there were 1000 structures sequence of aptamer that can be validated in the next process. The validation of the aptamer's structures sequence was based on their molecular free energy (MFE) produced. This validation uses RNALfoldz tools from Galaxy Europe (https://usegalaxy.eu/) in FASTA sequence format. Then, the sequence was rearranged in MS Excel with their specific MFE value and from 1000 sequences, the best five sequences was chosen has the lowest MFE value as presented in Table 1. Next, for 3D structure analysis, RNA Composer is used, and the input format are in FASTA sequence and in dot-bracket format. This study uses RNAfold WebServer as it provides an interactive graphical output of the MFE structure or aptamer secondary structure as shown in Figure 3. From that, RNAfold WebServer was used to transform the FASTA sequence format into dot-bracket format.

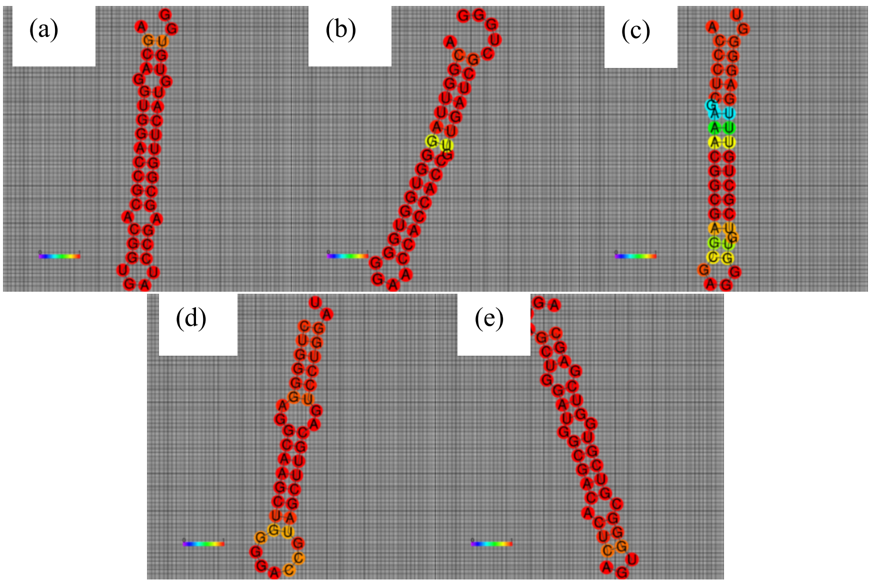

Fig. 3. MFE structure for (a) model 1; (b) model 2; (c) model 3; (d) model 4; (e) model 5.

Then, the five sequences of aptamer chosen are generated in RNAComposer software for three-dimensional structure in PDB file format as in Fig. 3 [14]. These five PDB files were analysed using BIOVIA Discovery Studio and ready to be docked with the target protein of Escherichia coli.

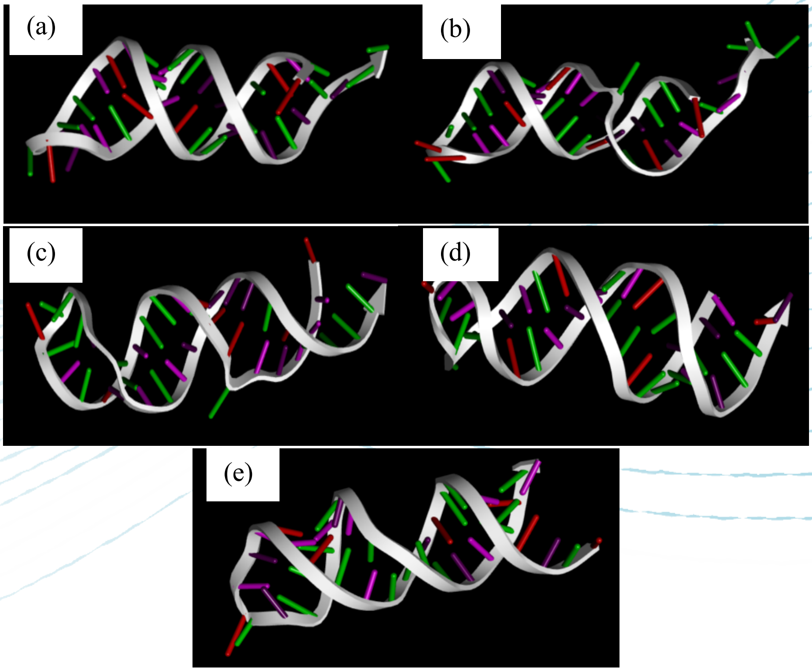

Fig. 4. 3D structures of 2AU4 Aptamer for (a) model 1; (b) model 2; (c) model 3; (d) model 4; (e) model 5.

2.3. Target protein Escherichia coli preparation

The crystal structure of target protein Escherichia coli was retrieved from PDB code: 1C48 called as Shiga Toxin (Stx). Shiga Toxin (Stx) is a potent cytotoxic protein that colonize human's colon and induce bloody diarrhea such as hemorrhagic colitis and hemolytic uremic syndrome that can lead to death [15]. There are many computationally approaches to generate accurate biomolecular structures predictions containing protein/peptide structures from amino acid sequences such as using PEP-FOLD4, AlphaFold 3, ESMFold, and OmegaFold [16,17]. Throughout this project, AlphaFold 3 were used as this software shows highly accurate prediction of the long peptide sequence structures [18]. The software operates the input sequence in FASTA format to read the peptide sequences. Next, the three-dimensional structures were visualized in Protein Data Bank (PDB) format using BIOVIA Discovery Studio software as shown in Fig. 5 and choose chart option to analyse the Ramachandran plot. The Ramachandran Plot was used to confirm the structure of peptide generate by these software [19]. Ramachandran Plot is a graphical representation of the dihedral angles, Phi (ϕ) and Psi (ψ) of amino acid residues in protein structures. There are four quadrants to explain the structure of protein as visualised in Fig. 6. In the quadrant-I that is the area of all conformations allowed, which it is the left-handed α-helix region. While quadrant-II, the biggest region, is the β-sheet region and quadrant-III is the right-handed α-helix region where both regions have better conditions for the conformation of atoms. Lastly, quadrant-IV has practically no framed locale [20].

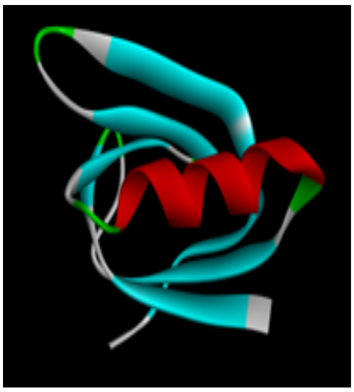

Fig. 5. 3D structures of Stx in the forms of solid ribbon

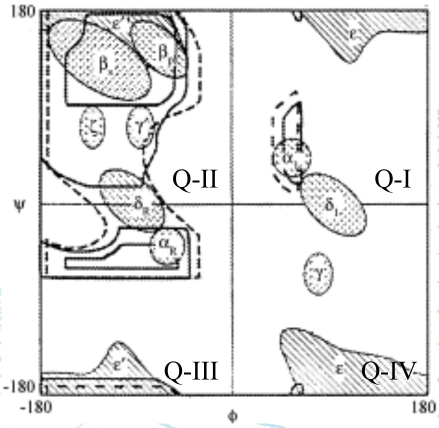

Fig. 6. Ramachandran Plot Quadrants [20]

2.4. Molecular docking of protein Escherichia coli and aptamer

Five chosen aptamers were docked with the protein Stx obtained from AlphaFold 3 as it shows stable structures as shown in Ramachandran plot, Fig. 7. The molecular docking process was using HDOCK server [21]. HDOCK server is a protein-protein and protein-DNA/RNA docking based on a hybrid algorithm of template-based modelling and ab initio free docking. The Stx protein as a ligand molecule and the chosen aptamer's PDB file was input as a receptor molecule. This was executed without any adding specification on the binding site. HDOCK results showed top ten possible docking residues prediction for each of five specific chosen aptamers and Stx protein in the PDB files format to visualize in the BIOVIA.

