FSH-PH Publication

AI INNOVATIONS IN EDUCATION

TRANSFORMING TEACHING AND LEARNING BEYOND TRADITIONAL BOUNDARIES

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A special note of thanks goes to our students. Your curiosity and adaptability in the face of emerging technologies serve as the primary inspiration for our research. You are the reason we strive to push the boundaries of traditional education.

Finally, we recognize the support of our families. Their patience and encouragement during the long hours of writing and research were indispensable. This book is as much a product of their support as it is of our labor.

With sincere gratitude,

Prof. Froilan D. Mobo, DPA, Ph.D.
Editor

Preface

The rapid evolution of Artificial Intelligence (AI) is no longer a distant prospect for the future; it is a defining force of the present. In the realm of education, this shift represents more than just a technological upgrade—it marks a fundamental transformation in how knowledge is constructed, delivered, and personalized. **AI Innovations in Education: Transforming Teaching and Learning Beyond Traditional Boundaries** was born out of a collective urgency to explore, document, and guide this transition.

As educators and researchers, we have witnessed the traditional boundaries of the classroom dissolve. Geographic limitations, rigid curricula, and "one-size-fits-all" teaching models are being challenged by intelligent systems capable of adapting to the unique pace and style of every learner. This book serves as a comprehensive exploration of that frontier, balancing the excitement of innovation with the responsibility of ethical implementation.

Why This Book?
The goal of this publication is threefold:

- **To Bridge the Gap:** Moving beyond theoretical AI to showcase practical applications that teachers and administrators can implement today.
- **To Challenge the Norm:** Examining how AI can break traditional boundaries, providing access to quality education in ways previously thought impossible.
- **To Empower Educators:** Providing a roadmap for teachers to transition from traditional lecturers to facilitators of AI-enhanced learning environments.

The Scope of the Work
Within these chapters, readers will find a diverse array of perspectives. We cover the integration of AI in curriculum design, the role of predictive analytics in student success, and the ethical considerations surrounding data privacy and algorithmic bias. By bringing together a multi-disciplinary team of authors, we offer a 360-degree view of the educational ecosystem—from the primary classroom to higher education and professional development. As you navigate this book, we invite you to look past the technology itself and focus on its potential to humanize education. By automating the routine, we free the educator to do what they do best: inspire, mentor, and connect.

It is our hope that this book serves as both a compass and a catalyst for change. Whether you are a teacher looking for new tools, a researcher seeking data-driven insights, or a policymaker shaping the future of schools, this work is dedicated to your journey in this new era of learning.
Development Goals (SDGs). From enhancing climate resilience and optimizing resource management to advancing equitable education and improving healthcare access, AI-driven solutions have the potential to reshape our world for the better.

This book, **AI Innovations in Education: Transforming Teaching and Learning Beyond Traditional Boundaries**, explores the transformative role of AI in addressing global challenges. Through a multidisciplinary lens, we examine how AI-powered technologies are being deployed across various sectors to drive economic growth, environmental sustainability, and social inclusion.

Each chapter delves into specific applications, highlighting real-world case studies, emerging trends, and the ethical considerations associated with AI implementation.
The contributions in this volume bring together insights from researchers, policymakers, industry leaders, and technologists who are at the forefront of AI-driven sustainable development. By bridging theoretical frameworks with practical applications, this book serves as a valuable resource for academics, professionals, and decision-makers striving to harness AI for a more sustainable and equitable future.

As we stand at the crossroads of technological advancement and global sustainability, it is imperative to ensure that AI serves as a tool for positive change rather than exacerbating existing inequalities. This book aims to spark critical discussions, inspire collaborative efforts, and provide a roadmap for leveraging AI in alignment with the SDGs.

We hope that readers—whether scholars, practitioners, or students—find this book both enlightening and empowering as they contribute to shaping a world where AI and sustainable development go hand in hand.

Prof. Froilan D. Mobo, DPA, Ph.D.
Editor

TABLE OF CONTENTS

CHAPTER 1
Generative AI and Media Education: Investigating AI Awareness and Utilization Among Local Journalist in Biliran Province
Page 1

CHAPTER 2 Development and Validation of STEM-EDP Modules with AI in Teaching Physics
Page 28

CHAPTER 3
AI's Potential in Designing Dynamic Curriculum for Experiential Learning in Pingtung Walking Tours
Page 50

CHAPTER 4
Smart Tools, Smarter Minds: AI in the Science Classroom for Critical Thinking and Problem Solving
Page 76

CHAPTER 5
Enhancing Operations Efficiency and Customer Satisfaction through Technology-enabled System: A Quality Function Deployment and Experience Mapping Approach in the future of retail
Page 101

CHAPTER 6
Generative Artificial Intelligence as an Inhibitor of Scientific Creativity: A Social Justice Perspective in Science Education
Page 138

CHAPTER 1

GENERATIVE AI AND MEDIA EDUCATION: INVESTIGATING AI AWARENESS AND UTILIZATION AMONG LOCAL JOURNALISTS IN BILIRAN PROVINCE

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ABSTRACT

Artificial intelligence (AI) has become a transformative tool in various industries, including media and journalism. This study aims to investigate the awareness and involvement of the local media practitioners on artificial intelligence in journalism on the different local media organizations in Biliran Province. The study utilized a convergent parallel research design which the researchers analyzed and interpreted the data collected through descriptive analysis for quantitative data and thematic analysis for qualitative data. It involved a total of 17 respondents using total enumeration sampling and 8 purposely selected participants. The result revealed that 25.94% of respondents are aware that AI can improve job performance in terms of accuracy, precision, speed, and competitiveness. Meanwhile, 20.41% of respondents occasionally rely on AI to gather essential data in writing articles and stories. In addition, participants expressed that they use AI in crafting their news articles because it makes their life easier and faster. However, despite of the participants awareness the application of AI in newsrooms remains very limited. These findings highlight the importance of in embracing the opportunities presented by artificial intelligence to stay effective and relevant in the modern digital age.

Keywords: generative AI, local media practitioners, journalism, newsroom, Biliran

INTRODUCTION

The rapid advancement of digital technologies has transformed learning, communication, and professional practice across multiple sectors, and journalism is no exception. Among these emerging innovations, generative artificial intelligence (AI) has become a powerful tool with the potential to reshape both newsroom routines and educational practices in media-related fields. In the context of AI in education, generative AI is increasingly recognized as a key component of digital literacy, enabling learners and practitioners to enhance efficiency, accuracy, and creativity in producing information. As journalism becomes more integrated with technology, AI literacy—defined as the ability to understand, evaluate, and responsibly use AI tools—emerges as an essential competency for journalists, media students, and educators.

Artificial intelligence, first conceptualized by John McCarthy in 1956 as "the science and engineering of making intelligent machines," now drives many of the automated processes that support contemporary information work. Studies show that AI can improve productivity, streamline tasks, and support decision-making in various professions, including the media industry (Reamer, 2023). In journalism education and practice, generative AI accelerates tasks such as transcription, summarization, data extraction, and content drafting. Algorithmic systems that convert structured data into narratives have become increasingly common in news production, reducing manual work while raising new educational, ethical, and professional questions (Carlson, 2015; Prato, 2023).

Technological advancements have long influenced journalism—from data journalism (Coddington, 2015) and immersive storytelling (Kang et al., 2019) to analytics-driven reporting (Tandoc et al., 2019). With generative AI entering newsrooms, journalism educators and

practitioners alike must grapple with how these tools alter writing processes, professional roles, and interactions with audiences (Lewis et al., 2019; Gómez et al., 2022). Although AI supports efficiency—automating portions of an editor's or reporter's workload (AIWS, 2021)—it also raises concerns about accuracy, creativity, fairness, and human judgment. As Stefanovic (2022) emphasizes, AI cannot replicate human intuition or the imaginative reasoning required in authentic journalistic work, underscoring the need for critical AI literacy in both formal and informal learning settings.

In the local context, media practitioners in Biliran Province—including those from BiliranIsland.com, the Philippine Information Agency (PIA), Radyo Natin, and DYLN Nice Radio—play a crucial role as information educators within their communities. Their practices influence public understanding, shape information ecosystems, and contribute to the region's media education landscape. Given their role as informal educators, it becomes essential to understand how these practitioners perceive, integrate, or resist AI in their workflow, and what this means for local media literacy and AI literacy development.

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While international studies (Stanescu, 2023; Tunez-Lopez, 2021; Noain-Sanchez, 2022) have examined AI's impact on journalism, limited research captures how local media practitioners in smaller provinces like Biliran engage with generative AI. Existing literature often focuses on large newsrooms, perceptions of AI risks, or the structural impact of AI on journalism, leaving a gap in understanding AI's actual use and educational implications in rural or community-based media settings.

This study addresses that gap by examining the awareness and utilization of generative AI among local journalists in Biliran Province. By exploring their experiences, levels of AI literacy, and the extent to which AI influences their news-writing practices, the study contributes to broader conversations on AI in education—particularly in enhancing media education, developing responsible digital skills, and preparing journalists and communities for an increasingly AI-driven information environment.

Objectives

This study aims to investigate the awareness and involvement on using Generative Artificial Intelligence (AI) in journalism among local media practitioners in Biliran Province.

Specifically, its look into the following:

1. Determine the socio-demographic profile of the respondents, in terms of:
    1. Sex;
    2. Age;
    3. Years of experience;

4. Media Organization;

2. Find out the level of awareness of the local media practitioners towards generative Artificial Intelligence (AI);
3. Find out the level of involvement of generative Artificial Intelligence in writing journalistic articles among local media practitioners;
4. Explore the extent of involvement of generative Artificial Intelligence in journalism;
5. Craft a policy brief based on the results of the study.

Methodology

Research Design

The study utilized a mixed method approach using convergent parallel research design. A mixed method in which the researchers combine the elements of quantitative and qualitative approaches for breadth, depth, and corroboration (Johnson et al., 2007). Convergent parallel design enables the collection of quantitative and qualitative data simultaneously and analyzes them separately. After completing both analyses, researchers compared the results to draw overall conclusions (George, 2022).

Research Locale

The study was conducted in the Province of Biliran since the respondents were the local media practitioners in the province from different media organizations. Biliran is an island province, one of the country's smallest provinces situated in the east of Visayas. According to the Philippine Statistic Authority 2020 census, it has a population of 179,312 people, with a density of 330 inhabitants per square kilometer or 850 inhabitants per square mile. Biliran is a small island province having only few radio stations and offices in media industry with a few local media practitioners.

Research Respondents and Sampling

Local media practitioners of different local media organizations in the Province of Biliran were the respondents of the study. The researchers used a total enumeration sampling for the quantitative data collection aiming to include all local media practitioners working in the local media organizations in Biliran. Total enumeration sampling is a systematic method used in research to investigate a finite set or population. It involved a total of 17 local media practitioners using total enumeration sampling, with 8 purposely selected participants for interview.

A purposive sampling was used in qualitative data collection to ensure that the participants need in the study was selected accordingly, it specifically aims to select two (2) news writer per media organizations. Purposive sampling refers to a group of non-probability sampling techniques in which units are selected because they have characteristics that is needed in the sample. In other words, units are selected "on purpose" in this sampling (Nikolopoulou, 2022). The researchers conducted an interview to the participants. A total of 8 local media practitioners were interviewed from the different media organizations, 2 from Radyo Natin, 2 from DYLN, 2 from Philippine Information Agency and 2 from Biliran Island. The participants were chosen based on their positions in the media organization because they are most probably a media practitioner who is assigned and responsible in writing, posting, and broadcasting news. The participants were chosen based on the following criteria: (1) he/she must be part of a media organizations or a media practitioner in Biliran; (2) must be assigned on news writing, broadcasting and who's responsible in posting news to the website, and most importantly; (3) he/she is willing to participate the study.

Research Instrument

The researchers utilized a modified survey questionnaire and researcher-made interview guide questions as a primary data collection tool. The study adopted a five-point Likert scale (Bello et al., 2023) on statements that measure the level of awareness, level of involvement of AI, explore the extent of involvement of artificial intelligence in Journalism and through the result of the study the researchers designed an intervention suitable for the local media practitioners whether there's or there is no involvement of AI in Journalism. The questionnaire was distributed to a sample of local media practitioners, including journalists, editors, radio broadcasters and other professionals in the newsroom. In addition, since the instrument used in this study is modified survey questionnaire and a researcher's made interview guide questions undergo a pilot testing to ensure and test the reliability and content validity of the questions. The sample is selected using a total enumeration sampling for quantitative data collection and purposive sampling for qualitative data collection to ensure representativeness and minimize bias.

Statistical Treatment

The Likert scale was analyzed using descriptive statistics. As the name implies, descriptive statistics, describe and classify the data process. In addition, descriptive statistics summarizes the characteristics and value distribution of one or more datasets. The central tendency and degree of value dispersion in data sets can be quickly viewed by analyst using traditional descriptive statistics (Kaur et al., 2018). In order to comprehend frequencies, averages, and descriptive investigations, quantitative analysis employs a numerical and statistical methods. Moreover, descriptive statistic is employed in the statistical analysis of data and was being checked by the statistician to ensure the reliability of the result. The following statistical tools was used in the study; the frequency and percentage are used to determine the demographic profile of the participants, the level of involvement of AI in journalism and the level of awareness of the local media practitioners towards the emergence of AI.

Data Analysis

The study employed an inductive thematic analysis. When conducting an inductive analysis, the researcher codes the data without attempting to fit it into an existing coding framework or their own analytical preconceptions. This type of thematic analysis is therefore data-driven (Braun and Clarke, 2006). Moreover, for qualitative data, the researchers used interview guide questions. In a semi-structured interview, questions are posed within a prepared theme framework as a means of gathering data. But neither the order nor the wording of the questions is predetermined. The researchers analyzed the interview data by following the six steps of Braun and Clarke's (2006) on thematic analysis.

Data Scoring

The study utilized data scoring such as scaling, frequency, level of awareness, level of involvement and interpretation. Scaling is the range that determines the level of awareness and the level of involvement of the local media practitioners to the emergence of artificial intelligence (AI).

To identify the level of awareness of the local media practitioner towards the emergence of artificial intelligence, the 5-point Likert rating scale was used, which include an indicator in terms of level of awareness. The interval in this scale is 0.8; the lower limit is one while the upper limit is 5. As a result, 1.0 to 1.8 means Not at all Aware; 1.9 to 2.6 means Slightly Aware; 2.7 to 3.4 means Somewhat Aware; 3.5 to 4.2 means Moderately Aware, while 4.3 to 5.0 means Extremely Aware (Bello et al., 2023).

Further, to determine the level of involvement of artificial intelligence in writing journalistic articles as one of the significant variables of the study, the following 5-point Likert rating scale were used in the survey questionnaire, which include an indicator in terms of frequency of involvement and its usage. The interval in this scale is 0.8; the lower limit is one while the upper limit is 5. As a result, 1.0 to 1.8 means Never; 1.9 to 2.6 means Rarely; 2.7 to 3.4 means Sometimes; 3.5 to 4.2 means Often, while 4.3 to 5.0 means Always (Bello et al., 2023).

Ethical Considerations

The researchers adhered certain ethical considerations to avoid misunderstanding and risks to the respondents. The researchers ensured the safety of the respondents and informed them about the reason of being part of the study. Also, the researchers assured respondents that the data gathered are confidential and secured for the respondents to feel safe and there’s no second thought for them to answer the questionnaire. The survey collects no identifying information about any respondents because all the survey are recorded anonymously. Moreover, it is included in the ethical consideration that a certain participant has the right to refuse in answering such questionnaires when he/she feels uncomfortable. A voluntary participation is the researcher’s primary goal. This ethical consideration must be applied to adhere to ethical principles to protect the dignity, rights, and welfare of the participants.

Researcher's Reflexivity

The researcher positioned himself as independent from the local media practitioner. The researcher has been a part-time media practitioner in a national media agency and currently teaching communication and media studies at the local university in Biliran. The researcher has no biased and conflict of interests in the study.

Usage of Artificial Intelligence

This research paper used Artificial Intelligence in some part of the paper to ensure the accuracy of the grammars utilize in the study. The researchers used AI grammar checker such as Grammarly to ensure that the terms and sentences that the researcher's used in this study is clear, concise, and free of grammatical errors. In addition, aside from it helps to spot errors, it also helps to hone the choice of words and the punctuations that has make the paragraph become more formal. Grammarly is a Ukraine-founded cloud-based typing assistant, headquartered in San Fransisco. It reviews spelling, grammar, punctuation, clarity, engagement, and delivery mistakes in texts and suggests replacement for the identified errors. Moreover, the researchers also use an AI-SCISPACE for some part of the study in order to easily gather scientific PDF's and literature that are related to this study. SciSpace Literature Review is an AI-powered literature review tool for researchers. It helps the researchers easily search and understand research papers (Lasker, 2024).

Results and Discussions

Table 1. Profile of the Respondents

Profile	*f*	%
Sex		
Male	13	76.47%

Female	4	23.53%
Total	**17**	**100.00%**
Age		
34	1	5.88
38	4	23.52
40	2	11.76
46	4	23.52
51	2	11.76
54	2	11.76
57	1	5.88
Prefer not to say	1	5.88
Total	**17**	**100.00**
Media Organization		
Radyo Natin FM	3	17.64
DYLN Nice Radio	6	35.29
Philippine Information Agency (PIA)	2	11.76
Biliran Island	6	35.29
Total	**17**	**100.00**
Years of Experience		
1-5 years	2	11.76
6-10 years	1	5.88
11 years and above	14	82.35
Total	**17**	**100.00**

Sex. Table 3, shown above, presented the socio-demographic profile of the respondents. The results show most of the respondents are male, which is the male group constitutes a significant majority of the sample, with 76.47%. This suggests a dominant presence of males within this specific dataset. While the female group represents a minority at 23.53%. This indicates a lower representation compared to males. These numbers of respondents which is the local media practitioners in Biliran province is common in the Philippines newsroom where males are greater in number than females. As supported by the World of Journalism, 51.1 percent of men dominated the Philippine newsroom today. In fact, according to Franken et al., gender disparities exist in the perception of Artificial Intelligence (AI), with women, as per self-awareness assessments, exhibiting a lower understanding of AI compared to men (2020). Men, in contrast, see more opportunities in AI, rate their own AI competence higher than women.

Age. Moreover, in terms of age, it appears that the greater percentage of the respondents are in the age of 38 and 46 years old, with 23.52 percent, both age gained the highest number of the total population of respondents. While the least are in the age of 34, 57, and to one respondent who prefer not to disclose his age with 5.88 percent. The survey revealed that local media practitioner in Biliran has least personnel who aged 34 and 57. This means that most of the Biliran Media Practitioners are mostly aged 38 and 46. According to the study of Du et al., it showed that age play a key role in explaining different quality perceptions and awareness (2021).

Media Organization. In terms of media organization, the result shows that DYLN Nice Radio and Biliran Island both has the most media practitioners with the frequency of 6 or 35.29 in percent. In contrast, the lowest result shows that respondents on the media organization of Philippine Information Agency (PIA) Biliran have only two (2) media practitioner or with a percentage of 11.76%. This indicates that Biliran Island and DYLN employs the highest number of practitioners while Philippine Information Agency (PIA) has the smallest workforce on the media landscape in the province of Biliran. Which shows that the more media practitioners working in a certain organization the high chances that majority of them will use AI (Malmelin & Villin, 2017).

Years of Experience. Meanwhile, it appears that the greater percentage of the respondents are in the bracket of 11 years and above comprising 82.35%, most of the respondents from different media organization in Biliran has been in the service for over 11 years. While 5.88% from the total population has been in the service for about 6-10 years. The said findings indicates that local media practitioners who are in the service for over 11 years have a deeper understanding of traditional media practices and, as a result, may be more skeptical of AI's integration into the field. These practitioners are more cautious about adopting AI, given their deeper understanding of the complexities involved, such as balancing human creativity with AI-driven processes and the potential biases in AI algorithms. Conversely, those with less experience might be more enthusiastic about AI, seeing it primarily as a tool for innovation without fully grasping the potential pitfalls (Chan, 2019).

Level of Awareness towards generative Artificial Intelligence (AI)

Questions	Mean	%	Interpretation
I am aware that artificial intelligence is a computer system program.	4.3529	25.58	Extremely Aware
I am aware about artificial intelligence and its application in journalism.	4.2352	24.9	Moderately Aware
I know about artificial intelligence adoption during news gathering.	4.0588	23.88	Moderately Aware
I am aware that artificial intelligence has a lot of values to journalistic practice.	3.8235	22.47	Moderately Aware
I am aware that AI has the potential to evolve quality job performance in terms of accuracy, precision, speed, and competitiveness.	4.4117	25.94	Extremely Aware
I am aware that AI can be use in newsrooms to create high-quality texts and reports, reducing the time spent on it by journalists.	4.4117	25.94	Extremely Aware
I know that AI can generate texts that are easy to understand by the readers.	3.9411	23.18	Moderately Aware
I am aware of the possible effects of AI in journalism.	4.2352	24.9	Moderately Aware
I am aware that artificial intelligence makes local media practitioners highly competitive.	4.2941	25.23	Moderately Aware
I know that artificial intelligence helps in detecting and uncovering misleading information and fake news.	3.4705	20.41	Somewhat Aware
I know that artificial intelligence is creating new forms of investigative reporting.	3.7647	22.12	Moderately Aware
I know that artificial intelligence helps to verify and fact-check news report.	3.5882	21.12	Moderately Aware
I know that artificial intelligence improves ethical implications in news writing.	3.8823	22.82	Moderately Aware
I am aware that artificial intelligence is creating a personalized user experience.	4.1176	24.18	Moderately Aware
I know that artificial intelligence kills journalists' level of ingenuity, creativity, and skillfulness	4.2352	24.88	Moderately Aware
I know that the adoption of artificial intelligence in journalism practice is becoming inevitable.	3.9411	23.18	Moderately Aware
Average Weighted Mean	**4.0475**	**23.79**	**Moderately Aware**

The results revealed that respondents are Extremely Aware of AI's potential to improve job performance in terms of accuracy, precision, speed, and competitiveness. Conversely, involvement is low, with practitioners Rarely using AI for eliminating bias or Sometimes relying on it for data gathering. Similarly, respondents are equally aware that AI can be used in newsrooms to create high-quality texts and reports, reducing the time journalists need to spend on these tasks. This indicates a strong understanding among respondents of AI's potential to enhance productivity and efficiency in professional settings. According to Somers (2023), Generative AI can improve a highly skilled worker's performance by nearly 40% compared with workers who don't use it. That's why it is necessary to have a more sophisticated understanding of these technologies so that it could help the journalists to grasp and apply these technologies more effectively (Oyeleke, 2022).

Statement *"I know that artificial intelligence helps in detecting and uncovering misleading information and fake news."*, on the other hand, had only a mean average of 3.47, indicating "Somewhat Aware", with a corresponding percentage of 20.41%. The result suggests that respondents have limited knowledge or understanding of AI's capabilities in combating misinformation and disinformation. In addition, it implies that the low awareness about AI's role in detecting fake news is that misinformation could spread more easily, as people may not fully trust or use AI tools designed to combat it. In fact, according to the World economic Forum (2024), AI technologies which can generate 'deepfakes' can also help combat false information through analyzing patterns, language, and context to aid content moderation. On the other hand, International Telecommunication Union (ITU) argue that AI has also a huge potential to reduce the damage done by fake news, however it will not eliminate it and the process will take time as AI tools continue to develop and improve (2022).

Level of Involvement of Generative AI in writing journalistic articles

Questions	Mean	%	Remarks
I use artificial intelligence (AI) in writing journalistic articles.	2.6470	15.58	Rarely
I use artificial intelligence to increase the speed of delivery in my journalism practice.	2.8235	16.59	Sometimes
I am using Artificial intelligence in order to produce tremendous amount of news stories.	2.4705	14.53	Rarely
I use AI because it produces content compatible with the audience.	2.7058	15.88	Sometimes
I use AI because it increases the momentum of my reports, creativity, and my ability to draw the attention of the audience in writing articles.	2.8235	16.59	Sometimes
I am using artificial intelligence to be highly competitive.	2.4705	14.53	Rarely
I use AI to help me makes my works easier and more convenient in writing journalistic articles.	2.8823	16.94	Sometimes
I am using AI because it provides me the necessary data for the content and stories I will be producing.	2.9411	17.29	Sometimes
I use AI because it can eliminate human errors.	2.4705	14.52	Rarely
I am using AI because it eliminates the sentiments and bias in media report.	2.3529	13.82	Rarely
I use AI so I can no longer have errors in writing journalistic articles.	2.5882	15.23	Rarely
Average Weighted Mean	**2.6523**	**15.59**	**Rarely**

The results revealed that majority of the respondents which consist of 17.29% or an average count of 2.94, interpreted as “Sometimes” for the statement *“I am using AI because it provides me the necessary data for the content and stories I will be producing*”, use AI tools in gathering necessary data for the content they will be producing. It implies that most of the media practitioners in Biliran province occasionally rely on AI to gather essential data in writing articles and stories. Research points out that the use of AI in journalism can help automate an editor’s job by 9%, and a reporter’s job by 15% (AIWS, 2021). In fact, the emergence of artificial intelligence (AI) has given a significant boost to content automation, the applications of content automation are commonly associated with the use algorithmic processes that convert data into narrative texts and news, with limited or no human intervention beyond the initial programming phase (Carlson, 2015). It can make journalists’ work more efficient, freeing them up from some repetitive or routine tasks (Diakopoulos, 2019).

