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Knowledge Management in Organisations

19th International Conference, KMO 2025
Kota Kinabalu, Malaysia, August 4–7, 2025
Proceedings, Part I

Part 1

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Lorna Uden · I-Hsien Ting
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Knowledge Management in Organisations

19th International Conference, KMO 2025 Kota Kinabalu, Malaysia, August 4–7, 2025 Proceedings, Part I

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Preface

The 19th International Conference on Knowledge Management in Organisations (KMO2025) - Generative AI and Knowledge Management: Innovations, Challenges, and Future Directions was held at Universiti Malaysia Sabah, Kota Kinabalu Sabah, Malaysia from 4–7 August 2025.

The conference was preceded by one day of free tutorials for participants who wished to learn the state of the art of research relating to the topics of KMO and LTEC. The tutorials were held on the 4th of August 2025. The conference itself commenced on the 5th of August 2025.

Generative AI is a powerful subset of artificial intelligence that leverages machine learning models, such as transformers and large language models, to create new content. This can include text, images, code, and other creative outputs. Knowledge management, on the other hand, involves the systematic approach of capturing, organizing, sharing, and effectively utilizing knowledge within an organization.

The convergence of these two fields has great implications for organizations. These include enhanced productivity; Improved Knowledge Access; Real-Time Knowledge Updating and Challenges.

This KMO conference aimed to bring together academics, practitioners, and industry leaders to discuss and share insights on the intersection of generative AI and KM. It focused on current advancements, applications, and challenges, and future research opportunities. This conference provided an interdisciplinary platform for researchers, practitioners, and educators to present and discuss their most recent work, trends, innovation, and concerns as well as practical challenges encountered and solutions adopted in the fields of Knowledge Management and generative AI.

These two proceedings volumes comprise forty-two papers covering various aspects of Knowledge Management. All published papers underwent a rigorous review process involving at least four reviewers. Authors of these papers come from 22 different countries including Austria, Bangladesh, Chile, China, Finland, Germany, India, Japan, Latvia, Malaysia, Nigeria, Philippines, Poland, Saudi Arabia, Slovakia, Slovenia, South Africa, Taiwan, Thailand, Turkey, United Arab Emirates, and United Kingdom.

The papers are organised into the following topics:

- Knowledge Transfer & Sharing
- Knowledge in Business & Organization
- Innovation & Knowledge Creation
- KM and Education
- KM Process and Model
- Information & Knowledge Management Systems
- AI, IT, & New Trends in KM
- Health Care

Besides the papers, we also had invited keynote speakers and tutorials. We would like to thank our authors, reviewers, and program committee for their contributions

and Universiti Malaysia Sabah, Malaysia for hosting the conference. Special thanks to the authors and participants at the conference. Without their efforts, there would be no conference or proceedings.

We hope that these proceedings will become a useful reference tool and that the information in this volume will be used to further advancements in both research and industry in Knowledge Management.

Welcome to the 19th KMO conference in Sabah, Malaysia.

August 2025

Lorna Uden
I-Hsien Ting

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Knowledge Transfer and Sharing

Knowledge Representation and Reasoning for Pharmaceutical Packaging Compliance: A Preliminary Study

Amalia Mukhlas[1(✉)], Shahrinaz Ismail[2], Bazilah A. Talip[1], and Jawahir Che Mustapha[1(✉)]

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Abstract. Product quality, safety, and regulatory compliance are essential in pharmaceutical packaging. This study proposes a conceptual framework that integrates a structured Knowledge Repository (KR) with Knowledge Representation and Reasoning (KRR) to enhance compliance management through intelligent reasoning, decision-making and optimisation in pharmaceutical packaging. Future research should focus on practical implementation and explore IoT, machine learning and blockchain to enhance reliability, efficiency, and regulatory adherence in pharmaceutical packaging operations.

Keywords: Knowledge Representation and Reasoning · Centralised Knowledge Repository · Regulatory Compliance · Pharmaceutical Packaging Technology

1 Introduction

The pharmaceutical industry plays an important role in the development, manufacturing, and distribution of healthcare products and medicine. The quality of products and compliance are crucial for maintaining a company's reputation, credibility and adherence to regulations. Several key factors influence the efficiency of pharmaceutical production and the packaging process such as the continuous manufacturing process, packaging technology, the technology used by the company, and regulatory compliance which are important for product stability, safety, and market readiness. However, challenges to maintaining regulatory compliance continue in the production and packaging process. The pharmaceutical companies need to search for ways to solve the obstacles. The inability to solve the obstacles could result in subpar performance across all areas [1]. Hence, this research objective is to develop a Knowledge Representation and Reasoning (KRR) framework to address regulatory compliance challenges in pharmaceutical packaging. The study adopts a qualitative research approach and theoretical exploration as the methodology to propose solutions. A single case study from a local pharmaceutical

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company is used to understand the process of pharmaceutical production and packaging. A case study approach was deemed suitable for in-depth exploration of regulatory compliance in pharmaceutical packaging. This approach allows in-depth research on best technology to propose for improving compliance process, practitioner perspectives and ensure suggested framework is applicable in the actual industry setting. This is also suitable to establish a ground concept that is later to be tested empirically in future studies. To meet the study's objectives, this study is guided by research questions, namely what are the components of KRR and how is the integration of KRR and technology in regulatory compliance involving pharmaceutical packaging? This study is divided into several sections. The next section discusses the background of this study, followed by the methodology used for data collection and a discussion of findings. Section 5 discusses the proposed solutions, followed by a conclusion and future recommendations.