3.0 Results and Discussion

3.1. Structures of candidate aptamers and target protein Escherichia coli

Result from the Table 1, conclude that the aptamer model 1 with the sequence: AGCAGGUGGACCGCACGGUGAUCCGAGCGGUUCAUGUGUGG, has the lowest MFE values from RNAfoldz tools which is -24.0 kcal/mol and followed by model 2 which is -23.4 kcal/mol and model 3 is -22.6 kcal/mol. However, for models 4 and 5, the MFE values are decreased to -20.5 and -20.0 kcal/mol respectively. These results suggest that all the 2AU4 aptamer sequences exhibit lower MFE, suggesting structural stability [12].

From the Ramachandran plot, Fig. 7, Stx protein operated in AlphaFold 3 visualize that both regions, right-handed α-helix (quadrant III) and β-sheets (quadrant II) are the most prevalent structure in Stx. This suggest that Stx structures imparts stability to proteins and is crucial for their proper folding and function. From the analysis on both aptamer and protein, it is suggested to dock the top five model aptamer sequences with AlphaFold 3's structure.

Table 1. Molecular free energy (MFE) values for the best five aptamer models sequences from RNALfoldz tools

Aptamer Model	Aptamers sequences	MFE (kcal/mol)
1	AGCAGGUGGACCGCACGGUGAUCCGAGCGGUUCAUGUGUGG	-24.0
2	ACGGUUAGGGUGGUGGGAACCACCACCGUUGAUCGCUGGG	-23.4
3	ACCCUCGAAACGGCGAGCGAGGGUGUCGCUGUUUGAGGGGU	-22.6
4	CUGGGGAGGCAAGCUGGGGACCGUAGCUUGCAGUCCUGGAU	-20.5
5	AGUAGCUGGAUGGCGACACUCAGUGGGCGUCGUGGUCGAGC	-20.0

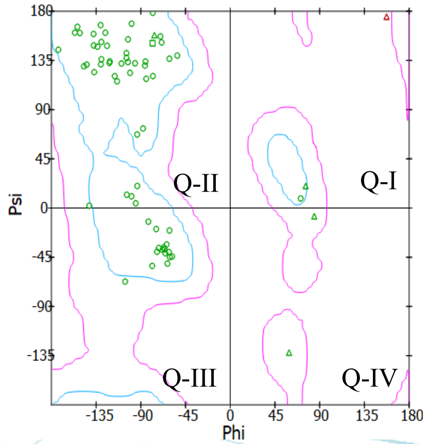

Fig. 7. Ramachandran plot for AlphaFold 3.

3.2. Molecular docking analysis

The analysis in 3.1 concludes that all of the 2AU4 aptamer structures are stable to be docking with AlphaFold 3's structures. Thus, molecular docking analysis was performed to estimate the binding affinity between the aptamer and Stx protein. There were 50 docking models produced from HDOCK server. The docking scores of the best prediction model in each of the five chosen aptamers with Stx are presented in Table 2, where the aptamers are ranked based on their docking scores. In general, the lower the rank, the better [22].

The scoring function that evaluates protein–aptamer binding is the most critical component of the docking method. A good dock score for a given aptamer signifies that it is potentially a good binder [23]. The results show that model 3 have the lowest docking scores of -267.50 as shown in Fig. 8. This is followed by model 2 and 5 with the binding energy of -250.90 and -244.88 respectively. However, even though model 1 has the lowest MFE values, it has higher docking scores of -232.13 compared to model 3, 2 and 5.

Next, averaging docking score proves informative method to account for multiple binding modes as computed by considering more proteins structures or more poses within a single structure [24]. The result from Table 3 suggests that model 2 aptamer has the lowest average docking scores of -227.73 for all the prediction models. However, model 1 only has an average energy of -216.93. This indicate that the docking score does not always directly correlate with MFE value. Even the aptamer itself is stable, there are also some effects that affect the docking score such as binding affinity between the aptamer and protein, and some aptamers undergo significant conformational changes upon binding.

Table 2. Docking scores for the best prediction model from five aptamer models sequences from HDOCK

Aptamer model	Aptamer sequence	Docking scores
3	ACCCUCGAAACGGCGAGCGAGGGUGUCGCUGUUU GAGGGGU	-267.50
2	ACGGUUAGGGUGGUGGGAACCACCACCGUUGAU CGCUGGG	-250.90
5	AGUAGCUGGAUGGCGACACUCAGUGGGCGUCGUG GUCGAGC	-244.88
1	AGCAGGUGGACCGCACGGUGAUCCGAGCGGUUCA UGUGUGG	-232.13
4	CUGGGGAGGCAAGCUGGGGACCGUAGCUUGCAGU CCUGGAU	-220.23

Table 3. Average docking scores of ten models for the best five aptamer models sequences from HDOCK

Aptamer model	Aptamer sequence	Average docking scores
2	ACGGUUAGGGUGGUGGGGAACCACCACCGUUG AUCGCUGGG	-227.73
5	AGUAGCUGGAUGGCGACACUCAGUGGGCGUCG UGGUCGAGC	-222.05
1	AGCAGGUGGACCGCACGGUGAUCCGAGCGGUU CAUGUGUGG	-216.93
3	ACCCUCGAAACGGCGAGCGAGGGUGUCGCUGU UUGAGGGGU	-211.96
4	CUGGGGAGGCAAGCUGGGGACCGUAGCUUGCA GUCCUGGAU	-211.26

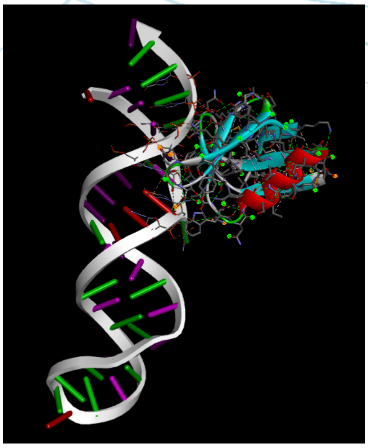

Fig. 8. 3D structures of best prediction model of model 3 2AU4 aptamer (white) binding with target protein Shiga Toxin 1C48 (red) in molecular docking process with -267.50 docking scores

4.0 Conclusion

In this study, in-silico methods have been used to investigate aptamer against the target protein of Escherichia coli using MFE calculation and molecular docking method. The analysis highlighted that the 2AU4 aptamer with the model 3 sequence and structure as in Fig. 8 displayed lower MFE values of -23.4 kcal/mol, lowest average docking score of -267.50 compared to others. However, as highlighted in Table 3, it is suggested that aptamer model 2 has the highest average docking scores value of its ten model predictions. This indicates that model 2's aptamer is stable and the interaction/binding strength between the AlphaFold 3's Shiga Toxin is higher. As a result, model 3 can be selected for the subsequent Molecular Dynamics (MD) simulation for advance confirmational stability such as Root Mean Square Deviation (RMSD) and Fluctuation (RMSF) plot of this protein-aptamer complex structure. In conclusion, because of the good result in docking analysis, we suggest that this aptamer model potentially is an effective detector that can be implemented in the future of aptamer-based biosensor technology such as colorimetric biosensor.