On the other hand, 13.82% of the respondents or an average count of 2.35, interpreted as "Rarely" for the statement *"I am using AI because it eliminates the sentiments and bias in media report."*, use AI tools due to the reason that it eliminates the sentiments and bias in media report. It indicates that only 13.82% media practitioners are using AI for this purpose, and they are not frequently relying on AI to remove bias or emotion from their reporting. Based on the result, researchers conclude that most of media practitioners in Biliran prefer using their own judgment and undergo process align with the ethical standard in writing to ensure fairness and accuracy in their work. The findings are further supported by the study of Manfredi et al. (2022), stating that this technology gives rise to a lot of questions and debate about the quality of the outputs created by AI, and the likelihood of these tools eroding ethical principles and the core values of journalism (Ufarte, 2021). Moreover, at the same time, it risks inaccuracies, ethical issues and undermining public trust (CNTI, 2023).

Extent of Generative Artificial Intelligence (AI) Involvement in Newsroom

Significant Usage

Generates New Information and Ideas. This theme refers to artificial intelligence as a tool of idea generation to bridge knowledge gaps, particularly in understanding complex research or unfamiliar topics. Generative AI provide additional idea and to expound the vocabulary of the local media practitioners.

Participant 6 expresses that there are some researches that they are not familiar with, so they often use AI to get an idea. It implies that they see AI as a helpful tool for learning and understanding things they find difficult.

"… may mga research na hindi ko masyadong kabisado o hindi ko masyadong naiintindihan so madalas, gumagamit ako ng AI para mas lalo kung maintindihan." (There are researches that I am not very familiar with, so I use AI to help me understand them better.) (Participant 6)

This result is supported by Lahti (2023) stating that in today's fast-paced world, creativity and innovation have become paramount. The rise of Artificial Intelligence (AI) is revolutionizing the landscape of idea generation, offering a myriad of possibilities for enhancing creativity and problem-solving. In addition, according to a BCG study (2023), 44% of companies reported using AI in the idea-generation process such as validating and surfacing the ideas.

Moreover, Participant 4 pointed out that although AI can help in writing journalistic articles however, we should not rely on the tools instead we should see it as a guide to help generate new ideas and information.

"..nakakatulong sa amin ang AI sa mga karagdagang impormasyon ibibigay. Huwag nating hayaan na iasa sa lahat sa AI lalong-lalo na isa rin tayong taga pag hatid ng balita, Isipin nalang natin na isa lang tong way or guide para magkaroon tayo ng mga ideas or impormasyon." (AI helps us by providing additional information. We shouldn't rely entirely on AI, especially since we are also news deliverers. Let's think of it as just one way or guide to generate ideas or gather information.) (Participant 4)

It suggests that although AI can make our work easier and faster, we should avoid being dependent on it. Especially as a media local practitioner where transparency, accuracy and ethical consideration are essential in writing. In addition, the result conforms to the quantitative result that shows that 17.29% of the local media practitioners sometimes use AI because it provides them the necessary data for the content and stories they will be producing. According to Hunt (2023), artificial intelligence algorithms will soon reach a point of rapid self-improvement that threatens our ability to control them and poses great potential risk to humanity. While generative AI can significantly increase the efficiency and speed of writing journalistic articles, it also brings threat to journalistic integrity and creativity. In fact, as Delgado (2023) stated on his article that relying solely on AI to improve and refine your ideas, consequently, you are risking to lose yourself in the process.

Moderate Usage

Accelerate News Writing. This theme refers to the extent of involvement of local media practitioners' usage of generative AI, which Participants expressed that through using artificial intelligence (AI) made their life "*faster*" and "*easier*". Generative artificial intelligence tools provide ease and convenience in doing the process of news writing allowing media practitioners to accomplish their respective task in more less time.

Participants 1 and 4 expressed that AI helps them to speeds up news writing providing them a convenience in writing journalistic article. Generative AI allows journalists to focus on more complex stories, speeding up the entire news writing process.

"… nasa isip ng mga tao pwede na nating makuha sa pamamagitan ng AI, dito napapdali ang mga bagay-bagay tulad na lamang ng pag gawa ng isang balita." (People think that we can now obtain information through AI, which makes things easier, such as creating a news article.) (Participant 4)

"Usahay mugamit ko ug AI kay sa akong bahin okay gihapon siya kay mapadali gud siya di lang ka maghunahuna ug daghan kay ang AI naman mo kuan, in a split of seconds maka kuan dayon siya maka, maka produced dayon ang AI." (Sometimes I use AI because it really makes things easier. You don't have to think too much since AI can quickly gather information and produce results in a split second.) (Participant 1)

The results implies that some of the local media practitioners in Biliran province sometimes use AI in writing their journalistic articles. They also revealed that through using generative AI it can create a news article in a split of seconds, accomplishing their respective tasks more in less time. This finding conforms to Heisterkamp (2023), which posits that through AI it can produce well-structured articles within minutes, saving both time and effort. This efficiency allows businesses and individuals to create a large volume of content in a short period, helping them meet tight deadlines and maintain a consistent online presence. In short, artificial intelligence had paved way to help journalists works easier and more convenient (Woo, 2022).

On the other hand, Participant 4, despite of acknowledging the importance of artificial intelligence tools in writing journalistic articles, he also emphasized that there's still a need to be vigilant of their usage.

"…mas napapabilis at napapdali ang paggawa ng articles na galing sa iba't-ibang tools na galing sa AI na pwedeng makatulong sa paggawa ng balita pero syempre kailangan parin naming maging

mapanuri." (It makes the writing of articles faster and easier using various AI tools that can help in news production. However, we still need to be critical and vigilant.) (Participant 4)

AI has become gradually more prevalent in mass media and news agency newsrooms. It carries several implications both positive and potentially concerning. This growing tendency has prompted intense debate about the negative impact on journalism, more particularly on the quality standards and ethical principles. This technology gives rise to a lot of questions and debate about the quality of the outputs created by AI (Manfredi et al., 2022), and the likelihood of these tools eroding ethical principles and the core values of journalism (Ufarte, 2021).

The result conforms to the quantitative result which shows that 16.94% of the local media practitioners sometimes use generative AI because it makes their works easier and faster providing them a convenience in writing journalistic articles. While 16.59% of the practitioners sometimes use generative AI to increase the speed of delivery in my journalism practice. Research points out that the use of AI in journalism can help automate an editor's job by 9%, and a reporter's job by 15% (AIWS, 2021). In fact, the emergence of artificial intelligence (AI) has given a significant boost to content automation, the applications of content automation are commonly associated with the use algorithmic processes that convert data into narrative texts and news, with limited or no human intervention beyond the initial programming phase (Carlson, 2015). It can make journalists' work more efficient, freeing them up from some repetitive or routine tasks (Diakopoulos, 2019).

Minimal Usage

Less AI Usage. This theme refers to the extent of involvement of artificial intelligence in the newsroom. Some of the local media practitioners revealed that they didn't use AI in writing articles on their respective media organizations, because they prefer personal interaction rather than AI.

Participants 2 and 3 argued that their organization didn't use artificial intelligence in the production of their articles. They also highlighted that in news writing it should have a '*personal interaction'* to gather necessary data and information to avoid delivering inappropriate information.

"Sa atong local media diris Biliran wala ni siya, kay dili man pud active kaysa tanan ang atong local media sa ingon ani so personal interaction gyud sa ato dire para di sayop ato mahatag na impormasyon." (In our local media here in Biliran, this is not the case, as our local media is not very active in this regard. So, personal interaction is important for us to ensure that the information we provide is accurate.) (Participant 2)

This implies that local media practitioners in Biliran have not yet adopted artificial intelligence in its operation because they still prefer to use traditional journalism.

"*We rely on our own, shall we say Human Intelligence HI not AI, though madali siya but sometimes dili na magamit ato paghunahuna bitaw. Kay, we depend much on AI. Ug usa pa ma displace gud ang mga tawo, ma wa gyud ang kanang employability sa mga sa tawo."* (We rely on our own, shall we say, Human Intelligence (HI) instead of AI. Although it may be easier to use AI, sometimes it doesn't engage our critical thinking. We depend too much on AI. Additionally, it can displace people and diminish employability for many individuals.) (Participant 3)

While AI can significantly increase the efficiency and speed of writing journalistic articles, it also brings threat to journalistic integrity and creativity, it also brought threat to job displacement and ethical concerns with regards to the information that journalists produced (Woo, 2022).

As noted by (Brennen et al., 2018), the implementation of AI in journalism can create new vulnerabilities, multiply information disorders as well as generate challenges relating to transparency. While the adoption of generative AI tools in newsrooms promises increased productivity and innovation, it simultaneously exposes risks such as inaccuracies, ethical dilemmas, and a potential erosion of public trust, as highlighted by the CNTI (2023). These findings suggest the importance of maintaining human oversight in the journalistic process, ensuring accuracy and accountability amidst the technological advancements.

On the other hand, Participant 1 revealed that they don't use artificial intelligence because they are not familiar with it.

"I'm not that very familiar but I know little bit about it, artificial intelligence, I am aware but not that aware about AI, well parang pinipeke. As I know it ahh…pati boses na pinipeke ng artificial intelligence." (I'm not very familiar with it, but I know a little bit about artificial intelligence. I'm aware of it, but not deeply aware. Well, it seems like it can imitate things. As far as I know, even voices can be imitated by artificial intelligence.) (Participant 3)

This suggests that local media practitioners in some media organization in Biliran province has a limited familiarity with AI. This limitation that mentioned by Participant 3 is evident in literature. According to Horowitz et al., 2023, journalists today often possess only a rudimentary understanding of artificial intelligence, which it limits their ability to engage with AI technologies. Journalists support and use AI autonomous technologies depends in part on familiarity and trust, even across use cases (Schepman and Rodway, 2020). Moreover, the study of Horowitz et al., finds out that those with familiarity and expertise with AI and similar technologies were more likely to support and use it compared to those who have a limited understanding of the technology (2023). However, based on Vero survey 90% of the journalists in the Philippines report familiarity with AI, yet only 52% have integrated it into their journalistic articles (Lachkar R. et al., 2024).

Conclusion

As generative AI continues to shape the future of media, equipping journalists with the necessary skills and ethical frameworks will be essential in ensuring that the core values of journalism are upheld in the digital era. The findings revealed that 23.79% of the local media practitioners are moderately aware on the emergence of artificial intelligence. Although they were generally aware of artificial intelligence and how it worked, some of them still don't use it, afraid of the risks it may brough to the journalism and media landscape. It implies that the application of generative AI in newsrooms remains very limited. The study underscores the need for a policy brief aim to provide awareness and knowledge towards this technological advancement and the responsible use of generative AI in journalism. The study is a call to action of a needed AI literacy training to address the gap between high awareness of potential benefits and low actual usage, which relates to the need for AI literacy in the broader education and governance fields.

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CHAPTER 2

DEVELOPMENT AND VALIDATION OF STEM-EDP MODULES WITH AI IN TEACHING PHYSICS

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ABSTRACT

This chapter aims to discuss the development and validation of three STEM modules with Artificial Intelligence (AI) for senior high school learners using engineering design process (AI-STEM-EDP). Using ADDIE framework aligned with PDSA cycle, the modules were systematically analyzed, designed, developed, and pilot tested. ChatGPT was integrated as a scaffolding tool across engineering design process, addressing constraints such as limited creativity, weak conceptual understanding, and insufficient iteration of student work. Validation involved nine experts in physics, education, and instructional design. The modules achieved high validity index (S-CVI=0.96) and demonstrate excellent reliability (α>0.80). Experts commented on the modules' real-world contextualization, alignment with STEM practices, and purposeful AI integration, while suggesting improvements in visual, clarity of instructions, and strategies for verifying AI outputs. Pilot testing with 59 Grade 12 STEM learners confirmed clarity, usability, and relevance, with recommendations for simpler definitions, engaging layouts, and relatable examples. The learners found the three modules highly appropriate for them as revealed by their mean perceptions. Overall, findings establish the AI-STEM-EDP modules valid, reliable, and pedagogically sound resources. They demonstrate how AI can meaningfully support design-based STEM instruction, fostering iterative problem-solving and creativity aligned with 21st century learning demands

Keywords: artificial intelligence, engineering design process, STEM education

Introduction

The emergence of Artificial Intelligence (AI) has redefined how teaching and learning takes place, offering vast possibilities for personalization, interactivity, and innovation (Díaz & Nussbaum, 2024). Within the field of Science, Technology, Engineering, and Mathematics (STEM) education, AI tools such as ChatGPT provide opportunities to support learners in exploring complex concepts, solving problems creatively, and engaging in iterative design processes (Mosaiyebzadeh et al., 2023). This chapter presents the development and validation of STEM-EDP modules with AI in teaching physics, an instructional innovation that integrates AI scaffolding into Engineering Design Process (EDP). Grounded on ADDIE framework and guided by Plan-Do-Study-Act (PDSA) cycle, the study highlights how thoughtfully designed AI-enhanced modules can address persistent challenges in physics learning.

The succeeding sections of this chapter outline the conceptual and methodological foundations of the study. It begins with discussion of the context and rationale for integrating AI into STEM and physics instructions, followed by the statement of the problem, theoretical and conceptual framework, and objectives of the research. This chapter further details the process of module development, validation by the experts, and pilot testing with senior high school learners. Finally, it presents key findings, implications for classroom practice, and directions for future research. Altogether, this chapter provides a comprehensive narrative on how AI can be meaningfully embedded in the design of STEM learning courses to promote deeper understanding, creativity, and engagement in physics classroom.

Problem Statement

In evolving landscape of education, the integration of Science, Technology, Engineering, and Mathematics (STEM) has become central to preparing learners for a knowledge driven and innovation-oriented society (Ammar et al., 2024). Physics, being a foundational pillar of STEM, demands a balance between conceptual understanding, analytical reasoning, and real-world application (Wandi et al., 2023). However, despite curricular reforms and the infusion of technology in classrooms, many senior high school students continue to have trouble in grasping abstract physics concepts. This struggle often results in disengagement, rote learning, and poor retention knowledge (Barrot, 2021). These challenges reveal an urgent need for instructional interventions that not only simplify complex ideas but also cultivate creativity and problem solving through active learning frameworks.

In this context, the Engineering Design Process (EDP) has emerged as a powerful pedagogical model that aligns with the principles of inquiry and design thinking (Abdurrahman et al., 2023). Through, EDP, learners are encouraged to define problems, design and test solutions, and refine their output, reflecting the authentic process of scientists and engineers. Yet, the full potential of this model is often hindered by limited opportunities for feedback, iterations, and guided explorations (WiNarno et al., 2020). Teachers, while aware of the benefits of EDP, face challenges in sustaining student engagement and providing individualized support due to constraints in time, resources, and expertise. Hence, there is a growing recognition of the role that emerging technologies, particularly Artificial Intelligence (AI), can play in providing adaptive scaffolding and enriching the EDP experience in the physics classroom.

Artificial Intelligence tools such as ChatGPT introduce new possibilities for dialogue-based learning, where learners interact with AI to clarify concepts, generate ideas, and reflect on their design processes (Salih et al., 2024). However, while AI has gained global attention in education (Bratovcic, 2025), its integration in STEM and physics instructions remains largely underexplored, especially in Philippine contexts. Few instructional materials have been systematically designed, developed, and validated to incorporate AI in a way that aligns with both content and process learning goals. The nascence of empirically validated AI-assisted modules that foster creativity, iteration, and critical thing presents a significant research gap in present STEM education.

Responding to this gap, the present study endeavors to develop and validate a set of STEM modules with embedded AI scaffolding, designed around EDP for teaching physics. Anchored on ADDIE framework and aligned with Plan-Do-Study-Act (PDSA) cycle, this research seeks to ensure that modules are pedagogically robust, contextually relevant, and empirically sound. Through examination of the validity, reliability, and usability of the AI-STEM-EDP modules, the study aims to contribute to the growing body of knowledge on how AI can be meaningfully integrated to design-based STEM instructions. It further aims to provide a model for enhancing student engagement, fostering creativity, and develop higher order thinking skills through the convergence of AI, EDP, and physics education.

Objectives of Research

This research aims to develop and validate three AI-integrated STEM modules using engineering design process. It seeks to ensure their content validity, reliability, and pedagogical appropriateness, examine expert evaluations, and assess learning perceptions of clarity, usability, and demonstrate how AI integration

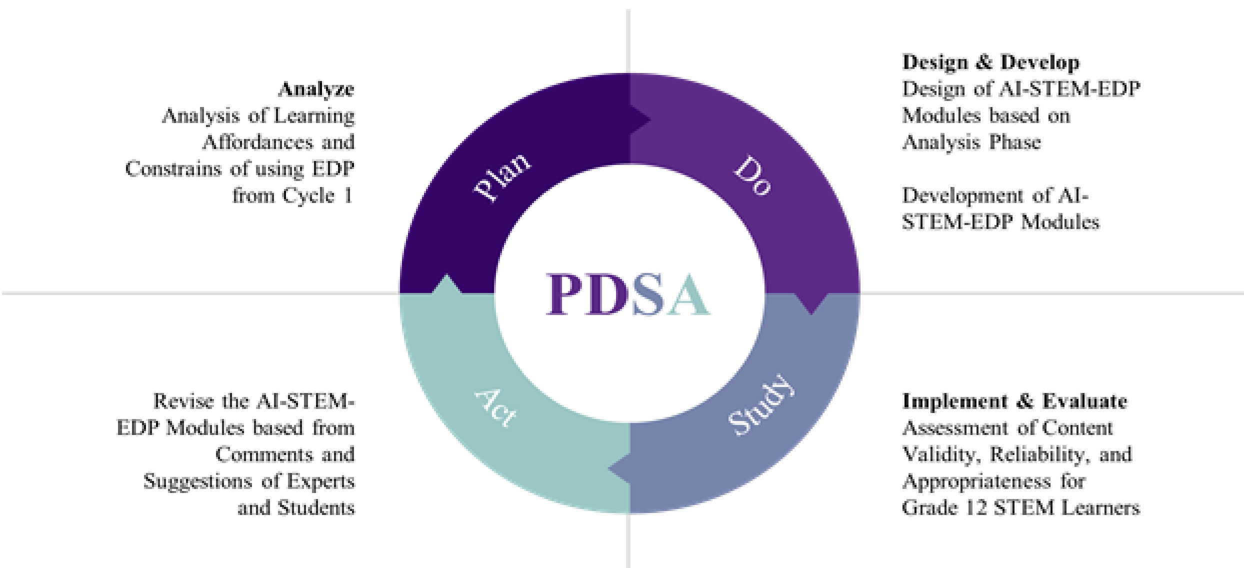
n supports iterative problem-solving and creativity in STEM learning.

Development and Validation of AI-STEM-EDP Modules

This stage presents the development and validation of three AI-integrated STEM modules using EDP framework. These module, termed AI-STEM-EDP modules, were designed to further enhance the students conceptual understanding, engineering design performance, and scientific creativity. Specifically, the aim was to design an AI-empowered and EDP-based STEM modules and assess their reliability and validity. This design process utilized the ADDIE model for the development of the modules as presented in Figure 1.

Figure 1.

Integration of PDSA and ADDIE Models for the Development and Validation of AI-STEM-EDP Modules



Stage 1: Analysis Stage

In this stage, the learning affordances and constraints of the students were analyzed based on their experience on the initial implementation of the EDP using the NASA material. Thematic analysis was employed to reveals the salient experiences of the students underscoring the affordances and challenges encountered in using the EDP in the first try out. The qualitative information in this stage is collected via reflection paper of the students. To establish the reliability and validity of the coding, a member checking was initiated from the students to affirm whether they experienced the findings revealed on the thematic analysis. Likewise, experts in thematic analysis were consulted to evaluate the findings from the qualitative data, and verify the procedure carried out the uncover the results. The expert agreed on the results of the study.

The learning affordances experienced by the students engaged in the EDP were uncovered using thematic analysis, which identified four key themes that encapsulates their experiences. First, student noted the exploration of creative solutions, where they were encouraged to think outside the box and propose innovative ideas to address the given challenge. This theme was closely related to the second, iterative problem-solving, as students engaged in cyclical process of designing, testing, and refining their solutions based on their feedback and outcomes. The third theme, reflection from learning experiences, highlighted the importance of self-assessment and critical thinking in learning, allowing students to draw insights from their success and challenges. Finally, systematic procedure, the fourth theme, underscored the structured nature of the EDP, which provided clear framework which provided the students to follow, thus fostering a deeper understanding of engineering design principles and practices.

In contrary, the challenges encountered by the students during their engagement with the EDP were also prominent in the thematic analysis of their reflective papers, revealing five significant themes. The first theme, Time Management Using EDP, indicated that the students often struggled to balance various phases of the process within the given timeframe, leading to stressed and rushed outcome. The second theme, Learning References, and Resources emphasized the difficulties students faced in locating adequate materials and references to support their design choices. Additionally, the third theme of Feedback and Iteration highlighted the need for constructive criticism, with the students expressing a desire for more guidance and timely feedback on how to effectively iterate on their designs. The Background on the Problem, the fourth theme, pointed to the necessity of the students to fully understand the relevance, context, and implications of the challenge they were addressing. Lastly, the fifth theme Communication and Teamwork reflected complexities of collaborating with peers, where differences in working styles and perspective sometimes hindered progress. Together, these themes provide valuable insights in the development of the AI-STEM-EDP modules.

Table 1 shows how the learning constraints were addressed in the design of AI-STEM-EDP modules.

Table 1. Learning Constraints Encountered in EDP and its Description and Solution

Constraints	Description	Solution
Time Management Using EDP	Students struggled to balance the various phases of the process within the given timeframe	The five-step EDP framework was adapted to streamline and enhance the application to the learning process. This adaptation significantly reduced the instructional time needed to engage in EDP, making the process easier to comprehend and more manageable to perform.
Learning References and Resources	Lack of adequate materials and references and access to information.	ChatGPT was used to provide recommendations for relevant resources and articles and at the same time give valuable insights based on students' queries.
Feedback and Iteration	Students need more guidance and timely feedback on iterating their designs.	ChatGPT was integrated to provide instant feedback on design ideas and suggest improvements. It also provided guidance on the iterative procedure on generating alternative solutions for improvement based on students' inputs.
Background on the Problems	Necessity for the students to fully understand the relevance, context, and implication of the challenge	The module EDP challenge was designed through contextualization and localization using STEM approach for the students to relate to the problem given.
Communication and Teamwork	Lack of collaboration with peers, including difference in working styles and perspectives.	The design of the module includes interaction with ChatGPT to articulate communication and articulate ideas of each student. It also gives students the opportunity to examine their ideas through ChatGPT interaction.

Stage 2: Design Stage

The design stage involved creating a detailed plan for the development of AI-STEM-EDP modules, defining learning objectives, instructional methods, and media. In this cycle, the design was based on the findings from the analysis stage and focused on formulating learning objectives, applying the EDP, using STEM knowledge, and integrating ChatGPT as an AI tool to support EDP.

The cognitive sequence of the modules is the EDP. The EDP emerged to be one of the widely available educational strategies for the implementation of STEM education (Hafiz & Ayop, 2019). The open-ended problem solving that is emphasized throughout the EDP helps students learn from their errors. This procedure develops students' capacity to come up with original responses to problems in any discipline. This procedure develops students' capacity to come up with original responses to problems in any discipline. EDP as a pedagogical strategy allows students to follow an iterative procedure to apply their mathematical, scientific, and engineering knowledge to generate the most operative solution to a given problem (Hafiz & Ayop, 2019). Moreover, EDP offers hands-on learning experience, foster problem-solving skills, and integrate multiple STEM disciplines, leading to enhancement of students' creativity and innovation. It also emphasizes real-world experiences and problems through an interdisciplinary STEM approach.

The three thematic activities in the AI-STEM-EDP modules were designed according to the five steps of EDP, aiming to help the students to experience of engineering process applying STEM knowledge. The adaptation of the EDP into a simplified five-step model responds to the students concern about the complexity, time constraints, and other challenges associated with the previously implemented nine-step model. Through streamlining the EDP, students can more efficiently navigate the stages of problem identification, brainstorming solutions, designing, prototyping, and testing. The simplified approach retained the core principles of EDP ensuring practicality and accessibility for the students. It also allows a more manageable and focused experiential learning. Figure 2 presents the five-step model of EDP originally developed for young learners and novice engineering enthusiasts.

Figure 2. ***Five-Step Model of Engineering Design Process (NC State University, 2019)***

The engineering design challenge of each module were carefully developed for implementation by applying engineering design principles, considering local contextual factors, and addressing context-rich problems. A holistic approach was ensured to the design process, integrating essential engineering concepts while also considering the unique needs, challenges, and context of the local environment. By framing the problem within the context-rich approach, students were encouraged to apply their knowledge and skills in a way that was meaningful and relevant to their community. In developing the modules, relevant STEM knowledge was integrated from the four STEM disciplines for each module. This multidisciplinary approach emphasized the interconnectedness of science, technology, engineering, and mathematics in problem-solving.