2 Background: KRR in Pharmaceutical Packaging

The ***pharmaceutical industry's production and packaging processes*** ensure the safe development and distribution of drugs. Production of pharmaceuticals takes place in specialized facilities built to comply with regulations, operational efficiency and contamination control. The steps include dispensing, granulating, compressing, and packing and testing follow the current Good Manufacturing Practices (cGMP) to guaranteeing product quality and adherence to safety regulations [2]. Pharmaceutical production and packaging face challenges that impact safety, integrity, and marketability. Several studies have investigated the importance of adhering to regulatory guidelines related to packaging materials and leachable testing which is important for safety and market withdrawal [3]. Material selection plays an important role in maintaining the stability and integrity of the products during storage and transportation. For example, Chatterjee (2024) emphasised that pharmaceutical items' stability and integrity throughout storage and transportation must be preserved by their packaging. Moreover, the characteristics of the drug and the requirement for stability during storage and transportation influence the selection of packaging materials [4]. While generic formulations often rely on existing reference products, new compounds demand a thorough assessment of degradation pathways to choose the best packaging [5]. In addition to material considerations, market and compliance face challenges. Packaging must increase marketability while guarantee regulatory compliance, which makes the design and production process more difficult [6]. Furthermore, pharmaceutical packaging is made even more complex by the requirement for visually appealing packaging that conveys crucial information [7]. A study by Mukhlas et al. (2024) highlighted the technology used in pharmaceutical packaging operations serves to automate the packaging process, reduce human error, increase productivity, and guarantee the efficacy, safety and quality of medications.

Knowledge Reasoning and Representation (KRR) is an area in artificial intelligence (AI) that focuses on how knowledge can be effectively represented and reasoned within computer systems [9], how to represent information in a structured format for computer system to reason and solve problems through logic and rules to make machines recognize and utilize knowledge effectively [10, 11]. This involves the development of methods and techniques to organise, manipulate, and infer knowledge, enabling intelligent systems

to make decisions and provide explanations [12]. The field encompasses various techniques and approaches, each with its strengths and applications across different domains [13]. Several studies have conducted research on KRR to explore its various aspects, highlighting different methodologies and applications. This involved knowledge graphs and reasoning [14], decision implications in knowledge representation [15], and the commonsense of knowledge representation [16], as well as techniques and methods in KRR [17]. The core elements of KRR include conceptual primitives [16], various representation techniques [17], and reasoning methods [18]. Despite advancements, there are challenges in the complexities of knowledge and reasoning. Traditional methods often overlook the interrelations within knowledge structures, leading to inefficiencies in reasoning processes. Addressing these limitations is crucial for the development of sophisticated AI systems. While significant progress has been made in knowledge representation and reasoning, ongoing research is essential to overcome existing challenges and enhance the capabilities of AI systems [12]. Knowledge reasoning and representation in pharmaceuticals are critical for enhancing drug discovery and therapeutic applications. Recent advancements in knowledge representation, particularly through ontologies [19], knowledge graphs [20], and semantics [21] have significantly improved the understanding and application of pharmacotherapy. Knowledge reasoning and representation in pharmaceutical packaging are critical for ensuring product efficacy, safety, and compliance with regulatory standards. The integration of advanced methodologies, such as artificial intelligence and ontology-based approaches, enhances the understanding and management of packaging processes. KRR in pharmaceutical packaging has been researched in the knowledge extraction techniques [22], cost estimation, and knowledge representation [23].

3 Methodology

This qualitative study used semi-structured interviews from two employees of pharmaceutical company in Malaysia, where the regulatory requirements for pharmaceutical packaging are particularly stringent. Hence, the research findings are influenced by an understanding of the practices and challenges. The qualitative approach allow to investigate experiences, viewpoints, and insights of participants about the difficulties and production process of pharmaceutical packaging. The two employees have consented to participate in this one-time interview. They were selected using purposive sampling, had minimum of three years of experience in the packaging operation under strict regulatory compliance standards. The data was collected through semi-structured, face-to-face interview which recorded via Microsoft Teams for transcription purposes. A backup recording device was used during the 60-minute interviews with participant consent to explore the packaging production flow, quality related matters, regulatory challenges and optimization of technology. Afterwards, the researcher was also brought to observe in the production area. This facilitates researchers' comprehension of the drug production process, packaging process, quality control and inspections, and compliance used during manufacture. A simple inductive approach was used for data analysis. It is a method that use detailed readings of raw data to extract concepts, themes or model through researcher's interpretation of the data. The goal of inductive approach is to build

research findings from frequent, dominant or significant themes in raw data [24]. This means, the researcher starts from raw data like the interview transcripts and observation and identifies the patterns, themes or categories that appeared from the data. The initial step for the researcher include verbatim transcription of the interview recordings. The researcher iteratively examined the transcribed data to comprehend the process flow, production flow and to identify technological and manual process. The key points of the process flow, technology involvement, automated systems, manual process, manual operations, compliance, and regulatory body were highlighted. The findings from observations were mapped to the technology involvement, automated systems, manual task performed and compliance. The figure below simplify the process of data analysis described for this study (Fig. 1).