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Fabrication of Solution-Processed Perovskite Solar Cells for Low-Light Energy Harvesting Applications

Izzah Afifah Ibrahim[1], Muhammad Fakhrullah Mohamad Azmi[1], Irfan Danial Ismadi[1], Muhammad Fadzlisyam Redzuan[1], Ikhwan Syafiq Mohd Noor[2], Nizam Tamchek[2], Mohd Ifwat Mohd Ghazali[1], Wan Haliza Abd Majid[3] & Shahino Mah Abdullah[1]

[1]*Faculty of Science and Technology, Universiti Sains Islam Malaysia, Bandar Baru Nilai, 71800 Nilai, Negeri Sembilan, Malaysia*

[2]*Ionic Materials and Energy Devices Laboratory, Physics Department, Faculty of Science, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor Darul Ehsan, Malaysia*

[3]*Low Dimensional Material Research Centre (LDMRC), Department of Physics, Faculty of Science, University of Malaya, Kuala Lumpur 50603, Malaysia*

Abstract

Fossil fuels contribute to air pollution and drive climate change. Transitioning to solar energy offers a cleaner alternative. Perovskite solar cells are a promising advancement, potentially exceeding silicon cell efficiencies with simpler, cost-effective manufacturing. This research demonstrates the feasibility of electricity generation using a solution-processed perovskite solar cell under low light in the room building. The fabricated cell achieved an open-circuit voltage of 1.49V and a short-circuit current density of 5.15 mA/cm². A maximum power conversion efficiency of 18.67% was obtained under only around 10% of actual one sun light intensity. Such a high obtained efficiency of solar cell fabricated using inexpensive materials under low light intensity has become our current work novelty. These results highlight the potential of cost-effective perovskite solar cells for indoor and ambient light energy harvesting, supporting a shift towards sustainable energy solutions.

Keywords **:** *air pollution; solar cells; perovskite; efficiencies; ambient light*

1.0 Introduction

The increasing reliance on fossil fuels for power generation has brought about significant environmental, health, and social concerns, necessitating cleaner and more sustainable energy sources. Burning fossil fuels causes global climate change, air and water pollution, land degradation, and disease, as emphasized by several studies [1,2,3]. The Intergovernmental Panel on Climate Change (IPCC) has emphasized the importance of the immediate reduction in greenhouse gas emissions to reverse the impacts of climate change [4]. Further, the hazardous chemicals released from fossil fuel-powered power plants, such as sulfur dioxide (SO_2) and nitrogen oxides (NO_X), are dangerous health risks, particularly for sensitive populations [5]. The limited supply of fossil fuels also raises concerns of resource depletion and environmental degradation, and therefore the need for alternative sources of energy [6].

Solar energy offers a strong alternative with a clean, renewable source of power and the ability to reduce greenhouse gas emissions significantly and improve air quality [7]. Compared to traditional fossil fuel power generation, solar power systems have no toxic emissions during operation and require minimal water use, thereby decongesting water resources [8]. The flexibility of solar energy systems facilitates installation on various types of land, minimizing habitat loss and land degradation. Solar power has the capability to create economic benefits and enhance energy security, particularly in regions with high solar radiation [9].

Even though there are advantages of solar energy, traditional silicon solar cells are highly effective outdoor and not indoors. This is a serious limitation in harnessing solar energy in urban areas where natural light is typically lacking. In response to this challenge, the objective of this study is to demonstrate the feasibility of generating electricity with a cost-effective solution-processed perovskite solar cell under illumination by room building light. This work stands out for its originality in using solution-processed perovskite solar cells for low-light applications. The key materials applied in this work include a perovskite precursor and nickel (II) phthalocyanine-tetrasulfonic acid tetrasodium salt (NiTsPc), which would enhance energy conversion efficiency under low light conditions. The incorporation of NiTsPc as a sensitizer enhances light absorption, making the cells innovative and highly applicable for indoor environments.

The emergence of perovskite materials in solar cells technology is a great milestone in the quest for efficient and affordable renewable energy sources [10]. The ability of perovskite solar cells, processed through solution processing techniques, to be very promising in high power conversion efficiencies has been of great interest [11]. The present study revolves around increasing the efficiency, stability, and scalability of perovskite solar cells, with emerging technologies such as tandem solar cells and flexible substrates unlocking diverse applications [12,13]. With scientists exploring non-toxic and abundant materials for perovskite fabrication, the potential for clean solar energy solutions rises [14]. The work hopes to advance this emerging research field by exploring the performance of perovskite solar cells in indoor illumination, hence opening the potential application areas of solar energy technology for cities. These cells can power IoT devices, sensors, and other low-energy electronics, offering a sustainable alternative to batteries.

2.0 Materials

2.1 Fluorine-doped tin oxide (FTO) glass

In the current study, a perovskite solar cell was fabricated with a highly selected set of materials, with each material assigned a specific function in enhancing the general efficiency of the solar cell. The most dominant substrate material used in the production of the solar cell is fluorine-doped tin oxide (FTO) glass. This material is specifically utilized as a highly conducting and transparent substrate, allowing light through while ensuring proper electrical conductivity [15]. The FTO serves a vital function in allowing the electrons from the photoactive layers to be moved to the outside circuit, thus ensuring efficient energy conversion.

2.2 Titanium dioxide (TiO_2)

The second critical component is titanium dioxide (TiO_2), which serves as the electron transport layer in the solar cell device. TiO_2 is described as a wide bandgap semiconductor that is noted for its efficient uptake of ultraviolet light and for its ability to promote the transport of electrons that are generated from the dye upon light absorption [16]. TiO_2 is normally used in porous film form, thus providing a large surface area that is favorable for the adsorption of the sensitizing dye, NiTsPc. This structure greatly enhances the overall efficiency of the solar cell by maximizing the interaction between the semiconductor and the dye.

2.3 Nickel (II) phthalocyanine-tetrasulfonic acid tetrasodium salt (NiTsPc)

The light absorption material in this solar cell fabricated is nickel (II) phthalocyanine-tetrasulfonic acid tetrasodium salt (NiTsPc). The blue dye is pivotal in light absorption, thus allowing the production of excited electrons when the solar cell is illuminated by visible light. The excited electrons then travel through the TiO_2 film, hence initiating the charge separation. The absorption spectrum for NiTsPc exhibits a very strong resemblance with the solar spectrum, thus allowing efficient light harvesting and energy conversion that is vital in ensuring maximum solar cell efficiency [17].

2.4 Iodine

Iodine is incorporated in the operating mechanism in the form of a redox mediator in the electrolyte medium. The major function is the regeneration process after the dye has been injected with electrons in the TiO_2 film. The iodine species, in particular in the I3- form, serve as charge transporters in the cell, ensuring the continuity of the electronic current and enhancing the solar cell efficiency in the process [18]. Regenerative process is essential for the extended use of the solar cell.

2.4 Perovskite precursor ink

The perovskite precursor ink that was applied in the current study was purchased from Ossila and is specially designed for processing in ambient condition. The perovskite ink is made from a combination of methyl ammonium iodide (MAI) and lead chloride ($PbCl_2$) dissolved in dimethyl formamide (DMF). When heated, this ink is converted to a methylammonium lead halide perovskite, eventually forming

methylammonium lead iodide with little chlorine, with the chemical formula $CH_3NH_3PbI_3$-xClx. This perovskite material is commonly used in the construction and design of solar cells and can be utilized in both standard and inverted configurations [19]. The ink exhibits the ability to attain power conversion efficiency (PCE) values that surpass 13%, making it a very important material in thin film organic solar cell production.