Stage 3: Development Stage

In the development stage, the AI-STEM-EDP modules were carefully developed according to the design plan on the previous stage. Integration of ChatGPT as Generative AI tool was initiated to transform the module to an AI-empowered instructional material. Expert validation follows; were science education specialists review the accuracy, instructional value, and usability. Pilot testing is then conducted to a select group of users to observe the perceptions of the students and gather feedback on the modules. Based on the feedback, revisions were made to address the issues and concerns of both experts and the student. Finally, documentation and reporting are prepared to support the final version of the modules for implementation.

(a) Integration of ChatGPT in the Modules

Central to the development of the educational modules is the integration of AI in the EDP as presented in Table 2. The strategic integration aims to leverage AI to enhance and improve each stage of EDP process, promoting an enriched educational experience. By integrating AI seamlessly into the EDP, the developed modules were expected to enhance the learning environment, address the problems encountered in the previous experience, and streamline the EDP. This research would also uncover the potential affordances and constraints associated with this integration, leading to a more effective learning materials for STEM education implementation.

Table 2. *AI Integration to EDP for the Module Activities*

EDP Steps	AI Integration
Ask	• *Define the Problem.* Utilize ChatGPT for initial problem definition, generating concise problem statements, and ensuring clarity in understanding • *Review Existing Solutions*: Consult ChatGPT to gather information on historical solutions, emerging technologies, and potential pitfalls
Imagine	• *Generate Solutions:* Engage ChatGPT in brainstorming sessions to generate diverse range of solutions, exploring unconventional and innovative ideas • *Idea Exploration:* Seek ChatGPT's assistance in exploring the feasibility and implications of different ideas, expanding the possibilities
Plan	• *Visualization:* Use ChatGPT to help create visual representations, providing insights into layouts, structure, and arrangement of the proposed solutions • *Material Planning,* Leverage ChatGPT for researching and recommending suitable materials for the design of the solution • *Strategic Planning.* Discuss implementation strategies with ChatGPT, considering potential challenges and planning for contingencies
Create	• *Implementation:* Integrate ChatGPT for real-time problem-solving during creation phase, addressing unforeseen issues and providing guidance • *Prototype Development.* Discuss prototyping strategies with ChatGPT, considering the efficient and effective ways to buil and test prototypes • *Testing*. Consult ChatGPT for insights into testing methodologies and potential scenarios to ensure comprehensive testing
Improve	• *Evaluation.* Engage ChatGPT in evaluating effectiveness of the initial design, discussing strengths, weaknesses, and potential improvements • *Modification:* Seek ChatGPT's input in modifying the design, exploring alternative solutions, and ensuring continuous enhancement • *Iterative Testing.* Utilize ChatGPT to discuss the results of iterative testing, refining the design based on insights gained from testing outcomes

(b)*Assessment Stage*

In developing educational modules, the product must be valid, reliable and appropriate. Thus, it is necessary to collect data and information to determine the effectiveness of the instructional materials

(Siew & Ambo, 2018). In this cycle, expert validation and reliability studies (Xue at al., 2023) were initiated to further enhance and fine-tuned the AI-STEM-EDP modules based on the feedback of the experts and target users.

Expert Validation of AI-STEM-EDP Modules

The modules that were developed and are divided into three thematic activities, resulting to three modules. Each module is composed of introduction, EDP activities, and evaluation that can be accomplished in 8 weeks depending on the phasing of the students. There are nine experts with specialization in science education, educational technology, and creativity research, invited to validate the AI-STEM-EDP modules. The basic information of the experts is shown in Table 3.

Table 3. *Profile of the Expert Validators*

Expert	Affiliation	Current Position	Educational Attainment	Expertise	Professional Experience	Research Experience
Expert 1	Private University	Master Teacher I	PhD	Creativity Research	8	8
Expert 2	State University	Associate Professor II	PhD Unit Earner	Creativity Research	13	6
Expert 3	State University	Associate Professor IV	PhD Unit Earner	Educational Technology	17	11
Expert 4	State University	Associate Professor V	PhD	Science Education	16	6
Expert 5	Private University	Graduate Student	PhD Candidate	Science Education	8	2
Expert 6	State Science High School	Special Science Teacher V	PhD Candidate	Science Education	20	2

Expert 7	Public SHS	Head Teacher I	EdD	Science Education	15	7
Expert 8	Public SHS	Master Teacher II	MA	Science Education	8	4
Expert 9	State University	Assistant Professor III	MS	Science Education	9	6

Education 9 6

The validation form was grounded from the study of Siew & Ambo (2018) and Xue et al. (2023). The form was adapted, adjusted and modified for the purposes of the validation protocol for the present study. The validity of the AI-STEM-EDP modules were assessed using content validity index (CVI). CVI is a method of proving empirically to determine the validity of the instrument such as test, survey, and modules. It is frequently used to establish the content of the learning adequately represents the concepts you intend to measure. CVI represents the inter-rater agreement to calculate the proportion of agreement. It can be calculated by obtaining the mean of expert's agreement on item level (I-CVI). The average of I-CVI scores for all items on the scale or the mean evaluation of experts is called scale-level CVI (S-CVI). To determine the level of acceptability, Yusof (2019) synthesized the guide for interpretation from the literature as presents in Table 4.

Table 4. *Number of experts and its implication on the acceptable cut-off score of CVI*

Number of Experts	Acceptable CVI Values	Source of Recommendation
Two experts	At least 0.80	Davis (1992)
Three to five experts	Should be 1	Polit & Beck (2006), Polit et al., (2007)
At least six experts	At least 0.83	Polit & Beck (2006), Polit et al., (2007)
Six to eight experts	At least 0.83	Lynn (1986)
At least nine experts	At least 0.78	Lynn (1986)

In this assessment stage, the developed modules were validated with nine experts; thus, the threshold for the assessment must be at least 0.78. This means that 78% of the experts agrees on the item. The validation form is composed of 12 items, subsequently evaluated by nine experts in terms of CVI. Based on the results on Table 5, the three AI-STEM-EDP modules all gained S-CVI of 0.96, suggesting a highly valid learning module.

Table 5. *Experts' Evaluation in terms of I-CVI and S-CIV of the AI-STEM-EDP Modules*

Items	Relevant	Not Relevant	I-CVIs
1. The module objectives are clearly stated in specific, measurable, and attainable form.	9	0	1.0
2. The activities in the module are suitable for senior high school students in Grade 12 STEM strand.	9	0	1.0
3. The language that is used is clear, concise, and appropriate for senior high school students in Grade 12 STEM strand.	9	0	1.0
4. The use of pictures and graphics are suitable for senior high school students in Grade 12 STEM strand.	9	0	1.0
5. The content of the module is correct and well-discussed.	8	1	0.89
6. The activities that are mentioned in the module are suitable for the AI-STEM-EDP approach.	9	0	1.0
7. The integration of AI in the activities in the module is evident.	9	0	1.0
8. The activities that are mentioned in this module are relevant to the real world.	9	0	1.0
9. Each activity in this lesson allows the students to meet the lesson's outcome.	8	1	0.89
10. The activity in this module encourages the students to integrate their knowledge in a multidisciplinary manner.	7	2	0.78
11. Each activity is arranged logically and accurately according to the engineering design process.	9	0	1.0
12. Each activity has been explained well and is easy to understand by the students.	9	0	1.0
S-CIV = 0.96			

Moreover, the experts' evaluators were also encouraged to provide comments and suggestions for improvement of the AI-STEM-EDP modules. These experts' comments and suggestions were compiled, summarized, and organized the modifications into key themes as presented in

Table 6. *Experts' Comments and Suggestions, and the Action Taken*

Experts	Comments/Suggestions	Actions Taken
Expert 1	The learning modules present practical applications of Physics concepts in real-world scenarios effectively, with easily understandable terms for students. Integrating engineering principles with physics theory in the activity engages students and enhances their comprehension of theoretical concepts through tangible experiences.	Integrated engineering principles more explicitly with physics theory to further enhance comprehension.
Expert 2	It is suggested to avoid neutral option and provide enough space for the students to write their answers creatively.	Removed the neutral option and provided ample space for creative student responses. Additional sheets were provided if students need more space.
Expert 3	Clearly label each section and provide a roadmap for learners. Suggest supplementary materials (books, websites, videos) for deeper exploration.	Clearly labeled sections and provided additional resources for deeper exploration, citing any supplementary materials used.
Expert 4	Provide instructions to verify the interaction of the students in ChatGPT. Balance the content and the space on the module.	Included instructions for verifying student interaction with ChatGPT and ensured a balanced content layout.
Expert 5	The activities are well-designed and fit well with the lesson and its objectives	Confirmed the feasibility of challenges and ensured module objectives aligned clearly with activities.
Expert 6	Check the feasibility of the challenge. Ensure that the module objectives clearly reflect on the activities.	Incorporated an evaluation question on the usefulness of AI to enhance alignment with the EDC model.
Expert 7	The module effectively addresses the significance of environmentally friendly building methods, crucial in contemporary contexts. Through clear organization and tailored content, it engages students in reflective activities, fostering active learning and deeper comprehension of	Addressed typographical errors and added an evaluation question regarding the AI's effectiveness, with a plan to implement suggested changes.

During the Development Stage, the modules were revised based on expert and student feedback to improve clarity, structure, and AI integration. Engineering principles were more explicitly connected to physics concepts, and additional space was provided to promote creativity. Instructions verifying ChatGPT outputs were incorporated to ensure responsible use of AI, while content layout was balanced for better readability. Modules objectives were aligned more clearly with activities, and evaluation questions on AI usefulness were added. Typographical errors were corrected, image citations were included, and more visuals, simpler definitions, and relatable examples were integrated to enhance accessibility and engagement.

C) Pilot Testing of the AI-STEM-EDP Modules

The second stage of the assessment involved the pilot testing of the modules. The pilot study is small-scale preliminary assessment of the effectiveness of the modules. The finding from this pilot testing were used to further improve the modules before the actual implementation. In the preliminary assessment, 59 Grade 12 students of STEM strand were asked to read the AI-STEM-EDP modules and assess its content. The three activities can be rated in four-point Likert scale in terms of content, language, and presentation. The internal consistency was tested using Cronbach's alpha, a statistical measure commonly used to assess the reliability of a set of items within a measurement scale or test. In this stage, Cronbach's alpha was used to evaluate the consistency of responses among the participants in the pilot study to the given students' evaluation form. In interpreting the reliability index, the study adapted the work of Cronbach (1951). The interpretation is based on alpha value 0.9 and above signifies excellent reliability, 0.8 to 0.9 indicate good reliability, and 0.7 to 0.8 is deemed acceptable value, and 0.7 below raises concern about reliability; thus, the threshold cut-off is set to 0.8, suggesting that the internal consistency of the responses of the students in the assessment of the modules is adequate. Results shows that AI-STEM-EDP Modules 1 to 3 gained an excellent reliability indices of 0.945, 0.957, and 0.891, suggesting highly reliable learning modules as presented in Table 7.

Table 7. Reliability of the AI-STEM-EDP Modules

Table 7. *Reliability of the AI-STEM-EDP Modules*

Module	Cronbach's Alpha			
	Content	**Language**	**Presentation**	**Overall**
1. Connecting Two Cities	0.883	0.776	0.899	0.945
2. Let there be Light	0.894	0.888	0.909	0.957
3. Cold in a Bottle	0.743	0.703	0.760	0.891

Following the pilot study, selected students from the Grade 12 STEM learners were interviewed. The interview serves as qualitative method to gain deeper understanding into the students' perceptions and insights regarding the developed modules. Through interviews, the students can express their opinions on various aspects, such as clarity of content, effectiveness of instructional methods, engagement level, and challenges encountered. The students suggested enhancing the module by incorporating more visual aids, simplifying definitions, improving organization and formatting, reducing the length of activities, and including real-life examples to enhance student comprehension and engagement. These recommendations aim to create a more accessible and impactful learning experience for students by making the content clearer, more concise, and relatable to real-world scenarios. The comments and suggestions were carefully analyzed and were addressed to fully improve the AI-STEM-EDP modules.

Conclusion

In conclusion, this chapter illustrates how AI can be effectively embedded within EDP to enhance STEM learning. Using ADDIE and PDSA cycle, the study produces a valid, reliable, and pedagogically sound modules that improved learners' engagement, creativity, and conceptual understanding. The same procedure may be adapted in similar education contexts, such as designing AI-assisted modules in chemistry, mathematics, or engineering, to foster inquiry and iterative problem-solving.

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CHAPTER 3

AI'S POTENTIAL IN DESIGNING DYNAMIC CURRICULUM FOR EXPERIENTIAL LEARNING IN PINGTUNG WALKING TOURS

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ABSTRACT

Now that rote learning is dead, AI and experiential-based education used together are offering a world of exciting possibilities – especially when it comes down to trickling inspiration into grassroots as what we're doing with Pingtung Walking Tours. This study pursues a radical new possibility: using AI to read the ever-evolving interests and curiosity of student as they wander through cultural institutions—reshaping content on-the-fly for that everyone stays connected and engaged, all-the-time. It's not supplanting the warmth of human guides, but amplifying it — turning every tour into a partnership exploration in which tech fades back as guides light up connection that's genuine. AI feedback and live curriculum update transform passive observation into active creation, as the content reacts to your interests with questions that get you thinking and stimulate self discovery. As I hope to have at least shown, the human-AI partnership isn't just about automating learning — it's also liberating for teachers to do what they do best: engaging with and forming relationships, creating life-altering experiences, making a humanity contribution. This study is ultimately a demonstration of what happens when AI and human creativity converge: You can have education that is deeply adaptive, culturally relevant and at its core genuinely human.

Keywords: ***AI in Education, Experiential Learning, Dynamic Curriculum, AI-Human Partnership, Cultural Heritage***

Introduction

We're living in a fast-changing world - maybe too fast. School's are increasingly emphasizing problem-solving, experimenting with materials, and getting kids to learn by doing instead of old-fashioned rote memorization. Adding AI to the mix has its own potential benefits and drawbacks. Yes, of course AI can help make learning more individualized and may even ignite creativity and motivation when coupled with activities such as hand's on projects and games . But there's also a downside: When learning relies too heavily on algorithms, it risks failing to capture the warmth and flexibility classrooms derive from living, breathing human teachers (Haleem, 2022).

You'll spot this push and pull everywhere — from Taiwan's schools to its local community efforts. The real quest, when tech gets embedded in walking tours or classroom games, isn't for efficiency so much as keeping things relevant, lively and meaningful to all who take part. Consider the Pingtung Walking Tours. We have known those who tend to play their canonical script, and some students just don't click. This study takes a novel approach: using artificial intelligence to analyze what students are interested in before and as the tour proceeds, to adapt to their curiosity.

"Learning by doing" blossoms when content is tailored to the bodies in the room, so that each lesson — or tour — is very much a shape-shifting and growing thing. And it's a trade-off: the more tech you include, the more personalization you bring on board — but also look out for lost creativity and dangers of treating learners as data instead of people (Haleem, 2022). The sweet spot? Let AI contribute, but with teachers, guides and students at the center — so that each moment remains thoughtful, adaptive and resolutely human.

Objectives of the Study

- Assess the effectiveness of an AI-based dynamic curriculum in student engagement and retention over a traditional static tour during the Pingtung Walking Tours.
- To study the capability of AI to customize learning experiences according to participants' interests and previous knowledge by adapting virtual tour content, route, and providing real time information.
- To determine AI's role as a pedagogical instrument that complements instead of replacing the human tour guide and to define ethical considerations and practical issues in engaging it within experiential learning context.

Literature Review

Data-Driven Learning Style Detection and Personalization

Teaching before was more one-size-fits-all, with all kids expected to learn the same way everyone else did, but double A's and AI-based systems are changing that around." Instead of assuming that one size fits all, these real-cohort platforms quietly follow a digital class as it unfolds in the corner and learn by watching how each student learns — be it through rapid quizzes, via storytelling or hands-on activities — fine-tuning their lessons over time. An analogy with children who simply have played for a longer time can be given in that after being on the tour or more experienced classes once, they then are able to identify shapes and play them as such the next time. It's more than matching test scores — A.I. can recommend alternative trails for Pingtung tours or personalize a personal story to ensure everyone keeps reading. Not only that AI also acts as scaffolding (Kong, 2021, Ramirez & Esparrell, 2023, Putri, 2025)— it's also leading to better understanding and better memory, because the whole course is configured around what you are truly interested in, and how you learn (Labrague, 2024).

But the metroplex of data that Starbucks is ramming down its customers' throats this very moment, alongside a series of attempts to personalize experiences with it, comes with some warning labels. The tech can be so numbers- and trend-crazy that it loses the strange, scenic little things about our world — what makes each of us an individual human instead of a number on a form — and ends up too enamored with what worked yesterday. Real teachers still have to reach out into space and time, feel into the social context within which relevant learning is possible — because no algorithm can tell us what is happening with a walking tour audience (Haleem, 2022). Artificial intelligence lets teachers and guides focus on sparking creativity and responding to real-time feedback instead of being bossed around. Once you do that, any lesson or trip becomes more meaningful and personal, not just another thing to check off.

AI-Powered Adaptive Feedback and Scaffolding

But AI-driven feedback tools are helping to take much of that guesswork out of the learning journey, especially when it comes to hands-on exercises like walking tours. Instead of relying on catching up with paperwork or post-tour surveys, AI can track, for instance, how long people's interest rates linger at each location and prompt them to ask questions in the moment when curiosity is piqued. These might read, for example: "In this spot in space there was a powder mill here hundreds of years back when Dutch occupied." Consider being on a Pingtung tour and getting a ping linking to the shop you're standing in front of or a nudge to go ask the owner about something unique he does with his craft. This real-time, intelligent feedback means everyone gets more out of the experience—not just those who would typically raise their hand. Feedback is instantaneously customized so participants can clarify misunderstandings as they arise and the dialogue of the conversation remains current to the group's interest and inquiry.

Such tools do not stay in the surface facts of a place; instead they provoke curiosity around them, e.g., why / what made a traditional tea house, a successful venture or how family owned shops survive in this digital age (Yilmaz & Yilmaz, 2023). After the tour is finished, the system can support designing projects or challenges according to what each group found interesting, for example designing a digital display or even thinking about new marketing ideas for a local tailor. What we can learn from emerging research is that the sweet spot here is AI guiding and suggesting, but not compromising the teachers' or guides hands-being able to riff off that data-mix in their personal stories-and adapt on-the-fly. (Geerling et al., 2023). That whole course is configured around what you are truly interested in (du Plooy, 2024) keeps things interesting, and ensures that learning doesn't slip through a sieve at the end of the tour.

Technological and Infrastructural Challenges in AI Integration

Attempting to incorporate AI into a hands-on teaching of history, as Pingtung walking tours do, can be like juggling too many balls in the air at one time. First, and most straightforwardly (if also significantly), there are: the logistics of ensuring each student or guide even has the tech cogs necessary to turn these smart tools — good phones, reliable internet connections, enough local servers so that guides won't fall behind. By some vague roll of the dice, a class in small-town or rural Taiwan — where the connections can be spotty to unreliable — feels more like Russian roulette: Will the digital prompts appear late (or not at all)? What's more, all of these new systems require teachers to be taught how to them and that just can't happen overnight; without AI confident teachers or (again) the guides, lessons run the risk of becoming scripted or falling apart due to technical problems and hardware hiccups.

It's not just the tech — there are big fairness and cultural fit issues. Sometimes AI is relying on things it has learned from a global data set that are no longer in line with local vibe, or missing out on the unique stories of how a place like Pingtung came to be. Automated systems, left to their own devices, can ignore the eccentricities of a local community or misrepresent cultural steps — or become biased if they are working off less diverse data. The real fixes are allowing community voices to help shape design, adding strict anonymization of personal data and requiring that human experts be on duty periodically to check what the A.I. is serving up. There is something inherently powerful using smart machines to augment smart locals - the art of having technology as an assistant, not a performer, of making it all about real storytelling, truthful history, and that every learner is part of the story (Geerling et al. 2023).

Interdisciplinary Applications of AI-Driven Adaptive Learning

AI-based adaptive learning isn't limited to classrooms or even online quizzes, but is invading every crevice of human culture — history walks, science labs and now art workshops. When you sprinkle in some AI to real-world activities, like walking tours of Pingtung, the tech can lean on ideas from psychology, cultural studies and even business to ensure that each lesson is evergreen and connected back to the world around us. For instance, a walking tour might use A.I. to prompt local stories students could read depending on their interests; ask them to consider environmental implications of what they're seeing; or task them with developing a mini-business plan as if you were the shopkeeper. This cross-curricular learning process allows students to comprehend the relationships between topics instead of considering them as compartments.

It’s cool because these cross-disciplinary approaches aren’t just more fun ways to learn, but they’re going to help students hold onto information and think at higher levels. When AI reframes problems in a more interdisciplinary manner, research has indicated that people have been able to make up a linear solutions and connect the dots easier (Yilmaz & Yilmaz, 2023). Whether it’s history combined with tech, or the arts folded into social science — the idea was to break down the barriers between subjects and give students a way to explore ideas in an integrated fashion that makes sense and feels purposeful. Teachers or guides can “hotter , the topics in the first place, on the other side students walk away with a enhanced and more complete experience of which remains in their mind after they have left this environment (Geerling et al., 2023).

Figure 1:
The AI-Driven Experiential Learning Model

It’s basically Kolb’s Experiential Learning Cycle (doing, reflecting, applying), with a twist: This version makes clear how A.I. and tech tools can help support every single step — not just classroom lectures or walking tours. You’ll begin, as before, with hands-on Concrete Experience — a trip to a store or trying something out. But then it also: a) provides a way for learners to store reflections (feedback, or even skill gap analytics in the moment). Reflective Observation is complemented by smart systems that can lead you on with what you didn't see and try to stretch your thinking a bit further, which makes the exercise less lonely and even more guided. Then it's on to Abstract Conceptualisation and Active Experimentation – with AI suggesting learning paths, digitally accurate simulations, performance analytics keep it all ticking over. The distinguishing characteristic of this model is that each of these technical layers personalizes the student learning journey, by practicing students in experiential learning, reflecting with live feedback, and making sense of one's own experiences (Wang, 2024).

That outer ring shown on the image brings in tools like AR/VR simulations, quick skill-gap ID, personalized content curation and performance tracking — meaning instead of a single "one and done" experience learning is continuous and ultra-adaptive. If you're weak in a certain skill, AI notices and suggests new practice assignments. Feedback systems kick in when a team is at rest, and recent findings suggest that the tools bring about improved knowledge retention, motivation and real-world usability of skills when paired with experiential learning (and not just plain old talking-at-you). In short, it's as if each learner had their own coach, guide and cheerleader in their pocket.

Methodology:

This research employs a systematic narrative review methodology, an organised but adaptable method of integrating interdisciplinary research in the growing domain of AI in experiential learning. Findings Synthesis: We will conduct a systematic and literative review of peer-reviewed databases and appropriate gray literature from 2015 to 2025 to support an all-encompassing thematic synthesis. This procedure guarantees the contribution of basic research as well as of the most recent advances concerning AI-driven personalization, adaptive learning and technology in cultural heritage preservation. The study is conducted under the perspective of a participant-observer, allowing a pragmatic view in which we can assess the theory on cultural heritage preservation.

Results and Discussion:

<u>The Pingtung Walking Tour: A Case Study in AI-Driven Learning</u>

Figure 2
List of places visited by the D1 Team during the Pingtung Walking Tour

Note: The places visited by the D1 Team were as follows: #3-Lung-Shen Cloth House, #19-Rong-Rong Tailoring Shop, #15-Donghua Embroidery Shop, #8-Zhen-Zhen Silver Shop, #4- Chong Sin (Old Trusty) Tea House, #14- the Dadongsen Watch & Clock Store

According to the photo of map provided on Pingtung Walking Tour, the D1 Team went to six landmark sites showing traditions and vitality. It all began at **<u>#3 Lung-Shen Cloth House</u>**, a popular site for local textiles. Next was **<u>19# Rong-Rong Tailoring Shop</u>** that specializes in bringing big-city tailoring techniques a little closer to the heart of Pingtung. Next on the list was #**<u>15 Donghua Embroidery Shop</u>**, one of those places that somehow manages to keep handmade embroidery alive and kicking through generations. The team then went to **#8 Zhen-Zhen Silver Shop**, which used to be a silver exchange site and its unique basement money exchange bond with China. 5. **#4 Chong Sin (Old Trusty) Tea House** A comfort house for homesick mainland Chinese and an early version of social networking, manufacturers worked on their tea tins in the airport's mechanics' shop. Closing out the D1 Team stopped at visit **#14 Dadongsen Watch & Clock Store** (where timepieces classic and colonial-era are repaired by Mr. Chen), a metaphor for an area that has survived, but deserves a good tune up.