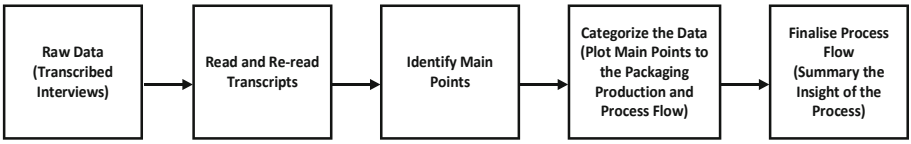

Fig. 1. Data analysis process

4 Findings

This study identified key stages of production and packing activities through interview analysis. The participants provided systematic responses allowing the data to be categorised into material qualification, production, validation, and distribution. This helped to comprehend the entire manufacturing and packaging process from start to finish. The findings were systematically integrated into the proposed KRR framework. Figure 2 shows the summary of the main flow of production and packaging process for the pharmaceutical company.

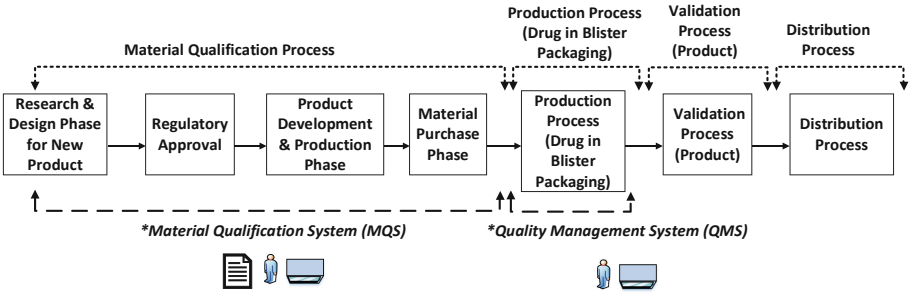

Fig. 2. General Process Flow of Pharmaceutical Production and Packaging

The material qualification process is the process of new product development that materials used meet the required quality standards to make sure the materials are suitable

for use by the customers. The materials for new products must be approved by the regulatory body before allowing the pharmaceutical company to release the new product. This phase is divided into several stages, such as the new product development by research and design (R&D) teams, regulatory approval, the product development and production phase, and the acquisition of materials. This is followed by the production process of the drug in the blister packaging and process validation. The production process of a drug in blister packaging is the process of packaging the drug in the blister packaging. Once the drug is packed in the blister packaging, the validation process takes place to validate the product prior distribute it to the customer, which is the company that bought the product.

The study also identifies the role of technologies in the production and packaging process. Nevertheless, technology does not entirely automate the production and packaging process. Not every section is entirely automated or uses technology to interact. Some aspects of the production and packaging process, such as the batch record system and the material qualification system, still rely on manual record keeping. Blister packaging also necessitates a manual procedure or offline in certain situations for the small batch of medications to be produced. Given the small number of tablets that must be produced, it is argued that offline operations are more suitable to provide room for tablets that are required to be produced in greater quantities utilizing online machinery. Additionally, some machines assist with certain tasks like testing. These machines have a history log that is used to reconcile operations with the documentation required for quality and inspection purposes. However, these machines operate independently and are not connected to centralized network.

The findings of this study demonstrated that the use of technology facilitates compliance. Technology like the camera inspection system on the blister packaging machine, which can assist in examining blister packaging, identifying tablet damage, and identifying tablets that cannot be placed into blister packaging, are examples of this. Technology like camera inspection systems can eliminate human error, expedite the packaging inspection process, and save costs by improving operational efficiency.

Nevertheless, the technology is used sparingly only to fulfill the company's operating requirements and it is not connected. The production process and packaging operations continue to lag in the use of cutting-edge technologies like blockchain, artificial intelligence, and the Internet of Things (IoT). This demonstrates clearly that the technology currently in use is only utilized to support company activities. This is due to cost, readiness, and other requirements that need to be prioritized by the company, apart from using advanced technology to support production operations and packaging processes. The business does not leverage advanced technology to obtain additional benefits including traceability, process optimization, predictive maintenance, and the capacity to automatically capture and store data for regulatory compliance purposes. Technology advancements have greatly increased the industrial productivity of pharmaceuticals yet there have been difficulties in implementing new technology [8]. Based on the findings, this study anticipated a solution and discuss it in the next section.

5 The Proposed KRR Solution

The proposed framework established upon knowledge management techniques incorporated the AI-based reasoning for regulatory compliance. It is designed to fill the current gaps in packaging process and regulatory compliance by leveraging KRR. The framework was developed upon findings from the interview and theoretical research, ensuring practical implementation feasibility.

KRR is a fundamental area in artificial intelligence that focuses on how knowledge can represented effectively and manipulated to enable reasoning in computer systems [11, 25] The study on KRR has evolved along with the development of AI, covering various topics including knowledge representation languages, rule-based systems, case-based or commonsense reasoning, spatial or temporal reasoning, action models, and handling uncertainties and beliefs [26]. The framework encompasses various techniques and methodologies like rule-based systems and logic, ontologies and semantic networks, and causal representation that facilitate the understanding and application. These techniques have been applied in many areas such as healthcare, agriculture, and education, demonstrating their versatility and effectiveness in solving complex problems [17]. The KRR effectiveness depends not only on the framework but also on the quality and structure of the data it process. Data acquisition is an important step that involves collecting, filtering, and structuring raw data prior to use by reasoning and decision- making. Data acquisition is visualized as a process of capturing data from various sources [27]. As shown in Fig. 3, the data acquisition phase in the machine learning process is important to ensure that important, high-quality data is accesses for knowledge processing [28]. It involves collecting real-time information from the database, devices, and systems which then proceed to ensure standardised data format, validation of entries, and successful data conversion. The stage then moves to ingestion to store the data in a semantic knowledge structure to capture the relationship between entities and processes. Finally, the reasoning is applied to analyse the data for predictive insights, and generate reports or visualizations.