2.5 Carbon conductive paste

Aside from the above-stated function, conductive carbon paste is also utilized as a counter electrode in solar cell design [20]. The material provides a conductive interface that favors the extraction of electrons from the outside circuit. The addition of carbon paste helps greatly in charge collection efficiency and is also vital in ensuring the stability and durability of the solar cell. Carbon paste ensures the efficient operation of the solar cell by limiting resistive losses, thus making it a vital component in the overall design.

3.0 Methodology

The production process of the perovskite solar cell commences with the precise measurement of 1.5 grams of titanium dioxide (TiO_2), which serves as the electron transport layer in the solar cell. To prepare an appropriate paste for application, TiO_2 is combined with 1 ml of polyethylene glycol (PEG) and 1 ml of ethanol with 99.99 in a ceramic vessel. The inclusion of PEG functions as a binder, enhancing the adhesion of TiO_2 particles to the substrate while also providing mechanical stability to the film. Ethanol is incorporated as a solvent to dissolve the TiO_2 and PEG mixture, resulting in a uniform consistency that is ready for direct application onto the substrate.

Upon complete dissolution of the mixture through extensive agitation, the resulting solution is then deposited onto the conducting surface of fluorine-doped tin oxide (FTO) glass by means of doctor blade technique. This process enables a controlled and uniform deposition of the TiO_2 mixture over about half of the FTO glass surface area. The coated FTO glass (Fig. 1) is subsequently heated at a temperature of 200°C by using hot plate for a period of 10 minutes in order to enhance the formation of a strong TiO_2 layer while removing solvent residue. After thermal treatment, the glass is allowed to cool down to room temperature, which in effect solidifies the TiO_2 layer and readies it for further processing.

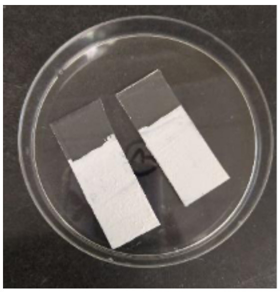

Fig. 1: TiO_2 particles coated on FTO glass.

The dye solution was prepared by mixing 1 ml of deionized (D.I) water and 10 mg of nickel (II) phthalocyanine-tetrasulfonic acid tetrasodium salt (NiTsPc). In this process, the dye serves as a sensitizer in the solar cell, while the use of D.I. water ensures removal of any contaminants that may interfere with the solar cell's efficiency. The pre-coated fluorine-doped tin oxide (FTO) glass, which has been pre-coated with titanium dioxide (TiO_2), is treated with the mixture of NiTsPc and D.I. water for a longer period, that is, overnight. The longer immersion in the solution enhances maximum adsorption of the dye onto the surface of the TiO_2 (Fig. 2), thus maximizing the light-absorbing properties, as well as the overall solar cell efficiency.

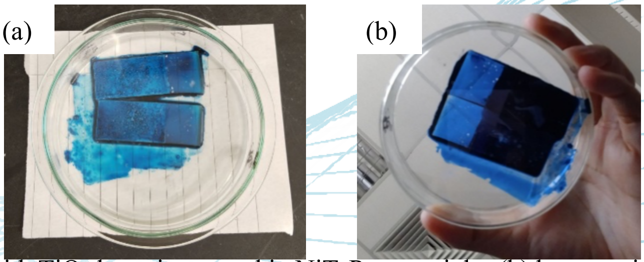

Fig. 2: (a) FTO coated glass with TiO_2 layer immersed in NiTsPc overnight; (b) bottom view of the substrate with TiO_2 and NiTsPc.

After long immersion, the FTO glass is removed from the solution, and the uncoated areas of the glass are carefully purified in order to remove any possible hindrance from the operational effectiveness of the solar cell. The glass is then annealed at 90°C for 20 minutes (Fig. 3) until it is fully dry, allowing the dye to adhere onto the TiO_2 layer.

Fig. 3: Annealing process of the coated FTO glass at 90°C.

In preparation for the counter electrode, another clean piece of FTO glass is applied with carbon paste to its conductive surface, covering about half of the area (2.5 x 2.0 cm). This carbon paste serves as the conductive layer that will facilitate electron collection. The FTO glass with carbon paste is then heated at 100°C for 10 minutes until dry (Fig. 4), ensuring a solid and conductive layer.

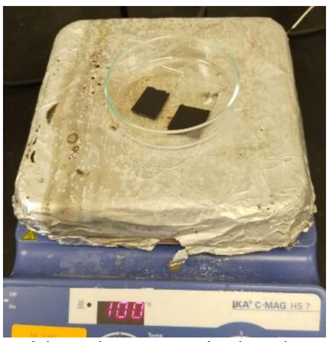

Fig. 4: The FTO glass with carbon paste is then heated at 100°C.

After the successful preparation of the electrode, 1.6µl iodine are carefully deposited onto the TiO_2 surface by using micropipette. The purpose of this iodine is that it acts as a redox mediator in the solar cell, allowing for the regeneration of the dye after it has been injected with electrons in the TiO_2 film. 0.8µl of perovskite solution was then deposited onto the same TiO_2 surface using micropipette, thus allowing the iodine and perovskite interaction that forms a functional charge-separation enhancing layer.

The final phase of the assembly process involves the attachment of the carbon paste-treated FTO glass onto the surfaces of TiO_2, iodine, and perovskite such that the latter layers face each other (Fig. 5). This particular positioning enables efficient charge transfer between the layers. To analyze the functional efficacy of the perovskite solar cell, the assembled device is connected to a source-measure unit, which tests both the efficiency and general function of the solar cell under low light intensity of about 10-12 mW/cm^2 (input power, P_{in}) to imitate indoor light range or ambient light conditions. This systematic approach ensures that all elements in the perovskite solar cell are carefully crafted and optimized for maximum efficiency, leading to a holistic improvement in the device.

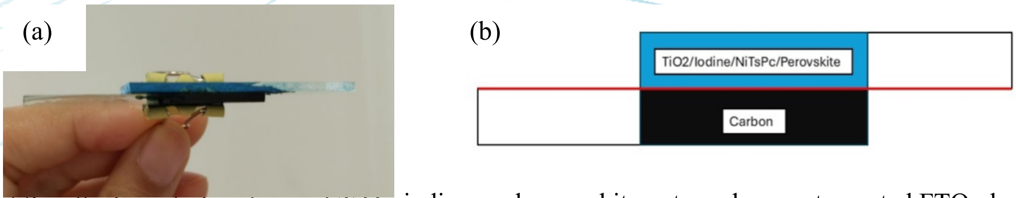

Fig. 5: (a) the attachment of surfaces of TiO_2, iodine, and perovskite onto carbon paste-coated FTO glass; (b) drawing of the layer structure.

4.0 Results and Discussion

Fig. 6 shows the current density (J_{sc}) against a voltage (V) curve. From this curve, the two main parameters can be directly extracted: the short-circuit current density (J_{sc}), defined as the current density at 0 V, and the open-circuit voltage (V_{oc}), defined as the voltage at 0 current density. Maximum J_{sc} is found to be 5.15 mA/cm², while maximum V_{oc} is 1.49 V. Besides, the general appearance of this curve gives a qualitative idea of the fill factor (FF) that describes how efficiently the cell delivers maximum power. A more rectangular shape corresponds to a bigger FF, while the observed linear slope correlates to a lower FF, which, according to the FF formula (Eq. 1), amounts to 0.29. The lower value (< 0.80) implies that the cell is not working at the maximum efficient state due to internal resistances and other losses [21].