Instead of writing about these spaces, AI might raise the resolution on how their stories are told, describing not just that a business had this and then that owner but detailing the altered socio-economic topography in which each one sits now. The generational fortitude and hand craft at shops like Lung-Shen Cloth House or Donghua Embroidery Shop — sites for episodes in which designers have been taken under those businesses' wings for a workroom challenge — offer rich demonstration data to an AI system. Instead of thinking about this as simply a matter of fact recall, AI can assist students in reflecting on how these spaces are engaged with through digital commerce, what local traditions either persist or are lost as well as, how the local economy is transformed—making for an area that explores critical thinking about Pingtung's industry: it's identity. At Dadongsen Watch & Clock, for instance, AI might reveal not only the artistry of Mr. Chen but also the market headwinds he encounters as digital watches change consumer habits. This kind of reading encourages students to negotiate between tradition and modern influences that see the university grounds as alive with the stories of socio-economic transformation.

What's more, from the chance for AI models to weave in anecdotes, textures and transaction data learners could visualise browsing tensions inside each shop – community belief, economics and personal story being a recipe which takes on its own complex form when smoking tradition meets technological fire. By using A.I. to analyze trends in shopkeeper stories and local customs, education's content can differentiate itself from the endless recycling of stale facts into invitations to new perspective — on how underground money exchange at Zhen-Zhen Silver Shop reveals interconnecting networks or the ways innovations brewing at Chong Sin Tea House build community even as flavors change. This is a method that wrenches the learning outcome from rote memory and into synthesis, enabling every student not just to reassemble for themselves how businesses in Pingtung — their city — are continuing to adapt and evolve what heritage means in the digital age.

Experiential learning with AI

Augmenting Critical Reflection and Conceptualization

The contribution of AI to the creation of a cognitive scaffold is also at the level of higher Order thinking operations in the Kolb cycle, particularly with respect to "abstract conceptualization. Post-Tour: Human-AI Hybridization At this point, the AI-enhanced connection between humans can transport visitors beyond mere reflection to new territories of theories and ideas. And an AI chatbot, say one that could digest both a user specific tour route and reflections of the person's relations to them might pose this question at the macro level: "Given the generational changes you encountered at Lung-Shen Fabric Store and Dadongsen Watch & Clock what are some overarching economic challenges for traditional businesses in Pingtung in the digital age? Mechanisms for such probing are critical to the ability to compile over multiple empirical statements and construct an integrated model, a step central to transitioning from “learning by doing” to learning about what one was choosing (Yilmaz & Yilmaz, 2023).

Finally, the organization’s AI might support this “active experimentation” stage, such that debriefing post-tour activities does not have to be an endpoint but part of a dynamic feedback loop. Additionally, the AI can suggest personalized projects or challenges that students can test their new ideas against. A student who developed a theorized account of the survival mechanisms of local businesses in Pingtung could be challenged to express that theory speculatively for something like an invitation current affairs platform that allowed users to flex AI’s visual muscles. This dynamic of learning, reflecting, conceptualizing and exercising MindSpace — facilitated so elegantly by the AI augmentation — underscores the principle that learning is not a one-time ‘event’ but an iterative process in which walk on top of our own experience — cornerstone to transformative educational experiences (Kolb & Kolb 2018).

AI-driven Contextualization in Pingtung Walking Tours

Among the first things we learned during Pingtung Walking Tours was that places like Lung-Shen Cloth House or the Zhen-Zhen Silver Shop weren’t just dots on a map: They’re living stories. The AI-guide anchored the student dedicated to a purpose, by selecting relevant clues from any description at which point it was available and also, most significantly, when the way that it suggested individuals should pursue leads beyond what they would naturally gravitate toward themselves: faded transaction ledgers at Zhen-Zhen; meticulously engineered hand-embroidering technique at Lung-Shen; or vivid price haggling that occurs behind the walls of Chong Sin Tea House. Where guidebook-style tours might have overlooked such “small moments,” The AI made visible the sharing of intergenerational knowledge and hidden exchanges going on beneath the surface that others frequently pass by. Recent research confirms this: changing student experiences, history used to articulate the broader fabric of culture -- both can help combat the “complexity trap”.

Still, there’s a trade-off. At times too, there was an inundation of digital prompts and context from the AI — not something that everyone found helpful or reinforcing, with some students being drawn away from the real physical environment and hands-on sensory experience they were meant to be concentrating on in taking the tour. Several learners said they “dual screened” their phones and were often “tugged” between the screens, where the AI offered snippets of history or questions to be asked, and the shopkeepers themselves. This is along the lines of what we’ve seen in more general studies on digital learning: Too much tech can strip away “concrete experience” and detach from physical space and real people. We found that our favorite moments were when the AI restrained itself, letting participant-driven exploration take the reins.

Yet, Those Students who were exposed to both the AI cues and on-the-ground experience, however, appeared to attain more sophisticated levels of synthesis. Their post-tour statements were not just about facts, but some narratives regarding the hidden significance of Chong Sin Tea House in local transaction network and meaning of oldest cloth pattern to Lung-Shen. These are realizations motivated by apt digital scaffolding but grounded in lived experience that show the way in which AI may cross the gulf lying between recall and critically culturally interpretive understanding.

Adaptive Content Delivery and Its Impact on Engagement

The Power of Real-Time Personalization in Fostering Immersion

The definition of an AI- based curriculum architecture makes it evident that personalized learning on a just-in-time basis can make an enormous difference in when learning happens, even to the point of making this mostly experiential. Rather than a static, one-size-fits-all tour that often promotes passive observation, an AI-guided tour could flexibly modulate the amount of content based on pre-tour interests and in response to visitors' live interactions with their environment. For example, to an art and design enthusiast, Rong-Rong Tailoring Shop may present rich, creative contents for both exploration and interaction by said group. Such immediate matching between content and user interest in fact transforms the walking tour from a general knowledge source to a personally meaningful experience, which is one of the main factors for enhancing learner motivation.

It's this level of personalization that forms a powerful feedback loop to hold our attention and provoke our curiosity. As users engage with the personalized content, the AI is training on what they are watching and surfacing material it thinks you might want to watch next…and pulling in appropriate contextual stuff. It cautions us of cognitive overload, as the learners should not get bogged down with one single story. The result is a learner-centred learning model, engendering a more personal and active form of experiential education where the learners in fact manage their own process of discovery that typifies high impact educational experiences (Number Analytics, 2025).

Conceptualizing the Role of Data-Driven Insights on Curriculum Efficacy

In addition to effects on the participants themselves, an AI-supported system should be able to provide data-cockpit and research insights which guide curriculum effectiveness. Silently keeping an eye on things like how long guests linger in certain places and which content they request most often, such a system might allow educators granular insights into what parts of the tour are resonating.

This real-time information, can give an instantaneous feedback to curricular modifications. This is far more effective than relying on the post-tour subjective surveys of the user, or anecdotal feedback. This doing on the fly would turn a tour from "a static performance into a dynamic, high-performance teaching tool."

The collected data an AI is assisting to gather might also be key intelligence for educators when it comes time to gauge their participants' "knowledge gaps" and learning needs. The system could suggest that a particular topic does not evoke impulses in a location, or that no one knew to begin with. This would facilitate a focused, sequenced approach to the evolving types of curricula development in order for each round of the walking tour to be as effective and timely as it can be. AI through a neutral rendering of the learner's trajectory, could allow educators to escape from general assumptions and carve solutions that are both accurate and cost effective in inducing value during learning.

Measuring Success: Shifting Outcomes from Recall to Synthesis

Beyond Factual Recall: Measuring Critical Synthesis

The potential of an AI-based curriculum reflects a change in desired outcomes of education; no longer the memorization but more critically synthesis of our students. Traditional forms of education tend to measure whether, or how well, a learner can recall and reproduce certain facts (e.g. dates or names). An active AI, alternatively, could help players piece information together in a coherent conceptual model. "An AI like that could go further than a site like the Zhen-Zhen Silver Shop and start cross-cutting with more of the business plan of something like Chong Sin Tea House through personalized tours and prompts." The individualized, active approach has the capacity to facilitate profound developments in higher-order thinking processes.

Value of this ‘map making’ process would be reflected through post tour qualitative findings in its feedback. Instead of simply documenting places they had visited, participants say in an AI-enhanced tour might be prodded to articulate more subtle findings and develop their perceptions into broader theories about economic change in Pingtung. So, for example, beginning Chinese students might be asked to connect Dadongsen Watch & Clock’s owners’ generational battles with broader tendencies about changing consumers in response — a much subtler form of recall. This ability to interrelate and apply knowledge in a significant manner is a key indicator of high-impact learning, making it what would be considered beneficial evolutionary step above guided tour education.

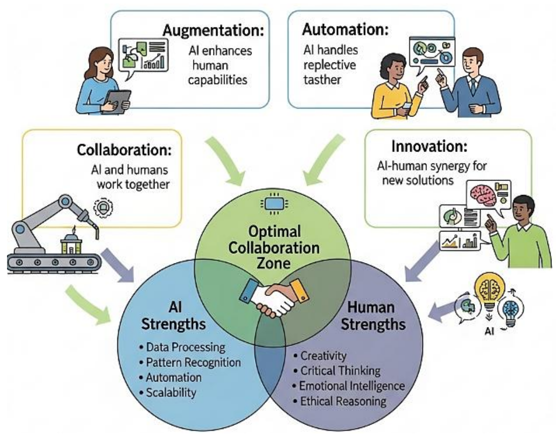
The Role of the Human-AI Feedback Loop in Formative Assessment

An AI-based tool has the potential to add value by providing a continuous formative assessment – as opposed to the “one-time” manual assessment – through driving dynamic feedback loops. The AI’s tracking of participant behaviors, such as time on task in particular locations and the number of questions posed, allows educators immediate feedback regarding learner engagement or interests. This type of fine-grained access is not traditionally achievable in conventional settings and would allow for teachers to guide learning as it is happening. So, for example if the AI sensed that it wasn’t getting much engagement at a particular tour stop, a human guide could descend on how to provide more interactive or personal context.

Furthermore, I can see the post-tour analysis generated by the AI system as a powerful formative assessment mechanism for teachers. Over a sample of tours, the system learned where there might be shared informational gaps or deficiencies in the curriculum. This could allow curriculum redesign to be based on evidence and for future tours not to 'repeat the same mistakes' we have made. This is a cyclical, iterative process of experience and data collection followed by revisiting - an ongoing cycle which is only achievable with human-AI partnership if the education system is to avoid getting stuck in a 'snapshot' mindset learning process and truly evolve into developing a growth culture.

The AI-Human Partnership: Facilitating and Augmenting the Tour Guide Role

Figure 3:
The AI-Human Partnership Framework



The AI-Human Partnership Framework provides a conceptual model, near the top of this hierarchy, for human-machine partnership and is depicted in the figure. At its essence, this model highlights the 'dog partner' aspect between what AI can compute (e.g., big data computation or automation of routine work) and valued aspects of humanity such as creativity, critical thinking and ethical reasoning. The strategic partnership goes beyond getting tasks done and spurs innovations in four key areas: augmenting human potential, automating mundane tasks, addressing collaboration challenges and sparking influential innovation that is not possible to achieve independently by any one of the partners.

The Redefined Role of the Human Guide: From Presenter to Facilitator

The study findings demonstrated that AI-enriched curriculum transforms the role of a human guide from simple expositors to experienced discovery facilitators. Once a guide is restricted to taking people round on a story that the tourist cannot affect then the information will be too one way and some tourists won't become as involved." But when A.I. is called upon to ride shotgun, putting it in charge of serving up, as if by magic, just-in-time dynamic personalized content or the like, the human guide can rise to do some more transcendent work." They can focus on generating trust with the cast instead, answering particular questions provoked by AI and building community of intersubjectivity. This turn is consistent with the growing consensus, from pedagogy, that it is not the teachers who are best at conveying information, but those who guide and encourage subjects to construct their own knowledge (Geerling et al., 2023).

This larger responsibility also gave human guide a chance to utilize their natural domain specific (or SBNG) skills where AI can't. The AI might have some information on the history of Chong Sin Tea House, but a human guide can tell you about drinking tea there with their grandparents when they were small and bring that history home in an emotional way. Such a degree of storytelling, and understanding of context, is necessary in producing a 360-degree experience that stands on its own. Furthermore, the human guide can read the group through non-verbal cues (eg people being confused or very excited about something) and adapt the pace or focal points of the tour in real-time – which AI cannot presently match. This symbiotic relations creates a force multiplier, abstractionoverlays expanded educator tool empowered to deliver transformative experiences and as an extension artificial intelligence is in charge of the delivery logistics or tours yet all performed in a logistical data driven fashion.

Optimizing Pedagogy Through a Symbiotic Feedback Loop

The fusion of human with AI induces a positive feedback system which, in theory, will elevate the pedagogical efficacy of the walking tour to a whole new level. "By being able to see data on dwell time at different locations, or how frequently content is requested – that is where the human guide gets actionable intelligence thanks to the AI system." For example: say the AI notices that a group seems to love the performances of Rong-Rong Tailoring Shop. If this occurs, guide will let the stop out and talk to owner at length. This kind of dynamical data driven interaction puts the tour not to an unique, nor fixed event but into an adaptive learning system.

Furthermore, this association also allows the user i.e., human guide to switch from being a reactive mode to a proactive one. With an AI collating the data on what a group is interested in, the guide can anticipate questions and prepare to glide through areas a little more, which can only make for an entirely better experience all round. The lessons learned in the study raise one consequence: that repeating transferring information—learner-to-AI-to-human-guide—is crucial to forming a high-impact learning environment. It also insures that this curriculum is not merely personalized, but on-going and ever-refined — the knowledge and experience of the human guide serving as that last necessary veneer in which raw data alone may be molded into an education encompassing deep observance of people.

Ethical Dimensions and Future Research

Table 1:
Ethical Considerations and Mitigation Strategies

Ethical Consideration	Mitigation Strategy
Bias in algorithms and data privacy	Such data will be anonymized, used exclusively for educational purposes and a "Privacy-by-design" principle will be enforced. Better monitoring Better human oversight is needed by continuing to check the AI-generated content.
Too much reliance on technology	Create training programs that allow guides to leverage AI as a secondary tool instead of it taking over their knowledge/thought.
The ability to scale and adapt across cultures	Use local data to personalize the AI model and generate content relevant to each community.
Analyzing the long-term effects	Longitudinal research to monitor retention of knowledge and the trans-formative potential effect of AI supported curriculum over time is needed.
Integration of AI across multiple modes is lacking	Use multimodal AI systems that produce visual resources or interactive simulations to support this "active experimentation" stage of the learning cycle.

The table presents a proactive strategy to embed ethical issues in an AI-based educational model. It addresses problems that have been raised, such as the risk of data privacy and dangers of algorithmic bias by offering solutions like anonymization and human-in-the-loop. Also, in the learner centric framework there is a shift of roles which applies to teachers as well - suggesting the development of new skills enabling teachers who will use AI to decide when they need to make use from it and not be dependent on it. It also identifies barriers to future development, including the need for a model that scales and is configured to individual cultural contexts, and the absence of longitudinal research studies that evaluate AI-supported learning impact over time.

Navigating Ethical Dimensions of Data and AI

But in Pingtung, the use of A.I. to steer experiential learning isn't just a tech upgrade — it raises its own cultural and ethical questions. One major danger is that an algorithm itself, in interpreting historical data about a place like Zhen-Zhen Silver Shop, might misapprehend or oversimplify its role as a money exchange service conducted underground. It's in danger that, if it does fall into the wrong hands, what should be a rich local history is at risk of being diluted or even erased by cartoonishly awful simplifications — and there's a real-life effect to how the community's story gets passed down. Heritage scholars argue that these biases, as unintended design failures could be deleting data to which people attach importance, with potential serious implications for shared historical memory and identity. And rather than only anonymizing or policing down data for garden-variety oversight, we must install a community-first framework: People who operate stores and are cultural stewards should also have a say in shaping and reviewing and adapting the stories AI platforms tell.

It is not enough for teachers and authors to try to apply technological solutions (anonymizing user data or restricting models only to creating elementary training programs). Drop too heavily on algorithmic suggestions and guides, and you're in danger of undermining their profound understanding and storytelling quality — deepening the chasm further between visitors and what Dadongsen Watch & Clock type places are really like. New research calls for a community role at every level, and for locally-based experts to verify AI-sourced information, spot inaccuracies and save rich meanings that can only be read in context. One concrete way to make sure that these communities extract, not just value but control from digitized stories is by taking a slice of the AI-enabled insights and data back to mom-and-pop-shop owners — instead of their being raw input for tourism or pedagogy.

Avenues for Future Research and Scalability

The Pingtung Walking Tour is just the first step. For sure, as the model stretches into new venues in the years ahead, AI-powered experiential learning will need its ethics watching closely and significantly better measurement. More research could explore how a "community-first" ethics might work in other Taiwanese towns or elsewhere, tweaking algorithms with new local input and watching shopkeepers' use of shared data to change stories themselves. But systematic reviews have also made a case for adaptive, multimodal AI — illustrated with visual simulations and interactional guides — that can be tailored to the local context to redress whatever distortions and exclusions arise as they mature.

They also highlight the importance of longitudinal tracking: following cohorts of people over time to see whether these initial cultural insights do indeed take hold, especially as native people co-create with AI. And some research suggests that interest and retention appear to hold when learners delve into a place's history through custom-tailored, data-enhanced tours — at least up against more traditional teaching methods. Ultimately, the move forward isn't just more technology but more collaboration — giving communities a role in shaping how their stories are told and positioning AI not as narrator but partner.

Conclusion

his is highly suggestive that AI can be a real asset in creating experiential based high-impact curriculum. It is this way of crossing boundaries in interdisciplinary research with a novel narrative arc which turned the static tour into an individualized one using AI-mediated approach answered the biggest limitation over educational constructs (Number Analytics, 2025). The regular feedback is personalized based on individual interest and it's of real time, and thus the AI supported system can play an important role in engaging novice participants attention and presence along with creating a context for active discovery learning. Not only does this make learning more actionable to students, but they also show that AI can turn what might’ve been a passive method for soaking up information into an actual adventure.

In addition, this research has demonstrated that AI is most effective as a complementary rather than replacement teacher, dynamic cognitive facilitator and strategic partner. Media and AI’s ability to automate localized content delivery at scale and in the moment with live data frees the human tour guide for performing higher-level, more human-centered work such as building relationship s, creating a sense of coherence among groups, and coordinating complex topics (Geerling et al., 2023). In this symbiotic relationship, the AI serves empirical bones and data-driven insight; the human supplies what can’t be replaced by algorithms — stories lived and treks taken, wisdom from those already in situ that add depth to story. This collaboration model is a new kind of education that is both highly effective and personalized, yet deeply human.

Overall, this study verifies that an AI-based curriculum is a scalable and effective solution to enhance CBE. The above implementation of Pingtung Walking Tour can be used as an example to demonstrate that using AI can bring local heritage to life in a dynamically shared way and that it leads to deeper learners’ affinity with the community other studies should explore whether improved performance of AI, cross-cultural differences in acceptance, and how knowledge learned maintained over time. Taken as a whole, the findings are a call for experiential education's future to engage technology mindfully in ways that helps us better teach, connect and develop transformative experiences for all.

Recommendation

Based on the findings of this research, we recommend educators and tour guides use a blended AI-human model in experiential learning. This includes the application of an AI system to power vital logistical and content-delivery services such as personalized tour routing support, and real-time, on-the-go information. This tactical use of technology also frees up human guides to focus on what they do best: build personal connections, share anecdotal knowledge and foster nuanced conversations that an algorithm can't match. This shift from content-broadcaster to discovery facilitator will also lead to better, more enjoyable and more memorable learning experiences for learners. For example, Pingtung tour guides could possible use the dataset of group interests with their AI system to organise local stories or anecdotes for each case.

Implications for policy makers Establish new standards to promote ethical and effective integration of AI into ET. Implications: Policy Recommendations Baseline requirements for privacy and anonymity of data that prevent the re-identification of participants are essential. "Additionally, a policy recommendation is to encourage cultural sensitivity and historical accuracy from the AI-generated content with companies having a self-review performed on their content periodically. Finally, universities as well as public and private educational institutions should be encouraged to invest in communities of practice training programs dedicated specifically to teacher AI pedagogical competence. This will ensure that the introduction of AI in experiential learning is both technically enabled and ethically informed and pedagogically rigorous.

The findings of this anxiety provide a promising base for future studies. We recommend researchers conduct long term studies to confirm how much knowledge and behavior change sticks in participants exposed to AI based curricula. Further studies could increase the scope of this model and perspective in other cultures or community. There may even be potential to explore the use of more advanced AI systems in your home, exploitable for running interactive simulations, multi-day learning quests. Objective: Subsequent research needed to move beyond proving concept on the whole, they must make transition from an innovative conceptual framework to and applied technology for the purpose not just of being a concept innovation but developing into an independent full-of-innovation education model.

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CHAPTER 4

SMART TOOLS, SMARTER MINDS: AI IN THE SCIENCE CLASSROOM FOR CRITICAL THINKING AND PROBLEM SOLVING

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ABSTRACT

This study explores the influence of integrating Artificial Intelligence (AI) tools on students' critical thinking and problem-solving skills in science education. Employing a mixed-methods approach, the research examined students' AI usage patterns, the statistical relationship between AI use and critical thinking, and the reflective practices learners adopt when interacting with AI. Thirty-four fourth-year science students kindly participated in a structured survey, and fifteen frequent AI users graciously took part in semi-structured interviews. The quantitative results indicated that while students perceived AI as beneficial for generating alternative solutions, promoting reflection, and enhancing evaluation skills, the correlation between AI use and critical thinking scores did not reach statistical significance at the conventional alpha level. The qualitative findings revealed that students engaged thoughtfully with AI by paraphrasing, fact-checking, asking follow-up questions, and verifying information to ensure accuracy and deepen understanding. Challenges included concerns about overdependence, accuracy issues, and AI's limitations when addressing complex scientific problems. Thematic analysis identified four key areas of engagement: verification practices, reflective engagement, process-oriented learning, and balanced reliance. Overall, the study suggests that strategic and guided use of AI can enhance critical thinking and problem-solving skills, provided that educators emphasize ethical use, reflective reasoning, and verification strategies. Recommendations include designing lessons that encourage active AI engagement, implementing teacher training on AI-integrated pedagogy, establishing clear guidelines for responsible AI use, and creating learning environments that foster independent thinking while leveraging AI's educational potential

Keywords: Artificial Intelligence; Educational technology; Critical thinking; Interactive learning; Personalized learning; Problem-solving; Science education

INTRODUCTION

Critical thinking is a vital skill in today's educational landscape. It involves analyzing, evaluating, and synthesizing information to make informed decisions (González-Pérez & Ramírez-Montoya, 2022). This skill is essential for understanding complex information, solving problems, and making informed judgments, which helps learners tackle various challenges in education and society (Berg et al., 2021). As O'Reilly et al. (2022) highlighted, critical thinking is crucial in modern education because it fosters independent, analytical, and adaptive reasoning, enabling students to thrive in fast-changing and unpredictable environments. Beyond academics, critical thinking prepares students for lifelong learning and career success by promoting deeper engagement, innovative problem solving, and reflective judgment. Anselmo et al. (2025) observed that teachers across different fields often struggle to develop students' critical thinking skills, especially when adapting teaching methods to meet evolving educational needs. This underscores the urgent need to make critical thinking a core part of today's curriculum. Collectively, these perspectives emphasize critical thinking as an essential educational goal for navigating the complexities of the 21st century and beyond. However, developing students' critical thinking skills presents several challenges. One major hurdle is the lack of training and resources for educators to nurture these skills effectively. Traditional education often emphasizes memorization over critical analysis and problem-solving, creating an environment in which critical thinking is not prioritized (Ullah et al., 2022). Additionally, in societies with conflicting educational goals, such as promoting national identity versus encouraging open-mindedness, fostering critical thinking becomes complicated. This tension can hinder the development of critical thinking, as educational approaches may prioritize conformity over independent thought (Bar-Tal et al., 2020). Artificial Intelligence (AI) holds great promise for transforming education by enhancing learning experiences and supporting the development of critical thinking. AI technologies can personalize learning, offer real-time feedback, and simulate complex scenarios, thereby creating dynamic and interactive educational environments (Mosly 2024). Moreover, AI can aid in integrating innovative educational strategies such as gamification, which boosts motivation and engagement in learning activities (Niño et al., 2024). However, there are concerns about AI's impact, such as potential biases and ethical issues, which require careful consideration to ensure that AI is used effectively and responsibly in education (Nadim and Fuccio, 2025).

Research Objectives

This study aimed to examine how the use of Artificial Intelligence (AI) tools in the science classroom influences students' critical thinking and problem-solving skills. Specifically, it seeks to:

- Determine the extent to which AI use influences students' critical thinking skills in solving science-related problems.
- Identify the ways in which AI fosters the development of critical thinking, particularly through practices such as reflection, verification and evaluation.
- Explore the challenges and limitations students encounter when using AI in Science learning, including issues of accuracy, overdependence, and the handling of complex or context-specific problems.
- Assess the overall implications of AI integration in science education, highlighting strategies to maximize its benefits while minimizing potential drawbacks.