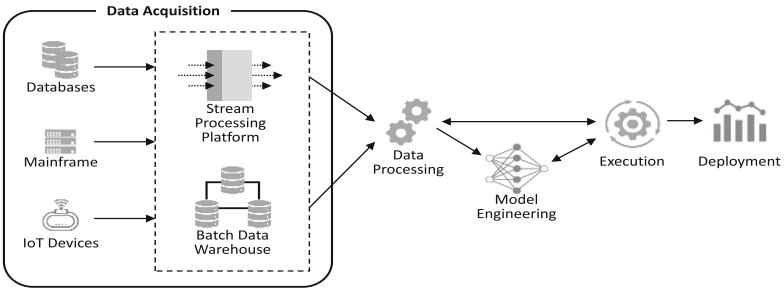

Fig. 3. Data acquisition in machine learning workflow (adapted from Seth, 2021)

The insights from Seth, (2021) data acquisition serve as the base for the proposed solution. This extends these principles by incorporating the knowledge repository into the knowledge representation and reasoning. The figure below depicts the overview of the improve approach.

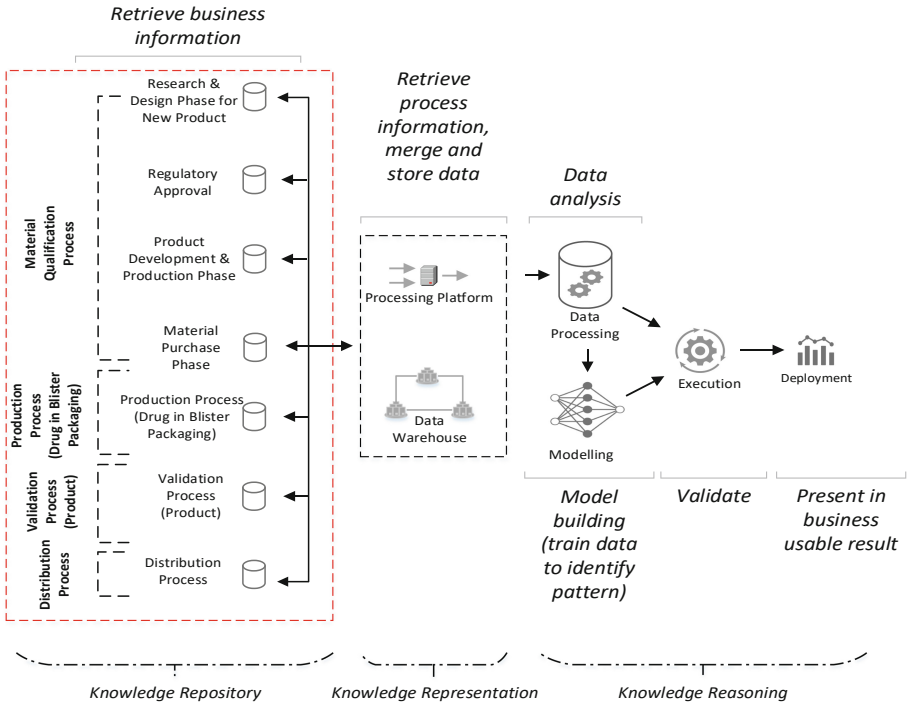

Fig. 4. Proposed solution of Knowledge Representation and Reasoning

Figure 4 summarises the researcher's proposed solution of a Knowledge-Based System utilizing Knowledge Representation and Reasoning to enhance data driven approach. The proposal was made after the researcher examined the data collected from the results of the interview activity with participants. There are three sections or components that comprise the diagram which are the Knowledge Repository, Knowledge Representation, and Knowledge Reasoning. The main feature of the diagram is to highlight the integration of data, knowledge, and the way the knowledge is represented and reasoned.

The initial section, Knowledge Repository (KR1) focuses on storing and retrieving business information related to sequential processes for product development. It serves as a centralized store of expert insights, best practices, and organisational knowledge. Knowledge repository is an important resource in setting knowledge management into practice especially in in the manufacturing and academic industries as the biggest asset to manage the product knowledge [29]. It serves as an organisation's memory where habits, history, business practices, human knowledge, and other information are stored [30]. The stored knowledge is important throughout the process which starts with research and design for the new product, followed by regulatory approval, product development and production phase, material purchase, production process, process validation, and distribution. This is the linear and systematic flow for bringing the product from concept to the market. KR1 consists of seven data storage parts for each phase segment. This is to satisfy each section's requirement for a database of its own to methodically store

data in each phase. This aligns with the definition of a knowledge repository designed to capture, store, and disseminate relevant knowledge throughout an organisation [31], and is often used to disseminate best practices among workers and is expected to improve organisational efficiency [32] that is organisations' productivity, flexibility, and innovativeness by enabling organisational members to share, integrate and reuse knowledge more effectively [33]. Knowledge Repository System is a system created for specific purposes of certain organisations or companies [29]. As for this study, a knowledge repository is a centralized online database that stores knowledge and information from an organisation that has been carefully collected, organised, and kept for authorized users to easily access and retrieve. A knowledge repository, which might contain documentation, protocols, expertise, and best practices, essentially acts as a central location for crucial information inside a company or community.