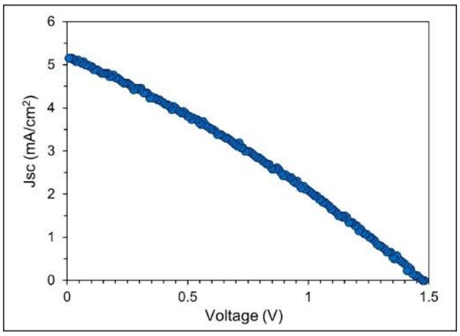

Fig. 6: Current density (Jsc) versus voltage (V).

$$FF = \frac{J_{max}\ X\ V_{max}}{J_{sc}\ X\ V_{oc}} \qquad (1)$$

To quantify the solar cell's performance, we calculate the power conversion efficiency (PCE), which is given by Eq. 2:

$$PCE = \frac{V_{OC} \times J_{SC} \times FF}{P_{in}} X\,100 \quad (2)$$

Where V_{oc} is the open-circuit voltage, J_{sc} is the short circuit current density, FF is the fill factor, and P_{in} is the incident solar power (mW/cm^2).

Fig. 7 presents the power density versus voltage curve derived from Fig. 7. To calculate the power at a specific point on the J-V curve, one multiplies the current density and voltage values. Subsequently, this power value is plotted against the corresponding voltage to generate the power curve. The maximum power point (MPP), which represents the highest electrical power output from the cell, corresponds to the peak of this curve. The voltage at this peak is defined as the maximum power point voltage (V_{max}), while the power value at this peak is designated as the maximum power (P_{max}). In this case, V_{max} is 0.8 V, and the power output reaches approximately 2.25 mW/cm². The power curve visually demonstrates how the power output from the solar cell varies with voltage, emphasizing the significance of operating the solar cell at the MPP to achieve optimal performance.

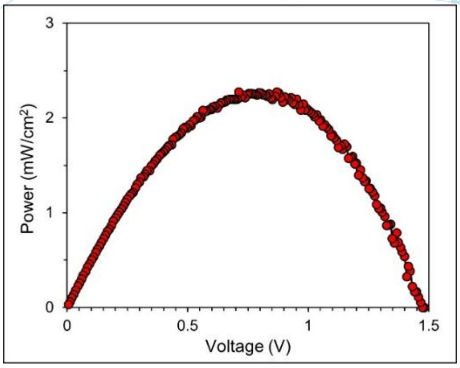

Fig. 7: Power density (P) versus voltage (V).

The analyzed perovskite solar cell has a power conversion efficiency of 18.67% after considering low light intensity applied on the cell (10 - 12 mW/cm^2, instead of 100 mW/cm^2 or 1 Sun). This efficiency, however, does provide evidence of its capacity to convert light into electricity [22]. The efficiency of a perovskite cell is very much dependent on the specific perovskite materials, the fabrication methods, and the environmental conditions under which it is tested. Some of the important parameters for evaluation of the cell performance are undeniably the short-circuit current density (J_{sc}) of 5.15 mA/cm² and an open-circuit voltage (V_{oc}) of 1.49 V. A high V_{oc} values indicate that the device is well capable of allowing charge separations, thus it is able to generate a relatively high potential difference. Its J_{sc} value is an indication of its ability to produce current in case no external resistance applies.

However, a critical aspect of this cell's performance lies in its fill factor (FF), which is 0.29. The fill factor is a measure of the "squareness" of the current-voltage (I-V) curve and is indicative of the efficiency with which the cell can deliver power. A low fill factor (FF), as observed in this study, indicates that the cell's I-V curve deviates significantly from the ideal rectangular shape, suggesting the presence of losses within the device. Several factors can contribute to a low FF. High series resistance within the cell can hinder current flow, while low shunt resistance may result in current leakage, both of which lead to a diminished FF [23]. Additionally, recombination losses, where charge carriers recombine before contributing to the current, can further impact the fill factor. Issues at the interfaces between the various layers of the perovskite cell structure can also negatively affect the FF. The I-V curve presented in the data visually supports the observation of a low FF, exhibiting a relatively linear slope instead of the sharp "knee" and rectangular shape characteristic of an ideal cell.

The Power-Voltage curve is a crucial tool in understanding the maximum power point (MPP) of a solar cell. It shows how the power output varies with the voltage across the cell, emphasizing the importance of operating the cell at the MPP for maximum performance. The I-V curve, with a general linear trend, provides insights into non-idealities of the cell. It shows that the slope of the I-V curve correlates to the cell's resistance, with higher slopes implying lower resistance. To increase the low fill factor in a perovskite cell, improvements in conductivity, shunt resistance, and recombination losses are needed. Additionally, optimizing interfaces between cell layers is also necessary.

5.0 Conclusion

This research has successfully demonstrates the capability of generating energy from a solution-processed perovskite solar cell under ambient light circumstances. The device showed promising performance, with an open-circuit voltage of 1.49 V and a short-circuit current density of 5.15 mA/cm². Furthermore, a power conversion efficiency of 18.67% was achieved after considering low light intensity applied on the cell (10 - 12 mW/cm2) which is only approximately 10% of actual 1 Sun light intensity. These findings indicate that solution-processed perovskite solar cells may generate electricity under ambient illumination, indicating their potential for use in indoor energy harvesting and contributing to the development of sustainable energy solutions. While additional optimisation is required, the findings provide a solid foundation for the usage of perovskite solar cells in low-light situations, broadening their application beyond traditional outdoor solar energy generation.

Acknowledgements

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A Novel Approach to Monkeypox Transmission Modeling via the Modified Picard Iterative Method

Ahmad Bazli Khairuddin[1], Mat Salim Selamat[2,*], Nor Azizah M. Yacob[3] & Siti Hidayah Muhad Saleh[4]

[1]School of Mathematical Sciences, Universiti Teknologi MARA, 70300 Seremban, Negeri Sembilan, Malaysia
[2,4]Department of Mathematical Sciences, Universiti Teknologi MARA, 70300 Seremban, Negeri Sembilan, Malaysia
[3]Department of Mathematical Sciences, Universiti Teknologi MARA, 26400 Bandar Tun Razak, Pahang, Malaysia

Abstract

Monkeypox, an infectious disease that is now easier to spread among people, must be modeled to help guide measures meant to control the infection. Although numerical methods help solve these models, problems with their accuracy and computational speed have not been resolved yet. In this study, the authors introduce a Modified Picard Iterative Method as a new approach to solve the monkeypox transmission model, which consists of eight nonlinear ordinary differential equations. This method is extra reliable, as it produces accurate solutions for both brief and long-term simulations similar to what the fourth-order Runge-Kutta method provides for all the time covered in the model. Offering an effective choice for classical numerical methods, the Modified Picard Iterative Method helps to discover insights about how monkeypox is spreading and improves the use of computational techniques in modeling infectious diseases.

Keywords: *Monkeypox, Modified Picard Iterative Method, Infected Case, Convergence.*

1.0 Introduction

The monkeypox virus is the cause of the uncommon zoonotic illness known as monkeypox [1]. Both the smallpox and monkeypox viruses are members of the Orthopoxvirus genus within the Poxviridae family. In the Democratic Republic of Congo, the first human case of monkeypox was documented in 1970 [2]. The virus can be transmitted from animals to humans and between humans via intimate contact with sick people or contaminated substances [3]. Symptoms include fever, rash, and lymphadenopathy, which distinguish monkeypox from smallpox [4]. Numerous laboratory techniques, like PCR and virus isolation, are used to confirm the diagnosis [5]. Antiviral medications such as tecovirimat and supportive care are available as treatment alternatives [4, 6].