METHODOLOGY

Research Method

This study employed a mixed-methods research design, integrating quantitative and qualitative approaches to examine how the use of Artificial Intelligence (AI) tools influences students' critical thinking and problem-solving skills in science learning. The quantitative phase involved a structured survey that measured AI usage patterns and their relationship with critical thinking, while the qualitative phase utilized semi-structured interviews to explore students' experiences and reflective practices when using AI tools. The combination of these approaches ensured methodological triangulation, thereby enhancing the validity and comprehensiveness of the findings.

Participants

The participants were thirty-four (34) fourth-year students enrolled in science-related courses at a State University. They were selected for their advanced standing and greater exposure to complex problem-solving tasks, making them ideal subjects for investigating AI's educational impact of AI. All students in the cohort were invited to answer the quantitative survey, while fifteen (15) students identified as frequent AI users were purposively selected for the qualitative interviews. Participation was voluntary, and ethical standards, including informed consent, confidentiality, and anonymity, were strictly observed throughout the study.

Instruments

Two research instruments were utilized in this study: a structured survey questionnaire and a semi-structured interview guide. The survey measured the frequency, context, and perceived impact of AI use on students' critical thinking and problem-solving skills using Likert-scale items and categorical questions designed to generate quantitative data. Complementing this, the semi-structured interview guide explored students' strategies, reflective habits, and evaluation practices when engaging with AI tools, including how they validated AI outputs, asked follow-up questions, and integrated AI-generated responses into their learning processes. Both instruments underwent expert review to ensure clarity, content validity and adherence to ethical research standards.

Procedure

The data-gathering procedure was conducted in three sequential phases. First, a structured questionnaire was administered to fourth-year science students in both online and printed formats to ensure broad accessibility to the survey. Second, the survey responses were screened to identify students with the highest frequency of AI usage. Finally, these selected students participated in semi-structured interviews to provide deeper insights into their learning behavior and critical engagement with AI tools. Throughout all phases, participants were informed of the study's objectives and their right to withdraw at any time, with voluntary participation, confidentiality, and data privacy being strictly upheld.

Data Analysis

Quantitative data were analyzed using descriptive and inferential statistical analyses. Frequencies, percentages, and mean scores were computed to describe AI usage patterns, while correlation and group comparison tests (t-tests and ANOVA) were used to examine the relationship between AI use and critical thinking levels.
Qualitative data from the interviews were subjected to thematic analysis following systematic coding procedures. Recurring themes, such as verification, reflective practices, and overdependence, were identified, refined, and validated through cross-participant comparisons.

Finally, findings from both strands were integrated through triangulation to provide a comprehensive understanding of how AI contributes to students' critical thinking and problem-solving skills in science.

RESULTS and Discussion

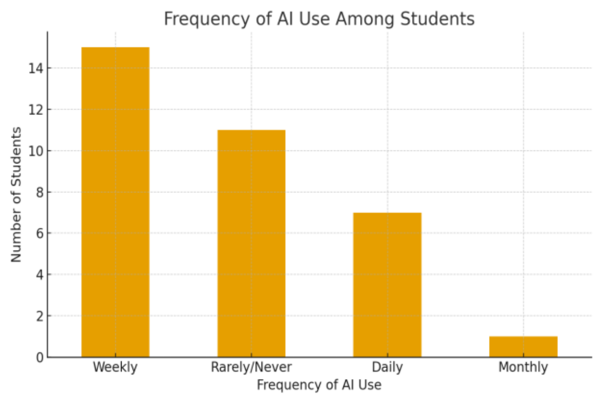


Figure 1

Figure 1 Integration of AI tools, such as ChatGPT, Quill Bot, and Grammarly, in academic settings presents benefits and challenges. Student usage patterns show that 44.12% utilize these tools weekly, indicating recognition of AI's advantages for productivity and personalized learning (Zhou et al., 2024; Erduran, 2023). However, 32.35% rarely or never used these tools, suggesting barriers such as lack of awareness or uncertainty about implementation. This aligns with research emphasizing the need for AI literacy education (Lee et al., 2023; Lee et al., 2024). While AI tools support critical thinking (Chandrasekera et al., 2024), concerns exist regarding over-reliance and academic integrity. Institutions should implement usage guidelines for the ethical integration of AI (Sağın et al., 2023). With only 2.94% of educators using AI tools monthly, they must demonstrate their practical benefits to enhance student learning (Favero, 2024).

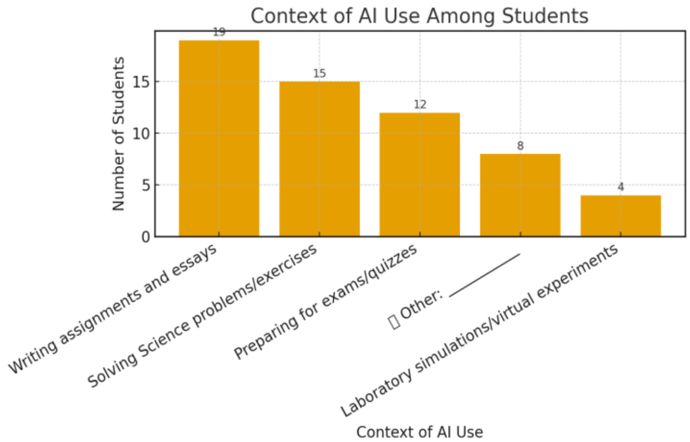


Figure 2:

Figure 2: Context use of AI The bar graph shows how students used AI tools in science learning. Writing assignments were the most common (19 students, 55.88%), followed by solving science problems (15 students, 44.12%) and exam preparation (12 students, 35.29%). Eight students (23.53%) selected "Other," using AI for grammar checking and lecture clarification, and four students (11.76%) used it in laboratory simulations. The data show that AI is mainly used for academic writing and problem-solving, with limited laboratory applications. Students used AI to understand difficult topics, check grammar and facts, and source information, with some using it only for assistance while others reported no usage.

Item	**N**	**Mean**	**Interpretation**
AI tools help me generate alternative solutions	34	3.53	**Agree** (high perceived effect)
AI encourages me to reflect before finalizing my answers	34	3.79	**Agree** (high perceived effect)
AI improves my ability to evaluate the correctness of solutions	34	3.91	**Agree** (high perceived effect)
AI makes me more dependent on instant answers (reverse-coded)	34	2.68	**Neutral** (moderate perceived effect)

Table 1 shows how people perceive the impact of AI tools on problem-solving based on mean scores. AI tools are effective in developing alternative solutions, with a mean score of 3.53. This suggests that many agree on their role in boosting creative problem solving. This finding aligns with research in design education, where AI is known to spark creativity and innovative thinking by allowing users to explore various solutions (Chandrasekera et al. 2024). Additionally, AI tools seem to encourage users to reflect before making final decisions, as shown by the mean score of 3.79. This matches studies indicating that AI's user-friendliness enhances self-regulation, prompting learners to think critically about their decisions (Zhou et al., 2024). AI tools also scored high in improving evaluation skills, with a mean score of 3.91, supporting the idea that AI helps assess the validity and efficiency of different solutions, especially in fields such as scientific and healthcare research (Fernandes et al., 2023; Ramirez and Esparrell, 2024). Conversely, there was moderate concern about increased reliance on instant answers from AI, as reflected in the lower mean score of 2.68. This highlights the need to balance AI's capabilities while maintaining independent critical thinking skills, a topic that is still being discussed in educational and professional circles (Alves et al., 2024). Overall, while AI tools significantly enhance problem-solving abilities, they must be integrated carefully to avoid overdependence.

Item (shortened)	**Response**	**Frequency**	**Percentage (%)**
AI tools help me generate alternative solutions…	Strongly Disagree	1	2.94
	Disagree	1	2.94
	Neutral	14	41.18
	Agree	15	44.12
	Strongly Agree	3	8.82

AI encourages me to reflect before finalizing my answers…	Strongly Disagree	1	2.94
	Neutral	12	35.29
	Agree	13	38.24
	Strongly Agree	8	23.53
AI improves my ability to evaluate the correctness of solutions…	Strongly Disagree	1	2.94
	Neutral	9	26.47
	Agree	15	44.12
	Strongly Agree	9	26.47
AI makes me more dependent on instant answers (reverse-coded) …	Strongly Disagree	4	11.76
	Disagree	9	26.47
	Neutral	12	35.29
	Agree	8	23.53
	Strongly Agree	1	2.94

Table 2 ***Frequencies and Percentages for Perceived Effect on Problem-Solving Items***

Students generally view AI tools as helpful for problem-solving. For instance, 44% of students agreed that AI helps generate solutions, 41% were neutral, and 6% disagreed. Regarding encouraging reflection, 38% agreed, 24% strongly agreed, and 35% were neutral. Regarding the accuracy of the solutions, 44% agreed, 26% strongly agreed, and 26% were neutral. However, opinions on dependency were mixed: 35% were neutral, 26% disagreed, and 24% agreed, suggesting that students did not feel overly dependent on AI. The use of AI tools in education is increasingly viewed positively by students, highlighting their supportive role in academic settings. Research shows that students find AI tools beneficial for enhancing their problem-solving skills and providing instant feedback. In design education, AI has been noted to improve workflows and reduce cognitive load (Chandrasekera et al., 2024). AI tools also offer opportunities for personalized learning environments and boost students' motivation and cognitive skills (Wang et al., 2024).

However, concerns exist regarding overreliance and potential declines in critical thinking skills. Studies suggest that excessive dependence on AI can disrupt learning processes, especially for English language learners using AI-based writing tools (Lee et al. 2024). While students appreciate AI's ability to improve solution accuracy, there are still worries about biases (Robleto et al., 2024). Ethical considerations call for structured guidelines to maximize AI's benefits of AI while minimizing its drawbacks (Vieriu and Petrea, 2025). Although AI tools enhance educational experiences, they also risk creating a dependency that may hinder independent problem-solving abilities. Both students and educators stress the importance of balancing AI use with traditional learning methods (Haroud and Saqri 2025).

Test	Statistic	p-value	Effect Size
Pearson correlation (AI use × CT total)	r = .19	p = .39	Small, ns
Spearman correlation (ordinal)	ρ = .19	p = .38	Small, ns
t-test (Frequent vs. Rare AI users)	t (≈32) = 0.89	p = .39	Cohen's d = 0.42 (small–medium)
ANOVA (3+ usage groups)	F (2,31) = 0.78	p = .52	η^2 = .07 (small)

Table 3 Inferential Test Results: AI Use and Critical Thinking

The inferential test results regarding AI use and critical thinking suggest various implications. The Pearson correlation between AI use and total critical thinking (CT) was not significant (r = .19, p = .39). Similarly, the Spearman's correlation showed a non-significant association (ρ = .19, p = .38). These findings suggest that AI use may not be strongly related to overall critical thinking skills in the context studied (Gonsalves, 2024; Muñoz-Basols et al., 2023). The t-test comparing frequent versus rare AI users revealed no significant difference in critical thinking ($t \approx 32 = 0.89$, $p = .39$), with a small-to-medium effect size (Cohen's $d = 0.42$). ANOVA assessing AI use across groups showed no significant differences ($F(2,31) = 0.78$, $p = .52$), with a small effect size ($\eta^2 = .07$), indicating that AI usage patterns might not significantly affect critical thinking (Dibek et al., 2024). While these analyses show limited effects of AI use on critical thinking, studies emphasize the need to revise educational frameworks to incorporate AI-specific competencies (Cornejo et al., 2022). This underscores the need for innovative teaching methods that prioritize reflective reasoning in AI-integrated environments (Saqib et al., 2023).

Test	**Statistic**	**p-value**	**Effect Size**	**95% CI (Effect Size)**	**Interpretation**
Pearson correlation (AI use × CT total)	$r = .19$	.39	Small	–0.23 to 0.56	No significant correlation; weak link
Spearman correlation (ordinal)	$\rho = .19$	.38	Small	–0.22 to 0.55	No significant monotonic association
t-test (Frequent vs. Rare AI users)	$t(32) = 0.89$	.39	$d = 0.42$ (SM)	–0.31 to 1.12	Small–medium effect, not significant
ANOVA (3+ usage groups)	$F(2,31) = 0.78$	.52	$\eta^2 = .07$ (Small)	–0.10 to 0.22	No significant group differences

Table 3a Effect Sizes and Confidence Intervals

The statistical analyses did not reveal a significant relationship between AI usage and students' critical thinking (CT) scores. The Pearson correlation was $r = .19$ ($p = .39$), indicating a small and non-significant association, with a 95% confidence interval ranging from –0.23 to 0.56. Similarly, the Spearman correlation suggested a small, non-significant monotonic relationship ($\rho = .19$ [$p = .38$], with a confidence interval from–0.22 to 0.55). The independent samples t-test comparing frequent and rare AI users resulted in $t(32) = 0.89$ ($p = .39$), with a small-to-medium effect size (Cohen's $d = 0.42$), although the confidence interval (–0.31 to 1.12) again crossed zero, indicating statistical non-significance. Additionally, ANOVA did not show significant differences across the AI usage groups, $F(2,31) = 0.78$ ($p = .52$), with a small effect size ($\eta^2 = .07$). Collectively, these results suggest that variations in AI usage frequency were not statistically associated with students' critical thinking scores, and any observed effects were weak and statistically insignificant.

Thematic Discussion

Table 4. Students' Use of AI Responses: Copying vs. Paraphrasing

Theme	Description	Responses
Critical Engagement and Understanding	Respondents emphasized paraphrasing and analyzing AI outputs before using them. This practice allows them to ensure accuracy, relevance, and deeper comprehension of the solutions rather than relying on AI blindly.	"I paraphrase and analyze first to gain an understanding of what I am doing." / "I analyze them first, because sometimes AI is not on point." / "I analyze it first to verify if the information is reliable and accurate."
Selective Use of AI Outputs	Some respondents acknowledged AI as helpful but limited their use of its outputs. They filtered responses, copied only what was necessary, or treated AI as a starting point for ideas, showing cautious reliance.	"I analyze it first and just copy the necessary answer." / "Just a basis." / "I'm just getting some ideas."
Refinement and Clarification of Concepts	Others used AI to elaborate or simplify complex topics, paraphrasing terms to make them relevant and finalizing answers only after careful review. This highlights AI's role in reinforcing conceptual understanding.	"I mainly use AI for explaining topics further." / "I would paraphrase and analyze as some terms are not relevant." / "I always analyze them before finalizing it."

The students' responses showed that they did not just copy and paste AI-generated answers. Instead, they approached these answers with caution and critical thinking. Many students emphasized the importance of paraphrasing and analyzing outputs before using them, which reflects their intent to ensure accuracy and relevance and gain a deeper understanding of the solutions provided. This indicates that they are aware of AI's limitations, acknowledging that it can sometimes be inaccurate or off point and therefore requires verification. Some students mentioned that they used AI selectively, copying only what was necessary or treating it as a basis for their ideas. This approach demonstrates a balanced reliance on technology while exercising personal judgment. Others highlighted AI's role in clarifying or expanding difficult topics, yet they still paraphrased terms or adapted responses to fit their contexts. This suggests that they viewed AI as a supportive learning aid rather than as a final authority. Overall, the responses suggest that students value AI for its ability to enhance learning and provide guidance, but they also recognize the importance of analysis, paraphrasing, and verification to maintain originality, critical thinking, and academic integrity in their work.

Table 5. Use of Follow-Up Questions to Deepen Understanding of AI Responses

Theme	Description	Responses
Deepening Understanding with Examples & Analogies	Learners request added examples, background, or analogies to strengthen comprehension of AI answers.	“I ask… for further examples or background to deepen my understanding.” / “I use prompts… and ask it to create analogies.” / “I ask the AI to elaborate the topic to understand it further.”
Clarification & Concept Differentiation	Follow-ups clarify terms, meanings, and distinctions between closely related ideas or historical attributions.	“Differentiate the pioneer who discovered ‘cell’… Hooke named it ‘cell’ (dead) while Leeuwenhoek discovered ‘living cell’.” / “If the given is inductive or deductive… then explain the difference in an easy way.” / “If I don’t understand a sentence or word, I ask for more follow up.” / “After defining ‘anthropogenic hazard,’ I ask for examples and effects.”

Theme	Description	Responses
Reasoning Transparency & Step-by-Step Processes	Students probe the *why* and *how* behind answers—asking for statistical reasoning and procedural steps.	"Explain the statistics… and how it came up with its answer." / "After AI gives the answer there's always a follow up why's and how's." / "Provide the step-by-step process so that I can easily cope up."
Verification & Conditional Follow-Ups	Some ask only when unsure or when responses seem misaligned; a minority do not ask follow-ups.	"Yes, if I am not sure about the previous." / "If the answer is not that connected… I add follow up questions." / "No."

The findings revealed that most students were proactive in using follow-up questions when interacting with AI responses. This shows their determination to dig deeper than surface-level answers and truly grasp the material. Many students asked for examples, background information, or analogies to make the explanations more relatable and thorough. This behavior indicates that they see AI as a learning partner that helps them build and strengthen their understanding. Another trend is that students often use follow-up questions to clarify and differentiate between concepts. They depend on AI to clarify any confusion between similar terms or ideas, such as distinguishing between Hooke's and Leeuwenhoek's roles in cell discovery or distinguishing between inductive and deductive reasoning. This suggests that they appreciate AI's help in refining details and ensuring accuracy in their understanding. At the same time, several students mentioned that they asked for step-by-step explanations or transparency in reasoning, especially in subjects like statistics, biology, or problem-solving tasks. This shows that they are not just looking for final answers but want to understand the logic behind them, reflecting their higher-order thinking and critical inquiry skills. On the other hand, a smaller group of students admitted that they only asked follow-ups when the initial answer was unclear, misaligned, or incomplete, and one respondent said they did not ask follow-ups at all. This indicates that while most students see follow-up questioning as crucial for learning, a few still consider AI outputs at their face value. These findings suggest that students engage with AI in an active, thoughtful, and curious way. They used follow-up questions to deepen their understanding, clarify distinctions, verify accuracy, and grasp processes. This shows that AI is becoming a part of their learning journey, not just as a source of ready-made answers but also as a dynamic tool that supports critical thinking, inquiry, and mastery of concepts.

Table 6. Students' Strategies for Evaluating Accuracy and Trustworthiness of AI Outputs

Theme	Description	Responses
Cross-Verification with Reliable Sources	Students often confirm AI outputs by checking them against other sources such as search engines, research articles, or educational websites. This shows their reliance on external validation to ensure the accuracy of information.	"I go over the entire answer and validate it by double-checking using other search engines." / "Verifying info in other sources." / "I compare it to trusted sources such as articles and other research." / "By verifying sources." / "Sometimes, but I'm making sure that it is accurate also by watching on different educational websites about that specific topic."
Fact-Checking and Reference Analysis	Learners verify AI answers by asking for references, checking citations, or using multiple AI tools to compare responses. They are cautious when sources are missing or unreliable, showing that credibility is linked to transparency.	"I try to use different AIs to fact check the answer or find an article that is similar to the topic." / "I would ask the AI to give me its sources and read the sources that the AI gives." / "By asking for references." / "If the given information is from the authentic source."
Independent Reasoning and Subject-Specific Trust	Respondents rely on their own knowledge, problem-solving, and analytical skills to assess AI answers. They expressed skepticism in areas like science, history, and math—recalculating	"I try to solve the similar problem, or I already have an answer in mind before making a prompt." / "Through analyzing it." / "When they answered my question correctly." / "Personally, I don't trust AI-generated answers… in Mathematics/numbers I

Theme	Description	Responses
	results or reasoning through the process themselves to confirm accuracy.	calculate on my own." / "When all of the resources I have gathered are the same."

The findings show that students are careful and thoughtful when deciding whether AI-generated answers are accurate or trustworthy. Many stressed the need to double-check information using reliable sources such as search engines, research articles, or educational websites. This indicates that students are aware that AI can make mistakes; therefore, they use external validation to boost their confidence in the information they obtain. Another important tactic was fact-checking and reference analysis. They would ask for citations, look at the sources AI provided, or compare the results from different AI tools. Their responses suggest that credibility is closely linked to transparency, as students tend to be skeptical when references are missing, irrelevant or unreliable. This shows that students value evidence-based responses and expect AI to provide verifiable information. Additionally, some students relied on their own reasoning and subject-specific trust, using their prior knowledge, logical analysis, and problem-solving skills to confirm the accuracy of the information. In areas such as mathematics, they preferred to recalculate results themselves, while in science or history, they sought additional fact-checking. This selective trust reflects a balanced approach—recognizing AI's usefulness of AI but not blindly depending on it. Overall, the interpretation suggests that students critically engage with AI outputs by combining external validation, reference checking, and personal reasoning, which reflects strong digital literacy and responsible use of technology in learning

Table 7. Influence of AI on Students' Approaches to Science Problem-Solving

Theme	Description	Responses
Enhancing Verification and Reflection	Students shared that AI helps them verify answers, clarify concepts, and reflect before finalizing their work. This reflective habit contributes to producing more accurate and reliable outputs.	"It helps me verify some of my answers or to clarify certain answers I may not understand firsthand." / "Using AI has helped me gain the habit of reflecting on my work before finalizing it which contributes to producing work that is factual and has little to no mistakes."
Supporting Learning and Process Understanding	Respondents noted that AI assists them in understanding problem-solving processes, step-by-step explanations, and learning scientific foundations in a clearer way.	"Yes, cause with the use of AI I get to check my answers especially in problem solving and it allows me to learn the process on solving the problem." / "Yes, through helping me to learn the proper and step by step processes in solving." / "I have understood the roots of science not just about the problem, it provides comprehensive ideas."
Simplification and Skill Development	Students highlighted AI's ability to simplify complex ideas into understandable terms and enhance their critical thinking and problem-solving skills. However, some noted limitations when problems are too complicated, or AI explanations are unclear.	"Yes, AI can be controlled on how it will explain in a way that you can understand. It can be adjusted in several ways." / "Yes, I use it to explain things to me in simple terms." / "Yes, it helps me improve my skills, and ability to think critically." / "Sometimes, because some problems are too complicated and if you ask help from AI, the answer is complicated too and not easy to understand."

The results show that AI influences students' problem-solving in science by promoting reflective and structured practices. Respondents indicated that AI helped verify answers and reflect on work, encouraging accuracy and reducing errors. This suggests that AI serves as a tool for building habits of self-checking and evaluation. AI also supports learning processes, with students using it to understand the steps in solving scientific problems and grasp foundational concepts. By breaking down problems and providing explanations, AI helps students focus on the "how" and "why" rather than just the results, deepening their understanding. Students valued AI's ability to simplify complex topics and develop critical thinking, appreciating how it explained concepts at their level. However, some limitations were noted with overly complex problems or confusing explanations, indicating that AI cannot replace independent problem-solving skills. The findings suggest that AI has positively changed students' approaches to science problem-solving by fostering verification, process-oriented learning, and critical thinking skills, while recognizing its limitations.

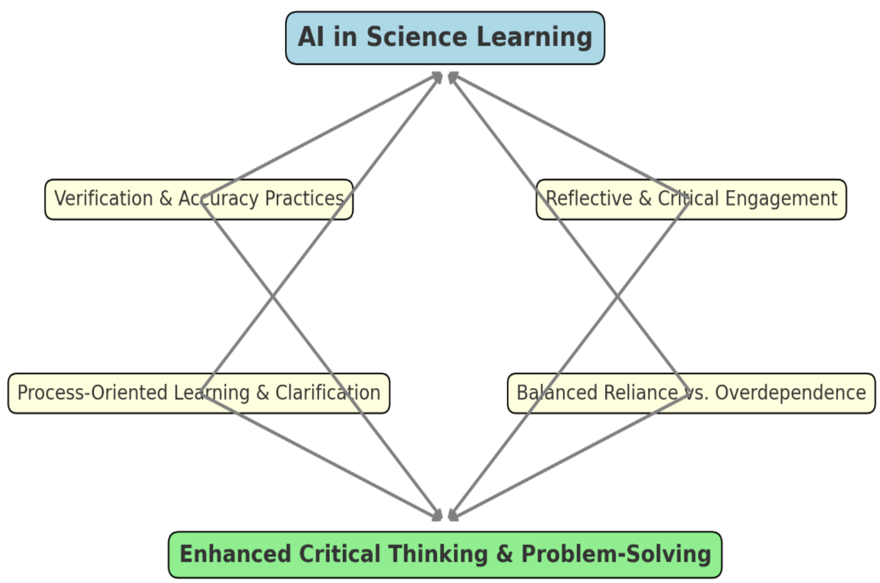
Table 8. Challenges and Limitations Encountered in Using AI for Science Learning

Theme	Description	**Responses**
Accuracy and Reliability Issues	Many students highlighted that AI is not always accurate, sometimes gives wrong or incomplete answers, and may rely on unreliable sources. This requires them to double-check using other references before trusting the output.	“It is not always accurate and requires double checking.” / “It gets answers wrong sometimes, so I don’t trust it fully.” / “The limitation I encountered would be that AI does not always get the correct answers due to it accessing unreliable information from unreliable sources.” / “Maybe, sometimes it does not have references that could prove the answer is reliable or correct.”
Overdependence and Behavioral Changes	Some students noted that relying on AI made them dependent, lazier, or prone to procrastination, as they became used to seeking quick ideas instead of thinking critically on their own.	“Sometimes, I have become dependent on it on asking for ideas rather than thinking one for my own.” / “As for learning in general, I think my behavior changed greatly knowing that I have the help of AI; I felt that I became even more lazy and procrastinate more.”
Limitations in Complex or Practical Problems	Students pointed out that AI struggles with complicated science problems, lacks clear answers in certain cases, or is limited by technical issues such as poor internet connectivity and lack of verifiable references.	“The challenges and limitations I have faced… it doesn’t always give exact information, so further research is needed.” / “AI has a limitation when it comes to complicated problems and AI can’t provide a clear answer.” / “In other aspects, the challenges I encountered is the internet connection and the authenticity of the information that AI was given.”