The second section, Knowledge Representation (KR2) provides methods for representation and automation using resources that explicitly describe entities like people, facilities, and organisations, as well as relationships. It improves document search and information retrieval by integrating descriptive ontologies, which allow querying based on any entity property [34]. This phase involves retrieving process-related information, merging data, and process-related information systematically. A structured data collection process ensures all information is fed into a central processing platform and data warehouse for efficient storage and management. Integrate descriptive ontologies enables the explicit representation of the entities of employee, procedures, facilities and organisations in the relationships. This structured data collection and representation facilitate query based on entity properties which improve document search, information retrieval and the automation capabilities within the system.

Finally, Knowledge Reasoning (KR3) which part of the Knowledge-Based System together with Knowledge Repository and Knowledge Representation. KR3 represents knowledge to draw inferences, solve problems, and give recommendations. It act like the brain of the system to apply the logical rules, inferences, and reasoning mechanism to derive insights and support decision-making. At this stage, the data undergoes analysis for valuable insights. The insights inform the modeling process where data is trained to build predictive or simulation models. The models are then evaluated and the results are presented in a business-useful style for process optimization and data-driven decision-making.

The combination of KR and KRR in this study gives a structured approach of how pharmaceutical company can manage and utilize the information for proactive and intelligent decision-making. Both are important in their specific role as KR ensures systematic data storage and retrieval while the KRR enables automated reasoning, generate inference, decision-making and problem-solving. The integration of KR and KRR improves operational efficiency, supports data-driven decision-making, and enhances regulatory compliance. As supported by Yu et al. (2023), KRR advantage is the ability to represent complex knowledge using logic, which can enhance the learning efficiency and performance in models. A study of Delgrande et al. (2023) discuss many advantages and strength of KRR such as contribution to information systems, machine learning, reasoning based in incomplete information and etc. However, despite the benefits KRR methods are very difficult to represent knowledge in domains of reality applications, because the

complicated of knowledge domain [18]. This is relevant to this study as pharmaceutical packaging involves many data sources, complex regulatory rules, compliance, and standards. Overcoming the challenges needs a well-structured knowledge model, ontologies that are specific to the domains, and reasoning techniques to improve the effectiveness of the current systems. Accordingly, research in KRR focuses on creating a method to signify knowledge in many areas, developing appropriate representation languages, specifying and analyzing reasoning over represented knowledge and employing systems that support the representation of knowledge, and reasoning over the represented knowledge [11].

The proposed solution contributes to a strategic approach through integrating knowledge repository and knowledge representation and reasoning to manage relevant knowledge while supporting reasoning for well-informed decisions in the company to enhance sustainability and processes. Additionally, the integration promotes smooth knowledge transfer, reduce errors and redundancies while supporting company access important data for optimum process and sustainability [35]. AI-driven systems can generate solutions and boost the efficiency of problem-solving approaches through reliable and authentic data from prior knowledge [29]. As supported by Gelfond & Kahl, (2014), systems support the ability to make decisions, and solve complex computational problems through logic and probabilistic formalism. Additionally, integrating centralized knowledge repository and an AI-driven systems like knowledge representation and reasoning can learn from experience and adapt dynamically. In real-world applications, the neural-symbolic approach enhances flexibility and reasoning skills, making it simpler to represent and compute symbolic knowledge [36]. Hence, the application of current knowledge offers several benefits to the company such as shortening time and cost, preventing duplication of development, lessening repetitive tasks, deepening and expanding experience, reducing training time, and accelerating work [37].

Although there are advantages from the enhancement, challenges occur in managing the complexity of knowledge representation and ensuring data consistency for the effectiveness of the systems. Additionally, it is challenging for the company to decide on the hardware and software to create the knowledge repository systems that fits to the specific features and functions while provide good mapping of the knowledge management functionality [29]. This is supported by Rall (2021) that many obstacles in the process of a creating knowledge repository like unclear goals, incorrect data, poor information sharing, and failure to update the knowledge stored.

6 Conclusion

This study proposed KRR framework to improve regulatory compliance in pharmaceutical packaging. The framework combines structured knowledge repositories with AI-driven reasoning to optimize compliance monitoring by integrate database, machines and systems for efficient management and decision-making. However, the conceptual framework has not been tested in actual environments. Therefore, future study should focus on actual implementation of this conceptual framework for empirical evaluation in its effectiveness in improving compliance process. By expand the model with advance technologies as IoT for real-time data acquisition, machine learning for adaptive compliance monitoring can develop practical application and blockchain technology for

data security and transparency. The outcome of this study provide the basis for advance intelligent compliance systems in highly regulated industries to facilitate efficient and transparent decision-making process in pharmaceutical packaging.

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Impact of Knowledge Sharing in Project Management

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Abstract. Knowledge is widely recognized as a source of competitive advantage for project teams and organizations, but its value depends on effective management and sharing. While project management is well-defined, knowledge sharing practices within the context of project management remain inconsistent, limiting their impact. This study assesses the role of knowledge sharing in project management and explores ways to enhance its effectiveness. A mixed-method approach was used to collect quantitative and qualitative data from project and knowledge workers. An online questionnaire gathered insights from 53 participants, revealing that while project teams understand the importance of knowledge sharing, management buy-in remains limited. As a result, knowledge sharing efforts are deprioritized in favour of immediate business value. Key challenges include insufficient time and budget for maintaining knowledge repositories, leading to repeated project mistakes and unnecessary rework. Findings from this research informed the development of a conceptual framework based on the SECI model by Nonaka et al., offering structured guidance for integrating knowledge-sharing into project management. By addressing these barriers, organizations can improve project outcomes, minimize inefficiencies, and enhance long-term knowledge retention, ultimately strengthening their competitive edge.