Various mathematical models have been used to study monkeypox dynamics. Models such as SIQRS with quarantine [7] and fractional-order systems [8] have demonstrated improved prediction and control capabilities. Modified SEIR models have shown that reducing contact and improving immunization are effective early-stage strategies, while delayed diagnosis can shift epidemic peaks [9]. Optimal control strategies often involve combining human vaccination with rodent population control [8].

Iterative methods like the Picard iterative method (PIM) have been used to solve epidemic models such as SIR [10]. Improved formulations, including multistage Picard methods and hybrid approaches, have achieved higher accuracy and stability compared to traditional techniques like Runge-Kutta and Adomian Decomposition [10, 11]. Additionally, recent studies have applied Banach fixed-point theory and fractional derivatives to prove existence, uniqueness, and solution stability [12, 13].

This study applies a Modified Picard Iterative Method (MPIM) enhanced with a multistage scheme to a monkeypox transmission model and compares its performance with the classical Runge-Kutta method (RK4). The study aims to evaluate the convergence and accuracy of the proposed method for modeling infectious disease dynamics. Building upon the need for reliable modeling techniques, the next section introduces the mathematical framework that underpins the monkeypox transmission model. This framework lays the foundation for applying and evaluating the proposed Modified Picard Iterative Method.

2.0 Mathematical Preliminaries

To explore monkeypox outbreaks in the United States, consider a nonlinear mathematical model proposed by Peter et al. [14] consisting of the population sizes of humans and rodents. The human population N_h is divided into five different classes, namely, susceptible class S_h, exposed class E_h, infected class I_h, isolation class I_h, and recovery class R_h. The population of rodents N_r is divided into three classes, namely susceptible class S_r, exposed class E_r, and infected class I_r. The model is given as follows:

$$\frac{dS_h}{dt} = \Lambda_h - \left(\frac{\beta_1 I_r + \beta_2 I_h}{N_h}\right) S_h - \mu_h S_h + \phi Q_h \tag{1}$$

$$\frac{dE_h}{dt} = \left(\frac{\beta_1 I_r + \beta_2 I_h}{N_h}\right) S_h - (\alpha_1 + \alpha_2 + \mu_h) E_h \tag{2}$$

$$\frac{dI_h}{dt} = \alpha_1 E_h - (\mu_h + \delta_h + \rho) I_h \tag{3}$$

$$\frac{dQ_h}{dt} = \alpha_2 E_h - (\phi + \tau + \mu_h + \delta_h) Q_h \tag{4}$$

$$\frac{dR_h}{dt} = \rho I_h + \tau Q_h - \mu_h R_h \tag{5}$$

$$\frac{dS_r}{dt} = \Lambda_r - \frac{\beta_3 S_r I_r}{N_r} - \mu_r S_r \tag{6}$$

$$\frac{dE_r}{dt} = \frac{\beta_3 S_r I_r}{N_r} - (\mu_r + \alpha_3) E_r \tag{7}$$

$$\frac{dI_r}{dt} = \alpha_3 E_r - (\mu_r + \delta_r) I_r \tag{8}$$

where the recruitment rates of humans and rodents are represented by Λ_h and Λ_r , respectively. The contact rate between rodents and humans is denoted as β_1, while β_2 and β_3 represent the contact rates between humans and rodents, respectively. The transmission rate of humans from the exposed to the infected class is given by α_1, whereas α_2 represents the rate at which suspected cases are identified, and α_3 denotes the transmission rate of rodents from the exposed to the infected class. The proportion of humans not detected after diagnosis is indicated by ϕ. The rate of transmission from the isolation class to the recovered class is expressed as τ, and the recovery rate is represented by ρ. The natural death rates of humans and rodents are described by μh and μr, respectively, while the disease-induced death rates for humans and rodents are indicated by δ_h and δ_r, respectively. With the structure of the monkeypox model clearly defined, attention is now turned to the numerical strategies used to approximate its solution. The Picard Iterative Method, a classical technique for solving nonlinear differential equations, serves as the foundational approach in this study.

2.1 Picard Iterative Method

The PIM, a classical approach to solving nonlinear and differential equations, is rooted in fixed-point iteration principles. Developed by Emile Picard, this method approximates´ solutions by iteratively applying a mapping function until successive iterations converge to an acceptable accuracy level [15].

This approach is particularly effective for continuous and well-behaved functions, which ensures the convergence of the iteration sequence [16].

In general, the PIM reformulates a differential equation as an integral equation. Given an initial approximation $u_0(x)$, each successive approximation $u_{n+1}(x)$ is defined in terms of an integral involving $u_n(x)$, the previous approximation. This iterative process continues, updating the solution until the difference between successive iterations falls below a predefined tolerance level, ensuring stability and convergence [15, 17]

The method begins with an initial approximation $y(t_0) = y_0$, and generates successive approximations using the iterative formula:

$$y_{n+1}(t) = y_0 + \int_{t_0}^{t} f\big(s, y(s)\big)ds \tag{11}$$

For a differential equation of the form:

$$\frac{dS_h}{dt} = \Lambda_h - \left(\frac{\beta_1 I_r + \beta_2 I_h}{N_h}\right) S_h - \mu_h S_h + \phi Q_h \tag{12}$$

With initial condition $S_h(t_0) = S_0$, the PIM is expressed as:

$$S_{h(n+1)}(t) = S_{h(0)}(t) + \int \left(\Lambda_h - \frac{\beta_1 I_{r(n)}(t) + \beta_2 I_{h(n)}(t)}{N_h} S_{h(n)}(t) - \mu_h S_{h(n)}(t) - \phi Q_{h(n)}(t)\right) dt \tag{13}$$

The success of this approach depends on the function $f(x, u)$ satisfying certain Lipschitz continuity conditions, ensuring that the Picard sequence $\{u_n\}$ converges to a unique solution as $n \to \infty$ Bartle et al. [18]. While the classical PIM provides a solid base, it has limitations when dealing with more complex or stiff systems. To address these challenges, the following section introduces the MPIM, which incorporates enhancements aimed at improving convergence and performance in modeling the monkeypox dynamics.

2.2 Modified Picard Iterative Method

In this section, the PIM was altered in this work to enhance its performance and suitability for resolving the Monkeypox Transmission Model. A multistage technique was incorporated as part of the change, enabling a more precise and effective computation of the answers. In comparison to the conventional PIM, this multistage augmentation breaks the iterative process into multiple phases, allowing the method to better capture the intricacies of the disease dynamics and guarantee faster convergence.

2.3 Multistage Picard Iterative Method

In the MPIM, the solution is computed over subintervals $[t_{j-1}, t_j]$, and the iterative correction for the j-th stage is given by:

$$y_{n+1,j}(t) = y_{n,j-1}(t_{j-1}) + \int_{t_{j-1}}^{t} f\big(s, y_{n,j-1}(s)\big)ds \tag{25}$$

where:

$y_{n+1,j}(t)$ is the approximation at the $(n+1)$-th iteration and j-th stage.

$y_{n,j-1}(t)$ is the approximation from the n-th iteration at the previous stage.

For each component of the system, this can be written as:

$$y_{i,n+1,j}(t) = y_{i,n,j-1}(t_{j-1}) + \int_{t_{j-1}}^{t} fi(s, y_{n,j-1}(s))ds \quad (26)$$

where i represents the i-th component of the system. The iteration continues until the solution converges with the desired accuracy. Having established the structure of the MPIM, the practical implementation and effectiveness of the method are now examined. The following section presents numerical results and a comprehensive analysis of the method's performance in modeling monkeypox transmission.