Interpretation

The results show that students encountered several challenges when using AI in their science learning. One common issue is accuracy and reliability, as many respondents reported that AI sometimes provides incorrect, incomplete, or unreliable answers. Consequently, they often feel the need to double-check information using other sources before trusting it. Another challenge is overdependence, with some students admitting that using AI has made them more reliant on it for ideas, which sometimes leads to laziness or procrastination instead of thinking critically on their own. Finally, students also observed limitations in handling complex problems, since AI cannot always provide clear answers to complicated science questions, and its usefulness is sometimes affected by poor internet connections or a lack of references. Overall, while AI is helpful, students recognize its limits and the importance of verifying information and balancing their own efforts in learning.

Synthesis



Thematic analysis identified four significant categories of student engagement with AI: verification and accuracy practices, reflective and critical engagement, process-oriented learning, and balanced reliance versus overdependence. Notably, students frequently cross-checked AI outputs through fact-checking, consulting reliable sources, or employing independent reasoning, thereby demonstrating commendable digital literacy (Robleto et al., 2024; Vieriu & Petrea, 2025). Additionally, some students emphasized paraphrasing, analyzing, and reflecting before finalizing their answers, which underscores AI's role in encouraging deeper evaluation and self-regulation (Zhou et al., 2024). These findings suggest that AI was not merely perceived as a simple provider of answers but rather as valuable support for verification and reflection, practices that are essential for nurturing critical thinking. Furthermore, students reported using AI for follow-up questions, analogies, and step-by-step explanations, highlighting its value in process-oriented learning (Mosly, 2024; Niño et al., 2024). However, it is important to acknowledge a certain tension: while many students used AI cautiously as a supplementary aid, some admitted to overdependence, which could lead to passivity or procrastination (Haroud and Saqri, 2025). To capture these dynamics, this study thoughtfully synthesized the recurring themes into a conceptual map that illustrates the pathways from AI use to student practices and, ultimately, to the development of critical thinking and problem-solving skills. This visual framework highlights that the educational impact of AI lies not in providing ready-made solutions but in shaping reflective habits, verification strategies, and balanced reliance, while also underscoring the importance of embedding AI literacy and ethical use into science education (Sağın et al., 2023; Anselmo et al., 2025).

Conclusion

The study "Smart Tools, Smarter Minds: AI in the Science Classroom for Critical Thinking and Problem-Solving" thoughtfully explores the transformative potential of integrating AI into science education to enhance students' critical thinking and problem-solving abilities. It highlights that, when used thoughtfully, AI tools can serve as valuable cognitive aids that support active learning, creativity, and engagement, rather than merely replacing student effort. By offering immediate feedback, adaptive challenges, and interactive learning experiences, AI technologies can assist students in developing a deeper conceptual understanding and the analytical skills essential for scientific inquiry. The research also emphasizes the importance of guiding students in the ethical and reflective use of AI to foster metacognitive awareness and responsible problem-solving practices. Overall, the paper concludes that the deliberate incorporation of AI in science classrooms can cultivate smarter minds equipped to navigate complex scientific problems, provided educators thoughtfully balance AI's advantages with pedagogical strategies that promote autonomous critical thinking and collaborative learning.

Recommendation

It is recommended that educators integrate AI tools into science classrooms with a strategic focus on enhancing critical thinking and problem-solving skills rather than simply automating tasks. This integration should involve designing lessons that encourage students to engage interactively with AI, use it as a cognitive partner, and critically evaluate AI-generated solutions. Teacher training programs should be developed to equip educators with skills to facilitate ethical and reflective AI use, fostering students' metacognitive awareness and responsible problem-solving. Additionally, instructional approaches should accommodate diverse learning styles, ensuring AI tools are accessible and engaging for all students. Educators should establish clear guidelines and policies that promote transparency, academic integrity, and balanced AI use to mitigate risks such as overreliance and plagiarism. Overall, cultivating an environment where AI enhances active learning, creativity, and ethical reasoning will maximize its potential to prepare students for complex scientific challenges and future careers.

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CHAPTER 5

ENHANCING OPERATIONAL EFFICIENCY AND CUSTOMER SATISFACTION THROUGH TECHNOLOGY-ENABLED SYSTEM: A QUALITY FUNCTION DEPLOYMENT AND EXPERIENCE MAPPING APPROACH IN THE FUTURE OF RETAIL

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ABSTRACT

Inventory management challenges, including stock discrepancies and operational inefficiencies, continue to hinder small-scale retail businesses in developing countries like the Philippines, impacting overall efficiency and customer satisfaction. The research utilized a mixed-method approach, incorporating pre- and post-implementation surveys with 20 store owners and 60 customers, through Quality Function Deployment and Experience Mapping from September to December 2024. Pre-implementation findings revealed inefficiencies in manual inventory management, such as inaccurate stock tracking and delayed service. Meanwhile, post-implementation results show measurable improvement; 70% of store owners reported improved inventory accuracy, and 65% said manual processing time was reduced. While customers reported higher satisfaction levels, with 54% being delighted about the availability of products and 47% about the speed of service. Demand forecasting, real-time inventory tracking, and automatic sales calculations were the system's important features that eliminated inefficiencies and enhanced service quality. Barriers such as high initial costs, limited technical expertise, and infrastructure constraints called for inexpensive, easy-to-use systems, local training, and financial support. This study contributes to the academic discourse on technology adoption in resource-constrained settings, emphasizing the importance of scalable, accessible technology to transform operational efficiency and competitiveness for small retailers in developing economies.

Keywords: Artificial Intelligence, Experience Mapping, Perpetual Inventory Management, Quality Function Deployment, Small Retail Business

Introduction

The advent of Technology-Enabled Systems has transformed multiple sectors worldwide, and retail is no exception. Small retailers, in particular, struggle with inventory management, often leading to stockouts, overstocking, and operational inefficiencies that reduce profitability and customer satisfaction (Bello et al., 2024; Jadhav, 2023). Technology-enabled predictive analytics has emerged as a powerful tool for addressing these issues, especially in demand forecasting. Ajiga et al. (2024) emphasized that the integration of advanced algorithms allows retailers to analyze historical sales patterns and market trends, resulting in more accurate purchasing decisions and optimized stock levels. This not only reduces waste but also enhances operational efficiency and responsiveness. Technology-enabled systems further contribute to inventory optimization by improving demand forecasting, stock control, and supply chain alignment (Bhat, 2023). Through system-driven automation, retailers achieve greater accuracy in inventory levels, reducing both stockouts and excess inventory (Kumar, 2024). In developing economies like the Philippines, adopting such technologies could strengthen brand identity and customer loyalty through increased product availability and timely service delivery (Kumar, 2024). Roy (2023) also highlighted that data-driven personalized customer interactions can boost repeat patronage through targeted promotions and recommendations. While large corporations in developed countries, especially in the United States have successfully integrated these technologies into their daily operations (Jack & Bommu, 2024), many SMEs in developing nations lag behind. Barriers such as limited technological infrastructure, high implementation costs, lack of digital training, and unstable internet connectivity impede system adoption (Okolocha & Udegbunam, 2023). These challenges create a research gap on how resource-constrained retailers can adopt technology-enabled inventory solutions. Considering that small retailers dominate the Philippine retail landscape, exploring scalable solutions tailored to their needs becomes crucial. Contemporary inventory practices increasingly rely on technology-enabled perpetual inventory systems capable of real-time updates and product tracking. Roy (2023) noted that such systems minimize stock discrepancies and build customer confidence by providing accurate inventory visibility. However, SMEs often face difficulty adopting them due to cost, flexibility, and data reliability concerns (Nweje & Taiwo, 2025; Taher et al., 2024). This reinforces the importance of identifying affordable and adaptable system models for small businesses. Studies show promising results: integrating ERP with perpetual systems enhances productivity and reduces operational costs (Rahmadoni et al., 2023), while technology-driven applications have improved quality and customer satisfaction in retail supply chains (Abualsauod, 2025). Despite these benefits, issues such as data privacy, algorithmic bias, and readiness for digital transformation remain critical considerations for responsible adoption (Ajiga et al., 2024). Proper change management and employee training are also necessary to maximize implementation success. Therefore, this study seeks to examine how technology-enabled perpetual inventory systems can help small-scale retailers in developing countries, specifically the Philippines, overcome persistent inventory management challenges by reducing inefficiencies, minimizing discrepancies, and enhancing customer satisfaction.

Methodology

This study employed a mixed-methods research design to investigate how the integration of a technology-enabled system influenced the operational efficiency and customer satisfaction of small retail businesses in the Philippines. The adoption of this approach was guided by Amerta and Madhavi (2023), who demonstrated the effectiveness of mixed methods in achieving comparable objectives in the service industry. To capture both quantitative and qualitative insights, two complementary techniques were used: Quality Function Deployment (QFD) and experience mapping. QFD was applied to identify and evaluate inventory management challenges, examine the features of the technology-enabled system, and assess their impact on operational efficiency and customer satisfaction. This method followed the approach of Vazry et al. (2024), who emphasized the value of QFD in aligning customer needs with system improvements in resource-constrained environments. Experience mapping, consistent with Eldred et al. (2023), supplemented these findings by documenting the actual experiences of business owners in adopting the system, thereby highlighting both barriers and facilitators to technology adoption integration.

Sampling and Participants

The sampling framework was adapted from Lumbab (2024). Small retail stores were selected using cluster sampling guided by Cochran's formula (95% confidence level, 0.5 standard deviation, 5% margin of error). Customers were chosen through purposive sampling, resulting in 1,925 potential participants (five per store), though time constraints limited the actual survey to 20 retail shops and 60 customers (three customers per store). Customer selection emphasized regular purchasing behavior, specifically those who had purchased at least five items in the past month, ensuring diverse purchasing patterns. To ensure the rigor of the research instruments, the questionnaire underwent expert validity testing. The panel of validators included professors from the fields of research methodology, language and communication, and business management, who reviewed the instrument for clarity, relevance, and alignment with the study objectives. Their evaluation produced a Content Validity Index (CVI) rating of 0.92, which indicates excellent content validity and confirms that the items were both representative and appropriate for measuring the intended constructs. A pilot test was then conducted with four small retail businesses in Barangay Guadalupe, Cebu City.

These pilot cases were excluded from the main study but were instrumental in refining the data collection instruments and ensuring the reliability of the research tools. In line with best practice, the study considered a more robust pilot size of 8–12 pilot stores with 5 customers per store (40–60 customers total) as the recommended benchmark for adequately testing research instruments, survey reliability, and the technology-enabled system prototype across diverse retail settings. However, due to time constraints, the researchers were able to complete the initial pilot with only four stores.

Data Collection

The data collection process was carried out in two phases. During the pre-implementation phase, surveys were administered to both store owners and customers to establish baseline conditions. The survey for store owners, titled “Challenges in Manual Inventory Management for Small Retailers,” focused on identifying issues such as stock discrepancies, manual sales computation, and other inefficiencies in traditional inventory practices. Meanwhile, the customer survey, “Customer Experiences in Retail Stores with Manual Inventory Systems,” examined satisfaction levels regarding product availability and the speed of service prior to the introduction of the technology-enabled system. In the implementation and post-implementation phase, the technology-enabled system prototype (Version 1.0), equipped with features such as real-time inventory tracking, demand forecasting, and automated sales computation, was deployed across 20 retail stores. Following this, post-implementation surveys were conducted to measure the system’s impact. For store owners, the survey entitled “Operational Changes Following the Adoption of Technology-Enabled System” captured changes in operational efficiency and stock optimization, while the customer survey, “Customer Satisfaction After the Implementation of Technology-Enabled System,” assessed improvements in satisfaction related to product availability and service delivery. Additionally, structured interviews were conducted with store owners and staff, and the findings were used to create experience maps. These visual representations illustrated the operational challenges and improvements observed after system adoption, thereby providing deeper qualitative insights to complement the survey results.

Data Analysis

Quantitative data was analyzed using descriptive statistics in Microsoft Excel, a widely recognized tool for summarizing survey results and identifying patterns in customer satisfaction and operational efficiency (Amerta & Madhavi, 2023). QFD results were employed to rank critical system features, while qualitative insights from experience mapping contextualized these findings within the day-to-day realities of small-scale retail operations (Vazry et al., 2024; Eldred et al., 2023).

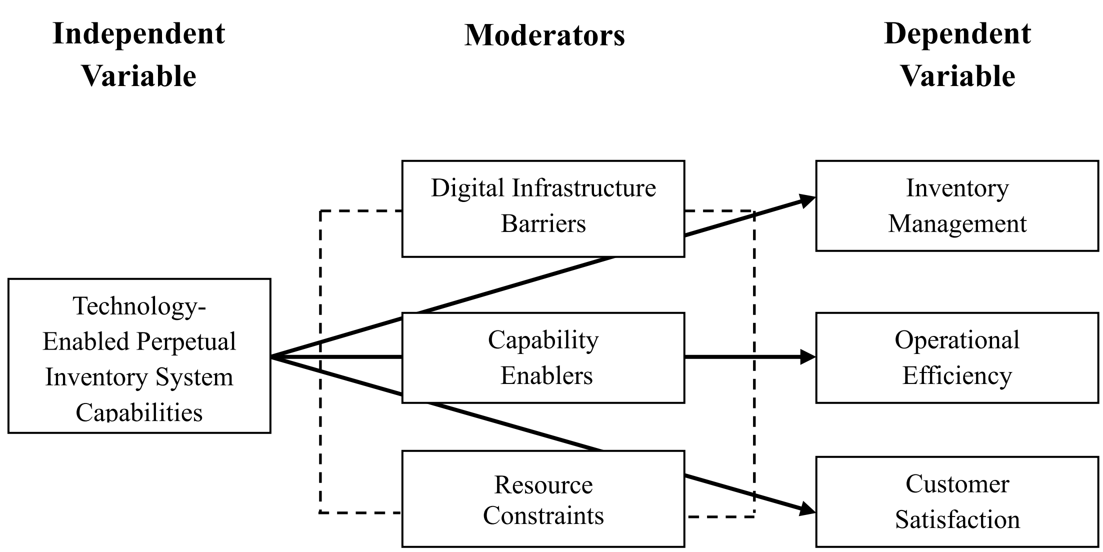
Ethical Considerations

Strict ethical protocols were observed. Participants were fully informed of the study's objectives and procedures, with informed consent obtained prior to participation. Store owners and customers were assured of voluntary participation and the right to withdraw at any time. Personal identifiers were excluded from data collection, and the technology-enabled system prototype's functions were explained in detail. Appropriate training was provided for safe system use, and all data were stored securely with access limited to authorized researchers.

Limitations

While Cochran's formula indicated an ideal sample size of 385 respondents, only 20 stores and 60 customers were surveyed due to time constraints. Moreover, the technology-enabled system prototype was tested for only four hours, which may not capture its long-term impact. The study was confined to Barangay Guadalupe, Cebu City, limiting generalizability across Cebu City, the province of Cebu, and the Philippines. Additionally, the focus was restricted to technology-enabled perpetual inventory systems, excluding other inventory control approaches. Despite these limitations, the study provides valuable insights into the potential role of technology-enabled system in addressing inventory management inefficiencies and enhancing customer satisfaction among small-scale retailers, offering a foundation for future research with broader scope and resources.

Figure 1. Conceptual Framework
Source: Author



This study is anchored on a conceptual framework that explores how Technology-Enabled Perpetual Inventory System Capabilities influence key performance outcomes in small-scale retail environments. The framework positions Inventory Management Efficiency, Operational Efficiency, and Customer Satisfaction as dependent variables, which are expected to improve through core system capabilities, namely predictive analytics, real-time inventory tracking, and automated replenishment processes. To address variations in implementation conditions, the framework incorporates three moderating variables: Digital Infrastructure Barriers, Capability Enablers, and Resource Constraints. These moderating factors shape the strength and direction of the relationship between system capabilities and performance outcomes. For example, strong technological infrastructure, staff readiness, and adequate financial resources may amplify the positive effects of technology-enabled systems. Conversely, limited connectivity, insufficient training, or lack of investment may hinder successful adoption and reduce overall impact. In the visual model, solid arrows represent direct causal pathways from system capabilities to the dependent variables, while dashed arrows illustrate the moderating influence of contextual conditions. This configuration reflects the dynamic interaction between technological innovation and real-world implementation, emphasizing the importance of context in evaluating system effectiveness—particularly within resource-constrained small retail businesses in the Philippines.

Technology-Enabled Perpetual Inventory System Capabilities as an Independent Variable

The integration of technology-enabled features into perpetual inventory systems has become a pivotal factor in driving operational efficiency and competitiveness among small retail businesses. Traditional periodic inventory systems, though simple and low-tech, often result in delayed updates and increased risks of discrepancies (Schwarz, 2024). In contrast, technology-enabled perpetual systems offer continuous, automated stock tracking that enhances real-time accuracy and reduces manual errors (Agarwal, 2023). Key functionalities such as predictive analytics allow small retailers to forecast demand trends, optimize inventory levels, and mitigate common issues like overstocking and stockouts (Kivimaa, 2024). Automation of routine tasks—including replenishment and error detection—further alleviates manual oversight while improving precision and efficiency (Agarwal, 2023). Multi-channel synchronization ensures inventory consistency across physical stores, online platforms, and third-party marketplaces such as Amazon and Shopify, addressing discrepancies that typically arise in manual systems (Khmelovskyi, 2024). Additionally, cloud-based and mobile-enabled inventory platforms provide scalable and cost-effective solutions, with systems like Zoho Inventory and SkuNexus offering integrated features such as inventory tracking, analytics dashboards, and automated alerts to support informed decision-making and operational control (Lieblich, 2024; Chang, 2025). These advancements not only modernize inventory management but also align it with strategic business growth objectives. Consequently, the inclusion of technology-enabled inventory systems as the independent variable in conceptual frameworks is well-founded, given their direct influence on the operational performance and sustainability of small retail enterprises (Kivimaa, 2024; Khmelovskyi, 2024; Chang, 2025).

Moderators for Small Retail Enterprises

The adoption of technology-enabled systems in small retail businesses is shaped by a constellation of moderating variables, notably technological barriers, resource constraints, and facilitating conditions. These factors influence the relationship between system integration and operational performance and thus warrant close examination in conceptual frameworks addressing digital transformation in resource-limited contexts. Technological barriers remain a significant impediment to system adoption. Abubakar et al. (2025) note that while technology-enabled customer relationship management (CRM) systems can enhance engagement and sales, their implementation is often hindered by infrastructural limitations and technical complexity. Nascimento et al. (2023) reinforces this view, identifying inadequate infrastructure and lack of technical expertise as critical obstacles, particularly in small enterprises operating in resource-constrained environments. Resource constraints further compound these challenges. Financial limitations and skill shortages are frequently cited as primary barriers to technology adoption. Abubakar et al. (2025) and Nascimento et al. (2023) both highlight the restricted capacity of small firms to invest in and sustain advanced systems. This is echoed in broader studies on SMEs, which emphasize that constrained financial and human resources delay adoption and limit the strategic utilization of technology-enabled solutions (Weilbach, 2025). Survey-based research by Abubakar et al. (2025) adds that these constraints not only affect implementation timelines but also diminish the potential benefits of system integration. Conversely, several facilitators have been identified that can mitigate these barriers and support successful technology adoption. Organizational readiness, particularly employee preparedness and strategic alignment, is a key enabler, as emphasized in the McKinsey report (2025). The evolution of technology adoption literature also points to the importance of awareness and planning in overcoming technological and resource-related challenges (Demirci, 2024). External support mechanisms, including policy interventions and infrastructure development, are likewise critical. Studies advocate for targeted efforts to bridge the digital divide and promote inclusive technology adoption in financially and technically disadvantaged settings (Weilbach, 2025). The literature underscores that while technological and resource constraints pose substantial challenges to technology adoption in small retail enterprises, these can be effectively addressed through strategic facilitators. Recognizing these moderating variables is essential for designing responsive frameworks that enable small businesses to harness technology-enabled systems for sustainable growth, competitiveness, and customer satisfaction.

Dependent Variables: Inventory Management Efficiency, Operational Efficiency, and Customer Satisfaction

Recent literature highlights the strong interrelationship between inventory management efficiency, operational performance, and customer satisfaction in small retail enterprises. Inventory efficiency is increasingly acknowledged as a core determinant of retail success, as effective stock control influences replenishment speed, service quality, and overall business stability. Meilanitasari and Ibrahim (2023) illustrate this through the development of an Integrated Warehouse Application (IWA) for SMEs, which consolidates inventory, order processing, and logistics functions. By streamlining workflow and improving order accuracy, the system enhances fulfillment speed, thereby strengthening customer satisfaction and loyalty (Meilanitasari & Ibrahim, 2023). Technological innovations, particularly predictive analytics and real-time data processing, emerge as essential mechanisms for optimizing inventory and supply chain activities. Famoti et al. (2025) emphasize that data-driven systems enable retailers to anticipate demand fluctuations and maintain optimal stock levels, which improves operational efficiency and reduces losses from stockouts and overstocks. This is exemplified by Walmart's strategic use of predictive analytics, which minimizes excess inventory, lowers operational costs, and increases customer satisfaction through reliable product availability (Alam & Shabbir, 2024). Advanced technologies such as RFID, automation, and smart retail tools further reinforce inventory and operational performance. Modi et al. (2024) present a smart shopping trolley equipped with RFID technology that accelerates checkout processes and improves inventory tracking accuracy, ultimately enhancing customer convenience. Similarly, Boussalham and

Ejjami (2024) emphasize the role of technology-enabled in-store logistics solutions—such as automated restocking and digital demand forecasting in optimizing space utilization and ensuring accurate inventory records, both of which are critical for efficient retail operations and positive customer experiences. In addition, customer-centered approaches contribute significantly to supply chain efficiency and satisfaction outcomes. Oyeyemi et al. (2023) stress that aligning inventory strategies with customer preferences enhances responsiveness and profitability within the supply chain. Although omnichannel systems may pose implementation challenges for SMEs, they facilitate integrated sales platforms, expand customer reach, and strengthen engagement, thus indirectly supporting inventory management improvements (Oyeyemi et al., 2023). This scholarly evidence demonstrates that technology-enabled tools, predictive analytics, and customer-focused strategies collectively enhance inventory management efficiency, operational performance, and customer satisfaction in small retail environments. These factors are not only interdependent but also central to the long-term sustainability and competitiveness of SMEs in an increasingly digital and customer-driven marketplace.

Results and Discussion

The study addressed the current inventory management issues affecting small-scale retailers in the Philippines, the most relevant features of the technology-enabled perpetual inventory system, the resources and facilitation needed for effective adoption, the impact of these systems on customer satisfaction in terms of product availability, service speed, and shopping experience, and the measurable improvements in inventory accuracy, operational efficiency, and other key metrics after implementation.