Keywords: Project Management · Knowledge Sharing · Knowledge Management

1 Introduction

Riis and Eskerod [1] define knowledge as information, expertise and ideas that individuals, project teams and organisations can use to perform tasks. Knowledge sources include "past experiences, expertise, proficiency, competence, skills, capabilities and embedded knowledge of all kinds", which, only when combined and integrated with each other, provide knowledge that is meaningful and useful [2: p. 238]. This accumulation of experience and capabilities is an iterative process and the sharing of this accumulated knowledge and wisdom can be enabled through participation in projects [2].

Ali et al. [3] describe four distinct processes within knowledge management (KM) that make it usable and transferable between projects. The first is knowledge acquisition,

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which involves identifying and collecting relevant information and knowledge that might be critical to a project's success [3]. The next process is knowledge assimilation, which analyses, processes and interprets knowledge so that it may support the objectives of the project [3]. The third process is knowledge transformation, which combines new and existing knowledge to identify opportunities for improvement [3]. Lastly, the process of knowledge exploitation involves using the insights gained from the new knowledge and improvement opportunities identified to support the objectives of the current project [3].

Projects are work packages that are organized around specific tasks which have specific deliverables [2]. Project managers should concern themselves with the management of knowledge-sharing between teams and knowledge workers through collaboration [4], since expertise and experience are difficult to codify. This implies that the interaction of individuals is a critical success factor of effective KM, as the utility of knowledge can only be realized through this interaction and the creation of social networks [4]. Social interaction enables effective knowledge-sharing, as it creates a shared goal and makes knowledge-sharing efforts more intentional [5]. Project managers should therefore plan how to share knowledge accumulated in one project with future and concurrent projects, as well as how to enhance communication between projects so that this sharing takes place more frequently [1]. Creating such a knowledge-based network of partners is fundamental to sustaining competitive advantage in an organisation [2].

The importance of social interaction as a means for knowledge-sharing is in contrast to the technical aspects involved in KM, and organisations stress the importance of codifying knowledge through technological means [5]. However, too much focus on information systems as a means to manage and share knowledge could inhibit the productivity and ability of knowledge workers to create new knowledge in order to sustain competitive advantages for an organisation [5]. Therefore, there needs to be a greater emphasis on the knowledge needs of projects and creating and sharing relevant knowledge, rather than spending time on codifying as much knowledge as possible that might not be used [5]. The increased volume of data, information and knowledge that has been brought about by digitalization and increased reliance on internet-based systems, makes the management of knowledge a necessity for organisations to be competitive [6]. Specifically, KM in information technology and telecommunications projects is particularly challenging due to the flood of information sources and the difficulties in discerning only the most relevant and valuable knowledge [6].

Therefore, the main research question that is explored is: *what is the impact of knowledge-sharing in project management?* By exploring this research problem, insights into the utilization of knowledge-sharing activities and practices in a project management setting are evaluated, and the impact of knowledge-sharing on project success is assessed.

2 Background

The challenge of KM in projects is the temporary nature of projects, which makes the objectives and deliverables of the projects a priority over developing knowledge-sharing channels while still delivering business value [7]. The purpose of a project is to deliver some value to the business, so dedicating additional time and resources to developing knowledge-sharing channels is not viable [8]. In the next sections we consider

the principles of PM, an overview of knowledge and KM, and knowledge-sharing aspects in PM.

2.1 Principles of Project Management

According to the Project Management Institute [9], the purpose of PM is to effectively and efficiently conduct project activities that meet project requirements. This is achieved by applying and integrating the prescribed processes, knowledge, skills, tools and techniques. The advantages to be gained by projects that follow these guidelines include meeting business objectives and stakeholder expectations, quickly responding to risks and constraints, effectively managing change, and identifying projects that are failing so that resources are not wasted [9]. The core of PM is to manage the organisation of highly unique, temporary tasks to deliver a product or service [10]. PM therefore addresses issues of coordination, control and governance of this work – control being most critical due to the high risk and uncertainty surrounding projects. Should projects be executed without the guidelines of PM, they face the possibility of missing deadlines and objectives, overrunning costs, mismanaging scope and quality, and being forced to rework project outputs because they do not satisfy stakeholders [10].

The Project Management Body of Knowledge (PMBOK) outlines ten knowledge areas which set out the processes to be undertaken throughout the duration of a project, from initiation to execution to closure. These knowledge areas include project-integration, scope, schedule, cost, quality, resource, communications, risk, procurement, and stakeholder management [9].

2.2 Overview of Knowledge and Knowledge-Sharing

Before discussing the concept of knowledge-sharing and its constituents, it is necessary to provide a definition of what knowledge is. According to Davenport and Prusak [11], knowledge can be defined as the dynamic combination of values, contextualized experiences and information, and insights that can be used to contextualize new experiences and information within an individual's current knowledge base. It is derived from information and exists within the minds of individuals, and it can become embedded in organisational repositories, processes, and practices. This would suggest that knowledge requires some sort of human action and interaction, be it with codified information or person-to-person contact [11].