3.0 Results and Discussion

In this section, all the research objectives will be addressed through a detailed analysis of the results obtained. Additionally, the discussion will highlight key trends, implications, and any observed limitations, providing insights into the accuracy, stability, and applicability of the MPIM in modeling the monkeypox transmission dynamics.

3.1 Numerical Solution on the Monkeypox model

In this section, numerical simulations on the Monkeypox model have been conducted. Firstly, the value of parameters and initial approximation are adopted from Kumar et al. [19], where $\Lambda_h = 0.34857$, $\Lambda_r = 0.60822$, $\mu_h = 0.00003$, $\mu_r = 0.00054$, $\alpha_1 = 0.42389$, $\alpha_2 = 1.79758$, $\alpha_3 = 0.02529$, $\beta_1 = 0.01150$, $\beta_2 = 0.74732$, $\beta_3 = 0.32110$, $\delta_h = 0.01502$, $\delta_r = 0.00003$, $\rho = 0.06769$, $\phi = 1.57545$, $\tau = 0.99976$. For the initial approximation is $N_h(0) = 10051$, $S_h(0) = 10000$, $E_h(0) = 50$, $I_h(0) = 0.57$, $Q_h(0) = 0.43$, $R_h(0) = 0$, $N_r(0) = 1110$, $S_r(0) = 0.43$, $E_r(0) = 0.43$, $I_r(0) = 0.43$. Maple22 is used to compute the iteration of the Monkeyox model using the PIM and MPIM. With the numerical setup and simulations established, the performance of the iterative methods is evaluated in terms of their convergence behavior and error analysis.

3.2 Analysis of Numerical Method

The following criterion was used to evaluate the iterative method's convergence:

$$\in = \left|S_{h(n+1)}(t) - S_{h(n)}(t)\right|$$

where $t = 0.01$, this step size is chosen because smaller step sizes generally improve accuracy by Arefin et al. [20]. The iterative process was stopped when:

$$\in \leq 10^{-10}$$

Table 1. Convergence Error Analysis for the PIM

Number of Iterations	Convergence Value
1	0.0140956035
2	0.6204624361
3	0.1065267951
4	0.0100164644
5	0.0006660823

Table 1 demonstrates the effectiveness of the PIM in solving the monkeypox transmission model. A rapid error reduction was observed, with convergence achieved by the 5th iteration, the error further dropped from 0.01410 at the first iteration to 0.00067 by the fifth iteration. The method quickly reached the predefined threshold of 10^{-10}, confirming its high accuracy and computational efficiency.

The MPIM maintained this fast convergence while enhancing performance. Limiting the analysis to $n = 5$ iterations allowed direct comparison with the standard PIM. Notably, the MPIM achieved a final error of 0.00067, demonstrating a significant improvement in convergence behavior. These results

confirm the robustness of the MPIM, offering accurate solutions with minimal computational cost, making it particularly well-suited for modeling complex infected disease dynamics such as monkeypox.

3.3 Comparison of Infected Humans Absolute Error for PIM and MPIM calculation with RK4.

In this study, the MPIM was implemented and programmed using Maple 2022. The built-in RK4 method in Maple was utilized as a benchmark for comparison. The computations were performed with a precision setting of 16 control digits, ensuring a high degree of accuracy. The time range for the analysis was set to $[0,110)$, allowing for a comprehensive study of the system dynamics over an extended period.

Table 2. Absolute Error for PIM and MPIM with RK4

Time	PIM	MPIM	RK4	$\lvert RK4-PIM\rvert$	$\lvert RK4-MPIM\rvert$
10	-4.64×10^{6}	16.808901	16.81129	4.6398×10^{6}	2.3839×10^{-3}
20	-6.77×10^{9}	30.574693	30.59555	6.7656×10^{9}	2.0860×10^{-2}
30	-8.85×10^{11}	55.037236	55.14161	8.8544×10^{11}	1.4038×10^{-1}
40	-3.23×10^{13}	96.302909	96.70828	3.2253×10^{13}	4.0537×10^{-1}
50	-5.29×10^{14}	159.759805	161.06192	5.2874×10^{14}	0.1302×10^{1}
60	-4.93×10^{15}	243.730915	247.16509	4.9265×10^{15}	0.3434×10^{1}
70	-2.87×10^{16}	331.943979	339.14826	2.8741×10^{16}	0.7204×10^{1}
80	-9.83×10^{16}	395.684123	407.40170	9.8348×10^{16}	11.718×10^{-1}
90	-2.91×10^{16}	412.001810	426.79792	2.9121×10^{16}	14.796×10^{1}
100	2.19×10^{18}	380.628245	395.57330	2.1919×10^{18}	1.4613×10^{1}
110	1.82×10^{19}	319.993497	332.60697	1.8224×10^{19}	1.2613×10^{1}

Table 2 presents the absolute errors of PIM and MPIM compared with RK4 with step size of $h = 0.01$.Results show that MPIM closely aligns with RK4, with a maximum deviation of 14.796×10^{1} at $t = 90$, indicating high accuracy over extended time intervals. In contrast, PIM exhibits substantial divergence, reaching a maximum error of 1.822×10^{19} at $t = 110$, highlighting its limited stability over time. Moreover, MPIM achieves comparable accuracy to RK4 with reduced computational effort, making it a more efficient and practical alternative for solving long-term simulations.

3.4 Fitting of Monkeypox Transmission Model using Real Data, PIM, MPIM and RK4

Figure 1 below presents a comparison of MPIM, RK4, real data, and PIM for the infected human, I_h cases over time, t. PIM is plotted on the secondary axis due to its magnitude, while MPIM, RK4, and real data are plotted on the primary axis. This visual representation reveals key differences in the performance of the numerical methods and their alignment with observed data.

In the early phase of infection, all methods (MPIM, RK4, and PIM) exhibit similar trends aligned with real data from Kumar et al. [19]. MPIM closely tracks RK4 and real data, accurately capturing the rapid rise in infections, with peak infection around $t = 80$. Post-peak, MPIM continues to show strong alignment, highlighting its effectiveness in modeling both the growth and decline phases.

In contrast, PIM begins diverging significantly after $t = 50$, overestimating infections due to numerical instability, as illustrated on a secondary axis. This limits PIM's reliability for long-term predictions. MPIM, however, maintains consistency with RK4 and real data throughout, demonstrating improved accuracy due to its modified iterative structure. Overall, MPIM balances computational efficiency with high accuracy, making it a reliable method for simulating infection dynamics over both short and extended periods.