Inventory System Usage and Its Implications for Small-Scale Enterprises

Current Inventory Management Systems refer to the various methods that small scale businesses used to track, manage, and optimize their inventory levels. Table 1 showed that most respondents (60%) rely on manual systems like paper logs, while 0% use Excel spreadsheets and have adopted app-based systems, and 40% utilize none

Table 1. Current Inventory Management Systems Used

Inventory System Type	n	(%)
Manual (paper logs)	12	60%
Excel Spreadsheet	0	0%
App-based Inventory Management	0	0%
None	8	40%

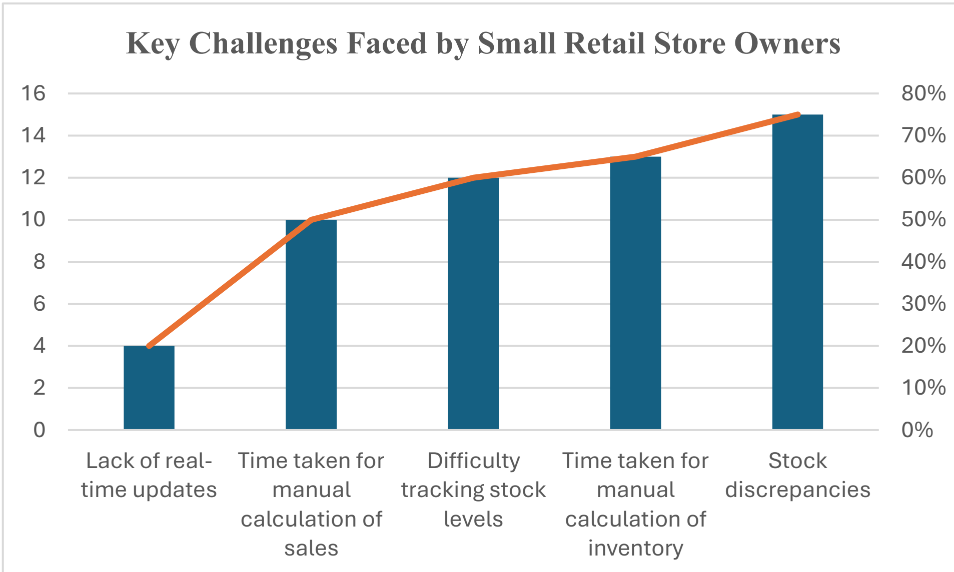
Source: Author's identified inventory management systems used by the respondents

The findings underscored a persistent reliance on low-tech or manual inventory tracking methods, which, while operationally simple, present significant limitations in terms of accuracy, scalability, and efficiency. The literature affirmed that manual inventory management remains common among small businesses with limited stock complexity, often driven by resource constraints and the perceived adequacy of manual processes for their operational scale (Turovski, 2025). However, such systems are inherently prone to human error, leading to stock inaccuracies, fulfillment delays, and financial discrepancies (Calisi, 2025). As inventory volume increases, these risks become more pronounced, and the absence of real-time data updates impairs timely decision-making and operational responsiveness. Historical reliance on manual systems was often rooted in operational simplicity. For example, the UVA Bookstore Case Study conducted by RFSMART (2025) demonstrated the transition from manual tracking to a more technology-enabled inventory system, illustrating a growing recognition of the limitations of manual methods in meeting evolving customer and operational demands. Similarly, small manufacturers may initially find manual tracking manageable, but expansion typically necessitates more automated and integrated solutions (Turovski, 2025). Critically, the literature suggested that continued dependence on manual systems can hinder business growth and scalability. Manual methods are increasingly viewed as outdated in the context of modern technological advancements and inefficient for maintaining inventory accuracy over time. The adoption of networked and advanced perpetual inventory systems has been recommended to address these challenges, offering improved control, scalability, and operational efficiency (Calisi, 2025). Nonetheless, small enterprises often delay this transition due to financial constraints, limited technical expertise, or resistance to change (Taylor, 2024; Turovski, 2025; Calisi, 2025). The survey findings reflected broader trends in the literature: while manual inventory systems remain prevalent due to their low cost and simplicity, they introduce substantial risks that compromise inventory management efficiency and operational performance. Transitioning to automated or semi-automated technology-enabled systems is increasingly recognized as essential for small businesses seeking to enhance accuracy, reduce errors, and support long-term scalability.

Challenges in Inventory and Operational Management Among Small Retail Store Owners

Survey data from small retail store owners revealed persistent operational challenges, with 75% reporting stock discrepancies, 65% citing time-consuming manual inventory calculations, 60% experiencing difficulty tracking stock levels, 50% burdened by manual sales computation, and 20% lacking real-time inventory updates. These findings reflected broader patterns documented in the literature, which identified inventory management inefficiencies and technological limitations as critical barriers to retail performance.

Figure 2. Key Challenges Faced by Small Retail Store Owners



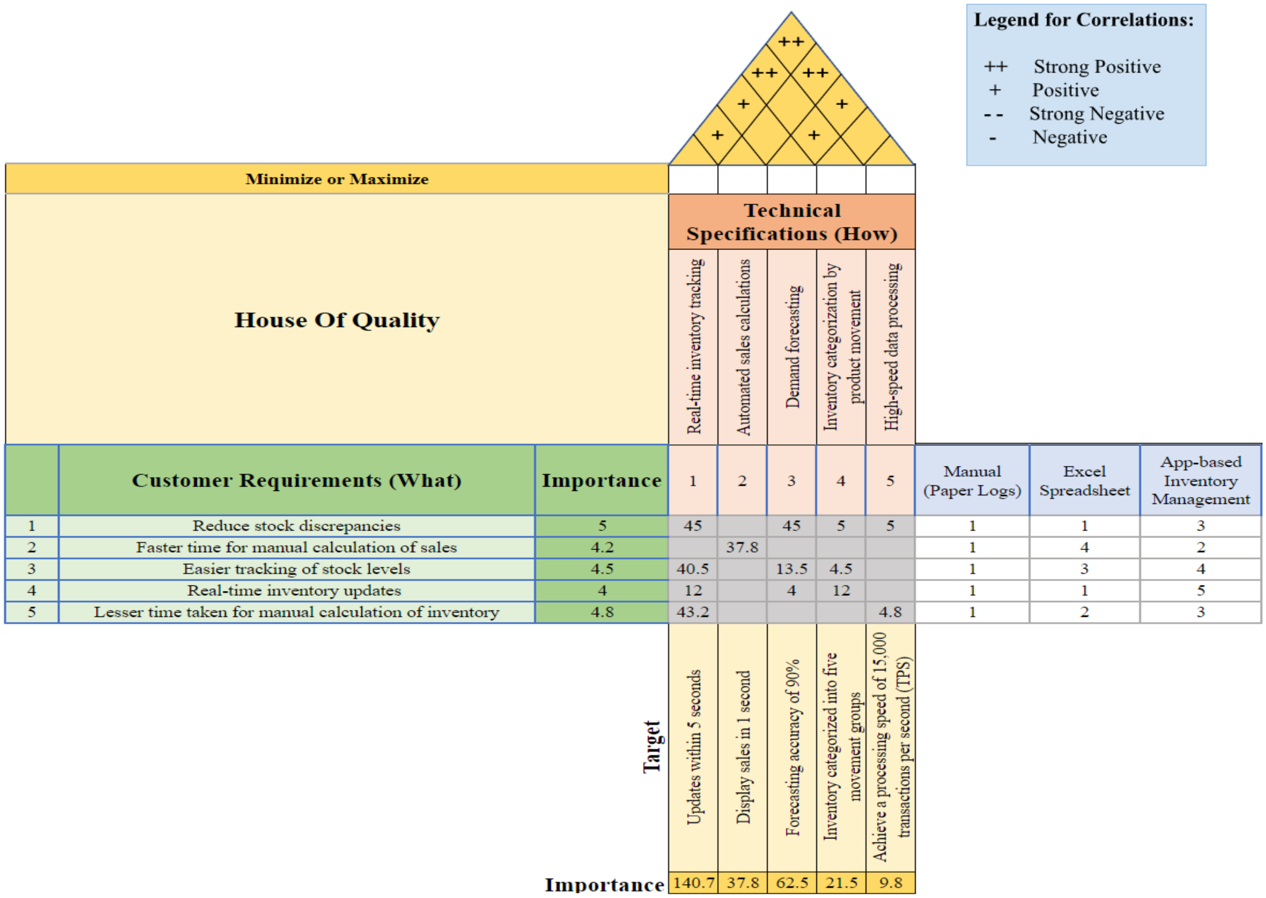
Source: Author's identified challenges by the respondents

One of the most pressing issues identified was the lack of real-time inventory visibility, which impairs decision-making and responsiveness. Riadi et al. (2023) emphasized the importance of data-driven inventory optimization using algorithms such as FP-Growth, which can help retailers identify purchasing patterns and adjust stock levels accordingly. However, limited technical expertise and inadequate data infrastructure often hindered the adoption of such tools, contributing to the 20% of respondents who reported lacking real-time updates. Manual processes also dominated small retail operations, as evidenced by the 65% of respondents who manually calculated inventory and the 50% who manually computed sales. These practices were time-intensive and error-prone, leading to inefficiencies and financial discrepancies. Lewis et al. (2023) highlighted how external shocks such as the COVID-19 pandemic exacerbated these vulnerabilities, forcing retailers to adapt quickly without the support of technology-enabled inventory systems. The reliance on manual methods also aligned with findings by Ye et al. (2021), who underscored the complexity of demand estimation in small-area retail environments, where timely data is essential for accurate stock planning. Difficulty in tracking stock levels, reported by 60% of respondents, was compounded by challenges in aligning inventory with consumer needs and health promotion standards. Schreiber et al. (2024) described how small retailers struggled to meet stocking requirements for healthy products, often due to resource constraints and lack of technical support. This challenge was further complicated by the need to engage diverse customer bases and adapt to fluctuating demand (Ye et al., 2021). Stock discrepancies, the most frequently cited issue (75%), reflected systemic weaknesses in inventory control and supplier coordination. Mujianto et al. (2023) emphasized the importance of relational marketing and supplier loyalty, suggesting that weak buyer-seller relationships can lead to inconsistencies in stock delivery and record-keeping. Additionally, Thomas et al. (2024) and Zhang et al. (2024) identified logistical and trust-related barriers in supply chain collaboration, which may contribute to inventory mismatches and operational delays. Digital transformation offered potential solutions but also introduced new challenges. Soekandar and Pratiwi (2023) discussed the role of digital marketing in boosting retail sales, yet small retailers often faced barriers related to technological literacy and resource availability. Lewis et al. (2024) proposed mobile applications as tools for enhancing customer engagement and inventory coordination, but their implementation required strategic planning and community alignment. The survey findings were strongly supported by existing literature, which collectively highlight that manual processes, lack of real-time data, stock discrepancies, and inventory tracking difficulties remain persistent challenges for small retail store owners. Addressing these issues requires targeted interventions that promote digital integration, supplier collaboration, and data-driven inventory management, while carefully considering the resource limitations inherent in small-scale retail environments.

Functional Requirements Derived from QFD for Inventory System Optimization

The House of Quality (HOQ) analysis identified five prioritized features of the Advanced Perpetual Inventory System based on their weighted importance scores. Real-time inventory tracking emerged as the most critical feature (140.7), reflecting its central role in enhancing inventory accuracy, minimizing discrepancies, and supporting timely decision-making. Riadi et al. (2023) emphasized that real-time visibility into inventory levels allows retailers to respond swiftly to demand fluctuations and avoid stockouts. Alam and Shabbir (2024) illustrated how predictive analytics and real-time tracking at Walmart reduced excess inventory and improved customer satisfaction. Lewis et al. (2023) further highlighted the vulnerability of small retailers during external shocks, such as the COVID-19 pandemic, where lack of real-time data hindered adaptive responses. Demand forecasting followed with a score of 62.5, indicating its strategic relevance in anticipating consumer behavior and optimizing stock levels. Ye et al. (2021) discussed the complexity of estimating demand in small-area retail environments, particularly in urban and tourist settings. Famoti et al. (2025) advocated for data-driven forecasting to enhance operational efficiency and reduce inventory waste. Boussalham et al. (2024) also noted that technology-enabled demand prediction supports automated restocking and space optimization, which are vital for small retailers with limited storage capacity. Automated sales calculations (37.8) were recognized for their contribution to reducing manual workload and improving transactional efficiency. Meilanitasari and Ibrahim (2023) described how integrated systems streamlined order processing and sales tracking, directly impacting customer satisfaction. Soekandar and Pratiwi (2023) linked digital transformation, including automated sales functions, to improved business sustainability, though they cautioned that technological literacy remains a barrier for some small retailers. The feature inventory categorization by product movement (21.5) supported more refined inventory control by enabling businesses to prioritize fast-moving items and streamline replenishment. Modi et al. (2024) presented RFID-enabled smart trolleys as tools for tracking product flow and enhancing checkout efficiency. Schreiber et al. (2024) highlighted the importance of strategic product placement and movement tracking in meeting health promotion standards, especially in resource-constrained retail environments. Lastly, high-speed data processing (9.8), while ranked lowest, was acknowledged for its role in improving system responsiveness and scalability in high-volume retail environments. These results reflected a user-centered design approach that aligned technological functionalities with the operational priorities of small retail enterprises. Thomas et al. (2024) demonstrated how advanced detection systems rely on rapid data processing to enhance security and operational control. Lewis et al. (2024) also discussed the development of mobile applications for community engagement, which require efficient data handling to support real-time interactions and inventory updates.

Figure 3. House of Quality



Source: Author's Constructed House of Quality

Essential Resources and Facilitation Requirements for Technology-Enabled Perpetual Inventory System Adoption in Small Retail Enterprises

The adoption of technology-enabled perpetual inventory systems among small retail enterprises had been shaped by a range of facilitation requirements and resource considerations.

Table 2. Resources Needed for Better Utilization

Resource Needed	n	%
Training and technical support	16	80%
Simplified user interface	12	60%
Financial assistance for adoption	11	55%
Additional hardware (e.g., scanners)	8	40%

Note: This outlined the essential resources required to optimize the implementation and effectiveness of the system.

Survey results revealed that training and technical support were the most critical enablers, cited by 80% of respondents. This finding aligned with earlier research, which confirmed that a lack of capital and technical capacity had been a major obstacle to the adoption of new technologies and policies in small-scale firms (Hvolkova et al., 2019). Despite these limitations, operational challenges such as inventory discrepancies and inefficiencies intensified the need for improved inventory management solutions. The importance of real-time stock monitoring and predictive analytics features, central to advanced perpetual inventory systems, has been well-documented. Singh (2023) emphasized that these capabilities offer substantial benefits in inventory control; however, a lack of awareness and technical skills in smaller organizations remains a significant barrier to adoption. This was consistent with the 60% of survey respondents who identified the need for a simplified user interface, reflecting the importance of intuitive, low-barrier platforms for users with limited digital literacy. Financial assistance for system adoption, cited by 55% of respondents, reflected the broader economic challenges faced by small enterprises. The World Investment Report by the UN Trade and Development (2024) highlighted how external economic factors influence digital transformation initiatives, including technology adoption. Legislative and policy frameworks also played a facilitative role, with jurisdictions actively regulating and promoting technology integration to create supportive environments for small businesses (National Conference of State Legislature [NCSL], 2025). Additionally, 40% of respondents noted the need for additional hardware, such as barcode scanners and mobile devices. This requirement was consistent with findings in related fields such as IoT, where successful implementation depended on clear standards and infrastructural readiness (Internet of Things [IoT] Advisory Board, 2024). The McKinsey (2023) survey further revealed that a growing number of organizations had adopted technology-enabled systems, reinforcing the importance of strategic investment and facilitation resources to support widespread integration. Technology's transformative role in other sectors, such as healthcare, has demonstrated its capacity to empower decision-making and optimize management processes when adequate human and technological resources are in place (Varnosfaderani & Forouzanfar, 2024). However, the transition to advanced systems often disrupted existing workflows, as noted by Bonetti et al. (2023), underscoring the importance of facilitation strategies such as training and co-evolution practices to help employees adjust to new operational models. Domain expertise and tailored solutions were also necessary to make technology adoption viable for small enterprises, particularly when tools were designed to align with local operational contexts (EY, 2025). The successful adoption of advanced perpetual inventory systems among small retailers depends on securing essential technological resources, providing training and technical support, simplifying user interfaces, and navigating supportive policy and investment landscapes. These facilitation requirements are critical in overcoming operational disruptions and enabling small enterprises to harness technology's potential for inventory management efficiency, operational performance, and long-term sustainability.

Experience Map of Resource Mobilization and Facilitation Pathways for Advanced Perpetual Inventory System Adoption in Small-Scale Retail Enterprises

The experience map captured the progression of small-scale retailers as they navigated the adoption of advanced perpetual inventory systems, revealing distinct phases of awareness, engagement, and outcome.

Awareness Phase:

Retailers became increasingly conscious of the limitations of manual inventory practices such as stock discrepancies, delayed calculations, and the absence of real-time visibility. These operational pain points, coupled with exposure to digital innovations, prompted interest in more efficient, technology-enabled solutions. However, the experience map showed that small-sized retail businesses had limited knowledge of advanced inventory systems and faced persistent barriers including heavy initial investment, weak technical skills, and limited internet access. These constraints echoed earlier findings by Hvolkova et al. (2019), who identified lack of capital and technical capacity as major obstacles to technology adoption in small-scale firms. Despite these limitations, the variation and inefficiencies in inventory management created a clear intention to adopt more modern systems.

Engagement/Usage Phase:

Retailers who engaged with advanced systems encountered both enablers and inhibitors. Simplified user interfaces and targeted training facilitated initial adoption, while financial assistance and hardware support (e.g., scanners and mobile devices) proved essential for full system functionality. The research emphasized that proper, practical training and continuous technical aid were vital for efficient implementation. Small-sized firms with limited technical capacities required user-friendly systems, and location-specific training programs, low-cost solutions, and offline-capable platforms were considered crucial in reducing adoption barriers and ensuring long-term usage. These findings aligned with Jaramillo et al. (2019), who observed that hands-on training and ongoing support were especially beneficial for small businesses with non-technical staff.

Outcome Phase:

The outcome phase reflected the tangible benefits realized through adoption. Retailers reported improvements in inventory accuracy, faster sales computation, and enhanced decision-making capabilities through predictive analytics and real-time monitoring. Singh (2023) emphasized that financial flexibility and scalability of system deployment had to be matched with the needs of smaller businesses, as cost-related challenges often hindered adoption. The adoption threshold could have been lowered through financial incentives such as subsidies or flexible payment plans. Additionally, there was significant demand in underserved areas for systems with local offline capabilities, given the widespread lack of connectivity.

These findings reinforced the importance of affordable pricing frameworks, continuous localized training, and customized functionalities in fostering sustainable adoption of advanced perpetual inventory systems in small firms (Singh, 2023).

Figure 4. Experience Map of Small-Scale Retailers in Adopting the Advanced Perpetual Inventory Systems

Experience Map: Resource Mobilization and Facilitation Pathways for Advanced Perpetual Inventory System Adoption in Small-Scale Retail Enterprises

	AWARENESS	KEY USAGE	OUTCOME
OBSERVATIONS	Small-scale retailers were largely unfamiliar with advanced perpetual inventory systems. Many had never encountered the concept and were unaware of its potential benefits. Their motivation to explore new inventory management solutions stemmed not from technological awareness but from persistent operational challenges such as stock discrepancies, manual errors, and lack of real-time visibility. These limitations, combined with competitive pressure from larger businesses, prompted interest in more efficient, technology-enabled systems. However, significant barriers emerged during this phase. High upfront costs, limited technical skills, and unreliable internet connectivity were common concerns. These constraints highlighted the need for greater awareness, education, and infrastructure support to enable informed decision-making and readiness for digital transformation.	During implementation, training emerged as the most critical resource. Respondents emphasized the value of hands-on workshops and demonstrations, though some noted that generic training failed to address specific business needs. Financial assistance, such as subsidies and flexible payment plans, helped reduce the financial burden and made system adoption more feasible. Technical support was essential for troubleshooting and maintaining system functionality. Simplified, user-friendly interfaces were crucial for staff with limited digital experience. Respondents consistently stressed the importance of intuitive platforms that could be easily navigated without extensive technical training.	Retailers identified several key improvements following system adoption. These included enhanced inventory accuracy, faster sales computation, and improved decision-making through real-time monitoring and predictive analytics. Respondents advocated for affordable pricing models, localized training programs, and continuous technical support to sustain long-term usage. Simplified interfaces with guided tutorials and low-stock alerts were seen as essential for accessibility. In underserved areas, offline functionality was especially important due to inconsistent internet access. Retailers also called for customizable system features and policy-level support, such as grants and public awareness campaigns, to foster inclusive technology adoption.
LEARNINGS	Operational inefficiencies drive interest in system upgrades. Limited awareness and digital literacy hinder adoption. Cost and connectivity remain major barriers.	Tailored, practical training improves adoption success. Financial support enables access to system features. Ongoing technical aid and intuitive design are vital.	Tangible operational benefits realized post-adoption. Affordability and customization support sustainability. Offline capability and policy support enhance accessibility.

Source: Author's constructed experience map based on qualitative interview findings

The experience map illustrated that the successful adoption of advanced perpetual inventory systems among small retailers depended on a combination of awareness-building, resource mobilization, and sustained facilitation. Key enablers such as customized training, financial support, and adaptive system design were essential in overcoming barriers and ensuring usability, particularly in resource-constrained and digitally underserved environments. These findings are consistent with existing scholarly literature and provide a strong foundation for developing inclusive, context-sensitive strategies that promote technology-enabled inventory management and support the long-term sustainability of small-scale retail enterprises.

Comparative Analysis of Customer Satisfaction Before and After Advanced Perpetual Inventory System Implementation

Table 3. Customer Satisfaction Ratings Before and After Implementation of Advanced Perpetual Inventory System Features

Aspect	Very Satisfied	Satisfied	Neutral	Unsatisfied	Very Unsatisfied
Product Availability	10% → 54%	12% → 38%	20% → 5%	38% → 3%	20% → 0%
Speed of Service	12% → 47%	10% → 41%	22% → 7%	25% → 5%	35% → 0%
Overall Shopping Experience	8% → 48%	13% → 43%	20% → 5%	27% → 3%	32% → 0%

Note: Values represent percentage of customer responses before and after system implementation. Arrows (→) indicate change in satisfaction levels.

The findings demonstrated a significant improvement in customer satisfaction following the implementation of advanced perpetual inventory systems in small-scale retail settings. Prior to adoption, customer ratings across key service dimensions, such as product availability, speed of service, and overall shopping experience, were predominantly neutral to negative. Only 10% of customers reported being very satisfied with product availability, 12% with speed of service, and 8% with the overall shopping experience. These low ratings reflected operational inefficiencies commonly associated with manual inventory systems, including stock discrepancies, service delays, and inconsistent product availability. Upon system implementation, satisfaction levels shifted markedly. Very satisfied ratings rose to 54% for product availability, 47% for speed of service, and 48% for overall shopping experience. These improvements aligned with existing literature emphasizing the positive impact of technology-enabled inventory systems on customer satisfaction. Souza et al. (2013) demonstrated that inventory process optimization through Six Sigma methodologies led to a notable increase in the customer service index (CSI), suggesting that reduced cycle times and improved inventory turnover directly influenced customer experience. Dharma and Suryadi (2024) similarly highlighted that ERP-based inventory modules enhanced operational efficiency and decision-making, enabling more accurate and timely responses to customer needs. This supported the observed improvements in service speed and product availability among small retailers. Additional technological innovations reinforced these outcomes. Modi et al. (2024) illustrated how RFID-enabled smart shopping trolleys streamlined inventory tracking and billing, contributing to reduced wait times and improved service quality, factors reflected in the post-implementation satisfaction ratings. The integration of IoT technologies also played a role in improving inventory accuracy and reducing stockouts. Ugbebor et al. (2024) found that IoT-enabled systems optimized stock levels and minimized carrying costs, ensuring timely product availability and delivery, key drivers of customer satisfaction. Anugrah et al. (2024) and Minasa et al. (2024) emphasized the importance of user-centered design and agile methodologies in developing real-time inventory systems that adapt to changing customer demands, reduce delays, and enhance responsiveness. The comparative data and supporting literature confirmed that advanced perpetual inventory systems positively influenced customer satisfaction by improving inventory control, accelerating service delivery, and enhancing the overall shopping experience. These systems addressed core operational challenges and aligned with customer expectations, thereby fostering loyalty and elevating service quality in small-scale retail environments.

Operational Gains Following the Adoption of Advanced Perpetual Inventory Systems in Small-Scale Retail Enterprises

Table 4. Measurable Improvements in Inventory Management and Operational Efficiency Following Implementation of Advanced Perpetual Inventory System Features

Measurable Improvement	Significant Improvement	Moderate Improvement	No Change	Decrease
Accuracy of inventory records	35%	45%	15%	5%
Time required for calculation of sales	50%	35%	5%	15%
Time required for inventory	45%	30%	10%	15%
Overall operational efficiency	65%	30%	5%	10%

Source: Author's constructed table based on survey data

The survey findings revealed measurable improvements in inventory management and operational efficiency among small-scale retail enterprises following the adoption of advanced perpetual inventory systems. A majority of respondents reported significant or moderate gains in key operational areas: 80% in inventory record accuracy, 85% in sales computation time, 75% in inventory processing time, and 95% in overall operational efficiency. These results underscored the transformative impact of technology-enabled inventory systems on core business functions. Inventory accuracy and record reliability were notably enhanced, with 35% of respondents indicating significant improvement and 45% reporting moderate gains. These outcomes aligned with Budiyanto and Muslim (2024), who emphasized that RFID technology, when integrated with IoT and blockchain, optimized inventory systems by improving data accuracy and operational transparency. Lengow (n.d.) similarly highlighted that specialized inventory management software automated recording tasks, reduced human error, and increased record reliability, directly influencing operational efficiency. Time efficiency in sales and inventory computation also improved substantially. Half of the respondents observed significant reductions in the time required for sales calculations, while 45% reported faster inventory processing. These findings were consistent with Ugbebor et al. (2024), which demonstrated that IoT-enabled automated inventory systems reduced processing times and enabled SMEs to respond swiftly to market demands. The integration of mobile-compatible technologies further supported real-time inventory management, streamlining both sales and stock updates (Sahil, 2025). Overall operational efficiency showed the most pronounced gains, with 65% of respondents reporting significant improvement. This aligned with Industry 4.0 initiatives discussed by Rashid and Kausik (2024), which aimed to optimize supply chain processes, increase productivity, and reduce waste. The application of just-in-time (JIT) inventory strategies, as detailed by Balkhi et al. (2022), demonstrated that real-time data and efficient tracking minimized stockouts and excess inventory, thereby enhancing agility and cost-effectiveness. The role of digital transformation in supply chain management further supported these findings. As noted by Shelley (2024), technology adoption improved inventory coordination and logistics performance. The use of RFID and IoT sensors elevated inventory accuracy and enabled faster decision-making (Holloway, 2024). For small enterprises, selecting appropriate inventory software was critical, as Radley (2025) emphasized that such tools enhanced agility, efficiency, and long-term resilience. Conclusively, the integration of RFID, IoT, and specialized inventory software played a pivotal role in improving inventory accuracy, reducing processing time, and enhancing overall operational efficiency. These technological advancements proved essential for small-scale retailers seeking to modernize operations, meet customer expectations, and remain competitive in a digitally evolving marketplace.