Nonaka et al. [12] discuss the existence of two knowledge types, namely, explicit knowledge and tacit knowledge. They describe explicit knowledge as being formal and systematic and expressed in written language or data. Knowledge in this form is processable, transmittable and storable. Tacit knowledge on the other hand is difficult to codify and primarily takes the form of subjective insights, values and ideals [12]. Fernie et al. [4] describe these differences in knowledge types by making the distinction between types of knowledge assets. They suggest that knowledge assets can either be easily codified (explicit) or context-dependent and difficult to formalize and communicate (tacit). Tacit knowledge, which primarily lives in the minds of individuals, can be transformed into explicit knowledge through manual capture or codification into knowledge repositories [4]. In knowledge-intensive organisations, transforming tacit knowledge into explicit

formats is especially important [2], as sharing knowledge in its unstructured, tacit form is a challenge [13].

Knowledge that is not accessible is of little use to organisations and therefore the need for knowledge-management practices has become more apparent over time [11]. Knowledge-sharing is an essential part of KM [13, 14], which can improve organisation performance and provide a competitive advantage. Knowledge is a unique, yet powerful asset, which transforms individual learning into organisation capabilities [7, 10].

The interactions between explicit and tacit knowledge are what creates new knowledge. To further explore how knowledge can be created and shared through the conversion of tacit knowledge into explicit knowledge and vice versa, Nonaka et al. [12] formulated the Socialization, Externalization, Combination and Internalization (SECI) model. In their work, they distinguish between the knowledge-creation processes of socialization, externalization, combination and internalization [12]. Socialization involves converting existing tacit knowledge into new tacit knowledge through sharing experiences and empathizing, apprenticeships, informal social settings or meetings, and interactions between those internal and external to an organization [12]. Externalization comprises those practices needed for articulating or transforming tacit knowledge into explicit knowledge through codification and the manual capture of ideas and experiences into physical or digital formats and models [12]. This knowledge then becomes the basis of new knowledge which can then be internalized. Combination involves connecting different sources of explicit knowledge together to create more complex knowledge, which can then be disseminated and applied to new contexts, much in the way that business reporting pulls data from all over an organisation and presents it in an operationalized, concise way for decision-making [12]. Internalization is the conversion or embodying of explicit knowledge into tacit knowledge, which then allows for action based on the newly internalized knowledge as it expands the individual's knowledge base [12]. The SECI model illustrates that the knowledge-conversion process happens in a spiral, with each repetition of the cycle adding onto previous knowledge and growing the individual's and organization's knowledge base (refer Fig. 1: SECI model).

2.3 Knowledge-Sharing Aspects in Project Management

Although knowledge-sharing is not defined as one of the key principles of PM, the Project Management Institute [9] does provide guidance for project-knowledge management, stating that it is the process of creating and using knowledge throughout the duration of a project, so it achieves its objectives and adds to the learning of the organisation or, more specifically, "Knowledge management is about making sure the skills, experience, and expertise of the project team and other stakeholders are used before, during, and after the project" [9]. The benefit of using KM is that project outcomes can be improved by integrating knowledge artefacts into product and service delivery [2], and it can support future projects and organisational operations. However, because knowledge lives in people's minds, it is crucial that an atmosphere of trust is created for the project team so that members are motivated and encouraged to share their knowledge so that it may be effectively managed. Knowledge-sharing can improve the quality of the project's execution and outcomes and increase the knowledge-learning ability between projects [10, 15]. According to the Project Management Institute [9], project managers and their

project teams should decide on the best combination of tools and techniques for KM and sharing, considering their unique context. Riis and Eskerod [1] suggest that knowledge-sharing is easier when there is a common understanding of PM, which needs to be supported by knowledge integration efforts.

Bresnen et al. [8] presented a case study from the construction industry, which is primarily project-oriented, and observed that social forms of knowledge-sharing are most often used in projects. Therefore, focusing on interpersonal and social aspects like having a shared vision of the role that knowledge and learning plays in project success, as well as establishing norms around such sharing, are critical to the success of knowledge-sharing efforts [8]. In fact, Ali et al. [3] suggest that the knowledge-management process for projects begins with establishing knowledge-based goals. For knowledge-sharing to be successful, the project team must have the shared vision or goal of 'solving problems' which will encourage them to get involved and engage with each other, thereby empowering them to create a culture of knowledge-sharing across all levels of experience [5]. Furthermore, team members need to act as knowledge brokers by connecting their personal networks, which provide them access to even more knowledge, to the projects they are engaged in and take these learnings to new projects [8]. The importance of the social dimension of knowledge-sharing is further emphasized by Ali et al. [3] as the results of their research indicated that projects that engage in a high level of social processes and interactions have a greater probability of retaining knowledge through knowledge-sharing.

While socialization has widely been accepted as a mechanism for knowledge-sharing, the various types of social interactions and their efficacy must be explored [4]. To address the evaluation of social interactions, Riis and Eskerod [1] presented research conducted on five Danish companies that were investing in creating and sustaining social processes used to enhance the sharing of knowledge. They concluded that the most popular knowledge-sharing activities that organisations employed in their knowledge-management strategies included lessons learned, communities of practice, lunch-and-learns, and coaching and mentoring.