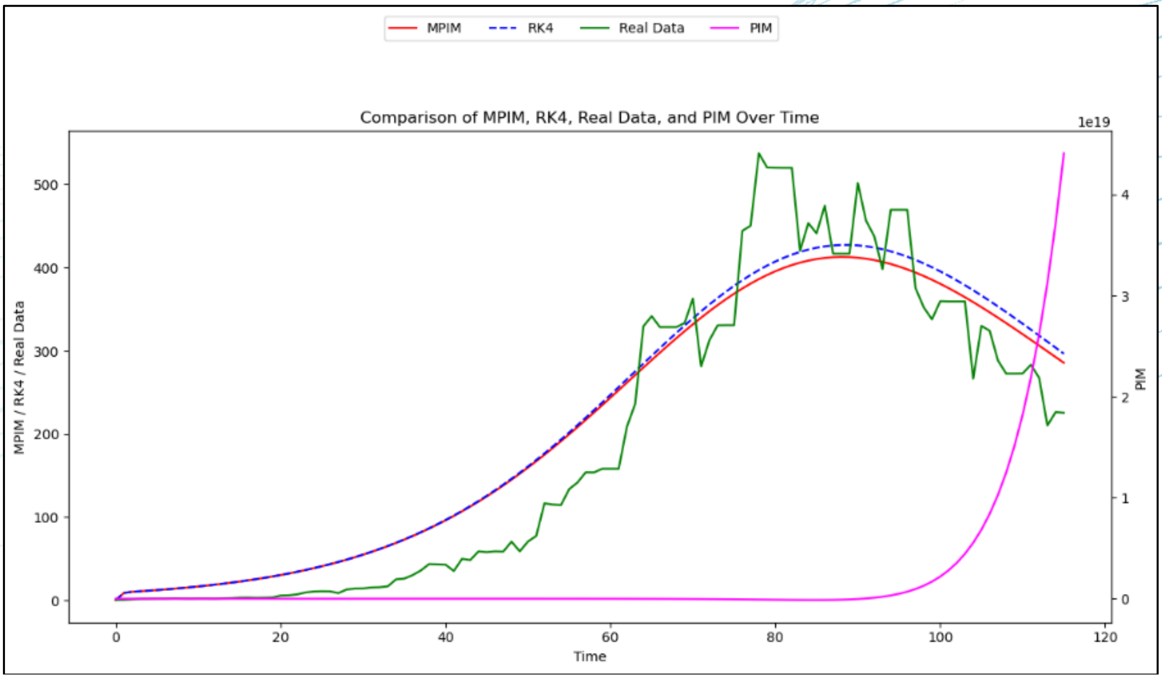
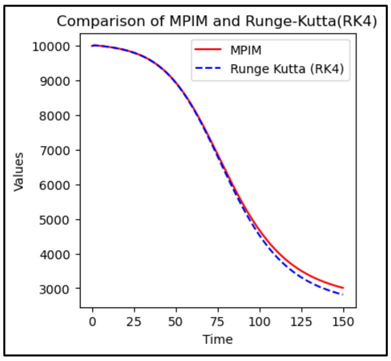
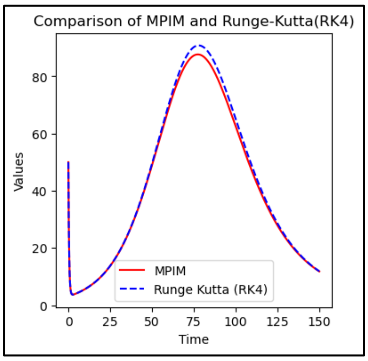


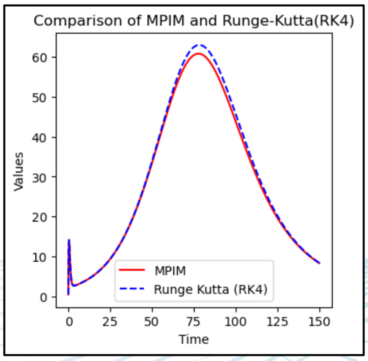
Figure 1. Infected class human, I_h over time, t

Figures 2 and 3 depict the dynamics of human and rodent populations across various compartments, including susceptible, exposed, isolated, and recovered classes. The results highlight changes over time influenced by transmission parameters and interspecies interactions. Comparison between MPIM and RK4 demonstrates the accuracy and behavior of each method, with MPIM effectively capturing the key dynamics across all components.

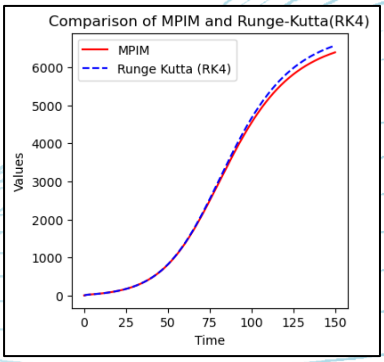




(a)



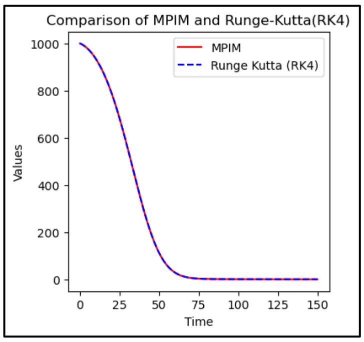
(b)



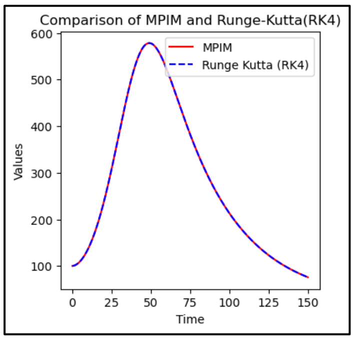
(c)

Figure 2. (a) Susceptible Humans, S_h; (b) Exposed Humans, E_h; (c) Isolation Humans, Q_h; (d) Recovered Humans, R_h

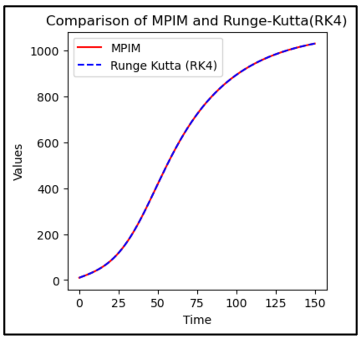
Figure 2 compares MPIM and RK4 across four population compartments. In Figure 2(a), both methods show strong agreement in modeling the susceptible human population up to $t = 50$, with MPIM displaying a slightly steeper decline beyond this point. Figure 2(b) shows that MPIM and RK4 align closely for the exposed rodent population until $t = 50$, after which MPIM slightly underestimates the peak. For the isolated human population in Figure 2(c), both methods peak around $t = 50$, followed by a faster decline in MPIM. In Figure 2(d), the restored human population initially aligns well, but MPIM predicts a steeper increase post $t = 50$, suggesting potential overestimation. Overall, MPIM closely follows RK4 in the early stages $t = 0$ to $t = 50$ across all compartments. Minor deviations in extended simulations indicate potential numerical limitations.



(a)



(b)



(c)

Figure 3. (a) Susceptible Rodents, S_r; (b) Exposed Rodents, E_r; (c) Infected Rodents, I_r

Fig. 3 compares MPIM and RK4 results for rodent populations. In Fig. 3(a), both methods show a steep decline in susceptible rodents from 1000 to near zero by $t = 50$, with near-perfect overlap, confirming MPIM accuracy. Figure 3(b) shows the exposed rodent population peaking at around 600 at $t = 50$, then gradually declining. MPIM closely follows RK4 throughout, indicating strong consistency. In Figure 3(c), the infected rodent population rises from zero to approximately 1000 by $t = 150$, with MPIM and RK4 showing complete agreement. These results affirm MPIM's reliability in modeling rodent population dynamics.

4.0 Conclusion

A multistage approach was incorporated into the standard PIM to boost its ability to solve the monkeypox transmission model both accurately and steadily. Comparison of the MPIM to the RK4 method within the time interval $t \in (0,110]$ using $h = 0.001$ showed how effective the MPIM was. From the study, it is clear that using MPIM makes the model more accurate compared to the standard PIM for a larger period of time. The strategies implemented in MPIM address the problem of divergence in the traditional PIM, so it could be used in models of diseases that have a long-term nature. This study demonstrates MPIM ability to help solve differential equations in epidemiology applications, mainly by making extended predictions.

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