Conclusion

This study underscored the transformative potential of advanced perpetual inventory systems in enhancing operational efficiency and elevating customer satisfaction within small-scale retail environments. By addressing persistent challenges such as stock discrepancies, delayed computations, and fragmented inventory tracking, these systems demonstrated their capacity to streamline operations and improve service delivery. Post-adoption findings revealed marked improvements in inventory accuracy, faster sales and inventory processing, and enhanced customer experience, critical outcomes for retailers operating in highly competitive and resource-constrained settings. Despite these promising results, widespread adoption remained hindered by high installation costs, limited technical expertise, and unreliable internet connectivity. The study identified key enablers for successful implementation, including investment incentives, localized technical training, and personalized support. To ensure long-term usability and sustainability, there is a clear need for streamlined and accessible systems equipped with flexible pricing structures, offline capabilities, and continuous technical assistance tailored to the realities of small enterprises. This research contributed meaningfully to both academic discourse and practical implementation by exploring the integration of technology-enabled inventory systems in the context of developing economies, specifically within small retail businesses in the Philippines. The ability of these systems to improve inventory management and product availability holds significant promise for fostering customer trust and loyalty. As digital transformation continues to reshape the retail landscape, the strategic deployment of advanced inventory systems in small enterprises offers vast opportunities for operational improvement and service innovation. However, the study was not without limitations. The small sample size, comprising only 20 stores and 60 customers, restricted the generalizability of the findings. Moreover, the system was tested over a brief four-hour period, which was insufficient to assess its long-term effectiveness under real-world conditions. The study's geographic scope, limited to Barangay Guadalupe, Cebu City, further constrained the applicability of results to broader retail contexts. These limitations point to the need for future research involving larger and more diverse samples, extended testing durations, and multi-site implementation to better understand the sustained impact of advanced perpetual inventory systems. Ultimately, the findings affirmed that with appropriate financial support, targeted training, and adaptive system design, small retailers can harness technology-enabled inventory solutions to reduce operational inefficiencies, improve inventory control, and enhance customer satisfaction. The future of retail, particularly in emerging markets, is poised for profound transformation, with advanced systems playing a pivotal role in shaping the agility, resilience, and competitiveness of small-scale retail enterprises.

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Conflict of Interest

The authors declare that they have no affiliation with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

Author Contribution

The authors confirm contribution to the paper as follows: study conception and design: A. Almaden, G.M. Anciano; data collection: G.L. Catadman, C.M. Dela Torre, J.J. Enario; analysis and interpretation of results: A. Almaden, G.M. Anciano, C.A. Lasdoce; draft manuscript preparation: A. Almaden, G.M. Anciano. All authors reviewed the results and approved the final version of the manuscript.

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CHAPTER 6

GENERATIVE ARTIFICIAL INTELLIGENCE AS AN INHIBITOR OF SCIENTIFIC CREATIVITY: A SOCIAL JUSTICE PERSPECTIVE IN SCIENCE EDUCATION

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ABSTRACT

The integration of Generative Artificial Intelligence (GenAI) is transforming science education, however, its impact on scientific creativity raises significant concerns, particularly from a social justice perspective. While AI can facilitate inquiry-based learning, problem-solving, and research efficiency, its widespread adoption risks inhibiting creativity by fostering passive learning and limiting students' ability to think critically. Unequal access to AI tools widens educational disparities, preventing marginalized students from engaging in creative exploration. Moreover, algorithmic bias reinforces stereotypes, restricting diverse perspectives and hindering innovation. As students increasingly rely on AI-generated content, their agency in learning diminishes, shifting their role from active problem-solvers to passive consumers of information. This shift also alters traditional power structure in education, reducing teacher's ability to guide inquiry and promote creative thinking. Ethical concerns further complicate AI integration, highlighting the need for responsible implementation that prioritizes inclusivity and equity. Without deliberate intervention, AI may reinforce systemic inequalities rather than democratize scientific learning. These challenges require policies and pedagogical strategies that ensure AI serves as a tool for empowerment rather than a barrier to creativity. A balanced approach is essential to fostering an educational environment where all students can develop scientific creativity and contribute meaningfully to STEM fields.

Keywords: Artificial Intelligence, Generative AI, Science Education, Scientific Creativity, Social Justice

Introduction

Generative Artificial Intelligence (GenAI), driven by machine algorithms, has reshaped teaching and learning in science education (Mariani & Dwivedi, 2024; Xu, 2024) transforming processes such as data analysis (Combrinck, 2024), hypothesis generation, and experimental designs. In the classroom, AI tools enhance students' engagement (Nguyen et al., 2024) by helping them visualize complex scientific concepts, simulate experiments, and explore hypothetical scenarios (Salinas-Navarro et al., 2024' Sun et al., 2021), making science learning more interactive and hand-on. GenAI tools also promote individualized learning by adapting lessons to the diverse needs of the students, allowing for more personalized educational experience (Chan & Hu, 2023). For teachers, AI streamlines tasks like lesson planning (Durmus, 2024; Hashem et al., 2023) and assessment (Nie & Chua, 2024), freeing up time for more focused instruction and facilitating deeper student-teacher interaction (Chiu, 2023). However, to fully understand the impact of GenAI on science education, it is crucial to examine how these advancements can also limit scientific creativity, particularly for marginalized communities, shaping inequitable learning environments.

Scientific creativity is central to the advancement of science and education (Daud et al., 2012; Hadzigeorgiou et al., 2012; Lin et al., 2023). It involves the ability to think critically (Álvarez-Huerta, 2022; Forrester, 2009; Park et al., 2023), explore unconventional solutions, and generate innovative ideas to solve complex problems (Oh, 2021). In science education, creativity encourages students to engage with inquiry-based learning (Kotsis, 2024), think independently (Wahyuddin et al., 2023), and apply their knowledge in novel approaches (Cropley & Cropley, 2020). Creative problem-solving drives scientific innovation, enabling breakthroughs in technology, medicine, and environmental science. While technology like GenAI can assist some aspects of scientific work (Marrone et al., 2023), true scientific creativity remains invulnerable to technology automation (Cropley, 2023; Cropley & Cropley, 2020). It requires human ingenuity, intuition, and the ability to think beyond predefined algorithms. Fostering scientific creativity is crucial for cultivating the next generation of scientists and innovators. Despite the benefits that GenAI offers in enhancing science education, it is important to recognize its limitations (Terrón, 2024), particularly fostering the kind of creativity that drives innovations in science.

II. Content

Problem Statement

While the AI enhances educational practice, it often limits scientific creativity, particularly among marginalized communities, through the lens of critical pedagogy (Healy, 2023; Modén et al., 2024). The reliance on AI-generated content stifle critical thinking, reinforcing passive learning habits that hinder students from engaging deeply with scientific concepts (Al-Zahrani, 2024; Habib et al., 2023). This issue is compounded by inequitable access to AI tools, which creates barriers for underrepresented groups, perpetuating existing power structure and maintaining the status quo (Holstein & Doroudi, 2021; Rodrigues, 2020). In the same manner, algorithmic biases in AI produce outputs that may exclude or misrepresent marginalized perspectives, alienating students who do not see their identities reflected in the curriculum (Cooper & Tang, 2024; Eden et al., 2024).

This chapter focuses on the intersection of GenAI, scientific creativity, and social justice in science education. It will be structured into five key sections. The first section will examine the inequitable access to AI tools, highlighting how the digital divides limit opportunities for creativity among marginalized groups (Holstein & Doroudi, 2021; Rodrigues, 2020). The second section will explore algorithmic bias, analyzing how biases in AI outputs can stifle diverse perspectives and hinder creative potential in scientific inquiry (Cooper & Tang, 2024; Eden et al., 2024). The third section will explore the diminished agency of students, emphasizing how reliance on AI can lead to passive learning, restricting critical thinking and innovation (Al-Zahrani, 2024; Habib et al., 2023). The fourth section will investigate how AI reinforces traditional power structure in education, diminishing teachers' role as facilitators of creative explorations (Selwyn, 2024; Seo et al., 2021). Finally, the fifth section will address ethical considerations, proposing strategies for integrating AI into ways that promote equity, creativity, and inclusivity, ensuring that all students can engage meaningfully in science education (Akgun & Greenhow, 2021; Kooli, 2023)

Inequitable Access to AI and Impact on Scientific Creativity

GenAI has revolutionized science education by enabling data analysis, hypotheses generation, and experimental simulations, which enables interactive and personalized learning experiences that promote scientific creativity (Mittal et al., 2024). However, digital divide – a disparity in access to technology – limits its transformative potential, particularly for the marginalized communities lacking reliable internet, modern devices, and adequate infrastructure (Afzal et al., 2023; Raihan et al., 2024). These inequities prevent many students from engaging with AI-driven tools that support inquiry-based learning, leaving them at disadvantage in developing critical STEM skills and perpetuating a two-tier education system, where the privileged benefit disproportionately (Al-Zahrani, 2024). From a social justice perspective, this disparity underscores systemic barriers that includes underrepresented group from fully participating in science education and innovation. Social justice emphasizes the need for equitable access to resources, advocating for the inclusion of all learners in educational opportunities.

Bridging the inequities in access to GenAI tools requires first understanding the broader issue of digital divides, which refers to the gap between individuals and communities with adequate access to technology and those without. Socio-economic factors, geographic disparities, and cultural barrier limits access to AI, particularly low-income, rural, and marginalized communities. The most affected are marginalized populations, including women, people of color, individual with disabilities, LGBTQ+ persons, and others (Gonzales, 2024). Global statistics show that young people (16-24) are 16% more likely to use the internet than older individuals (55-74). Similarly, those with higher education are 15% more likely to access the internet than those with lower education levels. Furthermore, the wealth gap is evident, as individuals at the highest income level are 12% more likely to use the internet than those with lower income (OECD, 2024). Furthermore, a recent international survey revealed from 31 countries have nearly equal concerns about AI, with 52% of adults feeling nervous and 54% excited about AI products and services. This underscores how age, education, and income contribute to existing digital gap and how fear often outweighs curiosity about AI technologies.

The United Nations Development Programme (UNDP) revealed that the transformative potential of digital technology, including AI, in advancing global development, with the capacity to support 70% of the 2030 Sustainable Development Goals (SDGs). However, despite its promise, AI development remains highly uneven, widening the global inequalities. The AI equity gap is evident in the lack of infrastructures and resources, particularly in developing regions. For instance, only 2% of the world's data centers are in Africa, and just 5% of AI innovators there have access to computing power they need. Likewise, one in three people worldwide still lack internet access, further limiting opportunities for technological advancement and participation in digital economy. This disparity is further reflected in AI investments trends. In 2023, the United States AI sector received an astounding

$67.2 billion in investments, while Kenya and Nigeria saw only $15 million and $2.9 million, respectively.

Bias in AI Outputs and Scientific Creativity Limitations

In a nationwide survey conducted in United States of America with a stratified sample of 79, 412 high school students across ethnicity, gender, high school grade point average, high school rank, and grade level, nearly half of the high school students surveyed used AI tools, with ChatGPT being the most common. Of the 54% who had not used AI, the main reasons were lack of interest (85%), distrust in the information provided (64%), and insufficient knowledge about the tools (55%). Other students argued that using AI is unethical and immoral, viewing the content and information supplied through AI tools as inaccurate, and personally resorting to not using AI in their work (Schiel et al., 2023). This survey highlights how bias in AI outputs can undermine the trust, with students expressing concerns about AI's accuracy and ethics. This bias limit scientific creativity through reinforcing existing stereotypes and hindering independent thought. When AI-generated content fails to offer diverse perspectives or innovative solutions, AI constrains critical thinking and problem-solving abilities. This can reduce opportunities for students to engage in creative process, limiting their potential in STEM and broaden scientific society. Understanding bias in AI is crucial as it directly impacts how AI outputs are generated, potentially limiting the diversity of creative solutions in scientific fields.

AI biases arise when AI systems produce skewed or unfair outcomes due to flaws in data collection, training models, or algorithm design (Ferrara, 2023; Min, 2023)). Bias in AI algorithm often stems from historical data reflecting societal inequalities, reinforcing stereotypes and systematic discrimination (Arora, et al., 2023; Ferrara, 2023). For instance, if an AI system is trained on datasets that primarily represent privileged demographics, it may produce recommendations or analyses that marginalize underrepresented groups (González-Sendino et al., 2024). Training model limitations, such as inadequate diversity in dataset of flawed labelling process, further exacerbating the biases. In education, biased AI outputs can reinforce inequities through misrepresenting student potential based on race, gender, or socioeconomic status (Min, 2023). For example, AI-powered grading tools have been criticized for systematically favoring the students from well-resourced schools while disadvantaging those from marginalized communities (Schiel et al., 2023). Similarly, AI-driven career counseling systems may intentionally steer underrepresented students away from STEM field due to gender or racial biases in training data (Rahman, 2023).

In summary, AI bias significantly impacts scientific creativity via reinforcing inequalities and limiting diverse perspectives in STEM fields. When AI tools are trained on biased datasets, they promote conformity rather than fostering innovation, disproportionately disadvantaging underrepresented students. Limited access to AI-driven educational resources further widens these disparities, restricting marginalized learners from fully engaging in scientific inquiry and creative problem-solving. These biases are crucial in ensuring that AI serves as an enabler rather than barrier to equitable education. To foster inclusivity and diverse innovations, educators, policy makers, and technology developers must prioritize equitable access to AI tools, ensuring that all students, regardless of background, can benefit from their potential. This includes refining AI algorithms to mitigate biases, incorporating diverse datasets, and implementing policies that promote accessibility in AI-integrated education.

Diminished Agency and Critical Scientific Thinking

Student agencies in learning refer to students' ability to take ownership of their educational experiences through regulating, controlling, and monitoring their own learning (Code, 2020), particularly in scientific inquiry, where critical thinking and problem-solving are essential. Science education has long emphasized independent reasoning, experimentation, and skepticism which involves scientific thinking and critical thinking (García-Carmona, 2023). These are skills necessary for producing innovative solutions and advancing knowledge. However, AI is reshaping how students engage with scientific inquiry, offering rapid access to vast information and sophisticated problem-solving capabilities. While AI enhances efficiency in research and data analysis, it also poses risks, such as reducing students' ability to think independently and critically (Patel, 2024). The increasing reliance on AI-generated outputs in science education threatens to shift learning from active exploration to passive consumption.

AI has transformed scientific inquiry through streamlining data analysis, identifying patterns, and generating hypotheses at unprecedented speeds (Padakanti et al., 2024). In classrooms, AI-powered simulations allow students to conduct virtual experiments, model complex scientific phenomena, and engage in predictive reasoning (Dai & Ke, 2022). These tools have the potential to enhance scientific thinking by enabling students to explore concepts beyond traditional textbooks and laboratory constraints. Moreover, AI can support personalized learning, adapting to individual students' needs and scaffolding their understanding of difficult scientific concepts (Chan & Hu, 2023). However, while AI assists in problem-solving, it does not inherently foster deep critical thinking or independent reasoning. AI-generated responses are based on existing data, meaning they reinforce prevailing knowledge rather than challenge assumptions or inspire novel insights (Robertson et al., 2024; Zou et al., 2023).

AI's role in science education presents both opportunities and challenges. While it has the potential to enhance learning through simulations, data analysis, and personalized instruction, its uncritical use risks undermining student agency and critical thinking. Overreliance on AI discourages inquiry-based learning, particularly among marginalized students who may already face systematic barriers to STEM education. Ensuring that AI fosters rather than hinders scientific creativity requires a balanced approach that integrates AI literacy, promotes independent problem-solving, and encourages skepticism. Educators, policymakers, and technologists must work together to create inclusive AI tools that enhance scientific inquiry while addressing biases. Prioritizing equitable access to AI and fostering a culture of critical engagement, science education can empower all students to contribute meaningfully to scientific progress.

Reinforcement of Traditional Power Structure in Science Education

Science education has historically been shaped by traditional power structures that dictate who has access to knowledge, who is considered an authority, and whose contributions are valued (Barton, & Yang, 2000). These hierarchies often favor dominant social groups, leaving marginalized voices underrepresented in STEM fields. With the advent of AI and digital tools, there is an opportunity to challenge these structures, yet there is also a risk of reinforcing them. AI systems are built on datasets that reflect historical biases, which means they can perpetuate existing inequalities rather than dismantle them (Lemieux, 2023). The integration of AI into science education must be critically examined to ensure that it does not deepen existing disparities but rather democratizes access to scientific knowledge (Park et al., 2023). As science education becomes increasingly dependent on technology, it is crucial to address systematic inequities to create an inclusive and just learning environment. Through recognizing the ways in which traditional power structures operate in science education, we can implement strategies to disrupt these hierarchies and promote equity.

Science education has long been dominated by Western perspectives, shaping what is considered valid scientific knowledge (De Jong, 2007). Historically, scientific discoveries from non-Western cultures have been marginalized or appropriated without proper recognition (Andresen, 1999; Khalid & Ting, 2025). The gatekeeping of scientific publishing, where prestigious journals and institutions control what research is legitimized, has further reinforced these disparities (Siler et al., 2014). Likewise, standardized curricula often exclude contributions from underrepresented groups, framing science as a field primarily advanced by Western male scientists (Sullivan et al., 2018). These power structures are reflected in academia, where access to advanced research opportunities, funding, and mentorship often depends on networks that favor historically privileged groups (Mukhopadhyay, 2019). The lack of representation in science education contributes to a cycle where students from marginalized communities struggle to see themselves in scientific fields, limiting diversity and innovation (Jones, 2022).

The persistent barriers to equitable science education are deeply rooted in systematic inequalities related to race, gender, and socioeconomic status (Vindigni, 2024). Many marginalized students lack access to high-quality STEM education due to underfunded schools, outdated resources, and a shortage of trained educators (Talaue, 2014). Schools in low-income communities often have fewer advanced placement courses, outdated laboratory equipment, and limited access to technology, which prevents students from gaining hands-on experience in scientific exploration. STEM education in low-income communities remains hindered by systemic inequities, limiting opportunities for underrepresented students. With fewer advanced courses, outdated laboratories, and restricted technologies, they lack hands-on scientific experience (Talaue, 2014). As nations debate science versus science for elites, marginalized students face academic penalties due to socioeconomic barriers (Whitcomb et al., 2021). These disparities, compounded with institutional inertia, weaken diversity in STEM fields (Kaggwa et al., 2023), underscoring the urgent need for equitable policies that foster inclusion, innovation, and long-term technological process.

Promoting equity in science education requires intentional efforts at multiple levels, from curriculum development to policy implementation. Decolonizing science curricula by integrating diverse perspectives ensures that students see themselves reflected in scientific knowledge (Khalid & Ting, 2025). AI literacy must be incorporated into education to teach students how to critically engage with technology and recognize biases in digital tools (Casal-Otero et al., 2023; Hazari, 2024). Policy makers must prioritize funding for STEM programs in underprivileged schools and ensure that AI resources are accessible to all students, regardless of socioeconomic status. Equitable access to mentorship programs, research opportunities, and hands-on scientific experiences is crucial for fostering diverse participation in STEM fields. (Mukhopadhyay, 2019). Community-driven approaches, such as partnerships between schools, universities, and local organizations, can help bridge resource gaps and provide students with real-world scientific exposure.

Ethical Consideration in AI and Scientific Creativity

Artificial intelligence AI has revolutionized scientific discovery and creativity by automating data analysis, predicting outcomes, and identifying patterns beyond human capability. However, as AI continues to shape scientific thought, that one back ethical concern emerges regarding its responsible use (Akgun & Greenhow, 2021; Kooli, 2023). AI's ability to enhance creativity depends on how it is designed, trained, and applied, raising questions about transparency, accountability, and bias. The reliance on AI in scientific exploration must be carefully managed to prevent the reinforcement of systematic inequalities, intellectual property disputes, and the erosion of human-led inquiry (Al-Zahrani, 2024; Habib et al., 2023). Ethical considerations must be at the forefront of AI development to ensure that it fosters genuine innovation rather than restricting diverse perspectives. Moreover, the rapid advancement of AI challenges traditional notions of originality and authorship in scientific research, necessitating clear policies to protect human creativity and integrity (Salinas-Navarro et al., 2023; Schiel et al., 2023).

AI presents various ethical challenges in scientific creativity, particularly in areas such as bias, fairness, intellectual property, and transparency ((BaHammam, 2023; Lockhart, 2024). Bias in AI-generated scientific knowledge arises from the data used to train models, often reflecting societal inequalities and historical prejudices (Healy, 2023; Modén et al., 2024). If unchecked, these biases can limit the diversity of science inquiry, reinforce dominant perspectives while exclude marginalized voices. Without clear explanations, scientists risk relying on AI generated conclusions without fully comprehending their validity. Accountability becomes complex when AI-driven errors or ethical breaches occur in the research – who should be held responsible? These challenges require robust ethical frameworks and regulatory oversight to ensure that AI supports scientific creativity without compromising fairness and integrity.

AI has significantly influenced scientific thought by accelerating discoveries, streamlining research, and offering novel insights into complex problems. Its ability to process vast datasets and identify correlations that humans may overlook has expanded the scope of scientific inquiry. AI-driven simulations, predictive modelling, and automation of routine tasks have allowed scientists to focus on higher level conceptual thinking (Nie & Chua, 2024). However, while AI enhances efficiency, it also raises concerns about limiting originality. AI often reinforces existing knowledge structures by drawing from historical data, potentially hindering groundbreaking discoveries that challenge established theories (Schiel et al., 2023). Moreover, AI's pattern-recognition capabilities may lead researchers to prioritize data-driven approaches over theoretical innovation, reducing the role of human intuition in scientific breakthroughs. There is also a risk that overreliance on AI could diminish the development of critical thinking skills, as scientists may accept AI-generated findings without rigorous scrutiny (Al-Zahrani, 2024; Habib et al., 2023).

Bias in AI is a major ethical concern that affects scientific innovation by reinforcing existing disparities and excluding marginalized perspectives. AI models learn from historical datasets, which often contain biases related to race, gender, geography, and socio-economic status (Cooper & Tang, 2024; Eden et al., 2024). As a result, AI generated scientific knowledge may disproportionately reflect dominant perspectives, overlooking alternative viewpoints and diverse experiences (Khalid & Ting, 2025). For instance, AI-driven medical research has been criticized for underrepresenting data from non-Western populations, leading to inaccuracies in diagnoses and treatments for marginalized groups. This exclusion perpetuates systematic inequalities, limiting the contributions of underrepresented communities in scientific advancements. To address this issue, scientists and policymakers must ensure diverse data representation, develop bias-detection mechanisms, and implement ethical AI guidelines that promote inclusivity. Furthermore, AI developers should collaborate with underrepresented groups to create technology that reflects diverse scientific needs and perspectives.

Scientists and educators play a crucial role in ensuring ethical AI use in scientific creativity by fostering AI literacy, promoting responsible research practices, and advocating for ethical policies (Resnik & Hosseini, 2024). AI literacy must become an integral part of stem education, equipping students with the skills to critically analyze AI-generated information and recognized biases (Casal-Otero et al., 2023; Hazari, 2024). Educators should emphasize the importance of human oversight in AI-assisted discoveries, encouraging students to question and validate AI outputs rather than passively accepting them (Fu & Weng, 2024). Scientists, on the other hand, must adhere to ethical research principles by ensuring transparency in AI methodologies and addressing potential biases in their work.

Ethical considerations in AI-driven scientific creativity are essential to ensure responsible innovation, fairness, and inclusivity. While AI offers immense potential for accelerating discoveries and enhancing creativity, it also presents significant ethical challenges, including bias, transparency, and intellectual property concerns. Without proper oversight, AI risks reinforcing inequalities, limiting originality, and reducing the role of critical human thinking in scientific inquiry. Therefore, scientists, educators, policymakers, and AI developers must collaborate to establish ethical guidelines that balance technological advancements with responsible use.

Conclusion

The integration of Generative AI in science education presents both opportunities and challenges. While it enhances instructions, personalization, and efficiency, it can also constrain scientific creativity and further inequities when access, bias, and agency were overlooked. Ensuring that GenAI serves as a tool for empowerment requires intentional, justice-oriented pedagogies and ethical implementation. Through promoting equitable access and supporting creative inquiry, educators can harness AI to enrich, not replace, human ingenuity in scientific learning.

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