3 Research Methodology

The aim of this study was to investigate, using a mixed-methods approach, the extent to which knowledge sharing enhances project success [16]. The sampling for data collection and analysis involved selecting a target population, which included all project and/or knowledge workers in our academic and professional network who (1) had experience with knowledge-sharing and project management practices, and (2) were willing and able to participate in the study. Random and self-selection sampling were used as it gave everyone with the specified experience an equal chance to participate and accessed the link to the online questionnaire [17, 18]. The online questionnaire comprised three sections through which demographic, content-specific and open-ended responses were collected. A combination of free text, Likert scale [19] and multiple-choice formats were used. Prior to data collection, the questionnaire was vetted through an academic professional and a project-team member. Their inputs assisted in refining and adding questions which were not originally included. Data analysis involved various different

approaches as data of a quantitative and qualitative nature were collected. The analysis of quantitative data involved tallying and tabulating the responses for each question and also involved the calculation of the mean, mode and median responses, as well as the standard deviation for Likert-type statement questions. Qualitative data were analyzed through the use of thematic analysis which was used to identify thematic threads and patterns [17].

4 Findings and Discussion

In the content-specific section of the questionnaire free text fields where participants were asked to share their understanding of concepts related to the research topic, were applied. Term frequency is the number of times a word or the most frequent word appears in a document, while inverse document frequency is a calculation of the "total amount of documents divided by the number of documents that contain a word" [20]. In the content-specific section, participants were given a statement and asked to what extent they agreed or disagreed with the statement and were given a five-point Likert scale to provide their answers. These questions were intended to assess the current level of knowledge-sharing within project teams and organisations. The results from these questions are summarized in Table 1.

Four themes were identified through the analysis namely, project management principles (refer Sect. 4.1), the constituents of knowledge-sharing (refer Sect. 4.2), aspects of knowledge-sharing in project management (refer Sect. 4.3) and final general respondent comments (refer Sect. 4.4). Further analysis of each of these is presented in the sections below – incorporating both the quantitative feedback (Table 1) and qualitative feedback.

4.1 The Principles of Project Management

Respondents reflected on their understanding of what PM entails and how they understood the key principles of PM. The most relevant concept for PM is "given constraint", although the term only appeared three times in the captured responses. As the literature has shown, constraints in PM can include scope, quality, schedule, costs, and resources [21]. Other relevant concepts include "desired outcome", "project management", "optimal use of people", "allocated sure resource", "adhered budget constraint", and "defined project objective". A lessons-learned repository is an expected outcome of project teams, as prescribed by PMBOK. According to the analysis, key thoughts from respondents related to lesson-learned repositories.

Two concepts were rated most relevant to lessons-learned repository: "maintained collection of information" and "usually incorporated lesson learnt". The literature has shown that a lessons-learned register is a key outcome of PM and should be "incorporated" in projects during their entire lifecycle. Furthermore, the capture and transfer of this "maintained collection of information" ensures that knowledge is not lost when a project closes [21].

In terms of the Likert scale content section of the questionnaire, respondents were asked questions related to the principles of PM (refer Table 1). The purpose for the question related to the 10 project-management principles (knowledge areas) as set out

in PMBOK, was to verify the validity of this assumption within the context of the participants' experience and knowledge base. The assumption was substantiated through the responses as 64% of participants selected 4 or 5 and therefore agreed or strongly agreed with the statement. The mode response was 4 and these results indicate that, through the many years of experience that each participant has and through the various

Table 1. Questionnaire statement analysis

Please indicate to what extent you agree or disagree with the following statement, where 1 is "strongly disagree" and 5 is "strongly agree"	Strongly disagree (1)		Disagree (2)		Neutral (3)		Agree (4)		Strongly agree (5)		Mean	Mode	Median	Std dev
	#	%	#	%	#	%	#	%	#	%				
I know about the 10 project management principles as set out in PMBOK	3	6%	4	8%	13	25%	17	32%	16	30%	3,74	4	4	1,15
My project team/s document lessons learned throughout the project lifecycle	2	4%	10	19%	13	25%	16	30%	12	23%	3,49	4	4	1,15
My team/s consult the lessons-learned repository as a first resort to challenges	14	26%	16	30%	16	30%	4	8%	3	6%	2,36	2	2	1,13
I have access to an organisational lessons-learned repository	12	23%	13	25%	12	23%	8	15%	8	15%	2,75	2	3	1,37
My team/s consult knowledge repositories when faced with challenges	9	17%	10	19%	13	25%	16	30%	5	9%	2,96	4	3	1,26

(*continued*)

Table 1. (*continued*)

Please indicate to what extent you agree or disagree with the following statement, where 1 is "strongly disagree" and 5 is "strongly agree"	Strongly disagree (1)		Disagree (2)		Neutral (3)		Agree (4)		Strongly agree (5)		Mean	Mode	Median	Std dev
	#	%	#	%	#	%	#	%	#	%				
I know about knowledge sharing tools and practices	2	4%	5	9%	12	23%	18	34%	16	30%	3,77	4	4	1,10
I take part in knowledge sharing activities	0	0%	7	13%	8	15%	22	42%	16	30%	3,89	4	4	0,99
There is a knowledge sharing culture in my team/s	0	0%	3	6%	12	23%	22	42%	16	30%	3,96	4	4	0,88
There is a knowledge sharing culture in my organisation	0	0%	9	17%	15	28%	21	40%	8	15%	3,53	4	4	0,95
I believe that knowledge can be codified	2	4%	5	9%	14	26%	20	38%	12	23%	3,66	4	4	1,06
I believe projects and project teams can benefit from codified knowledge	1	2%	3	6%	12	23%	16	30%	21	40%	4	5	4	1,02

N = 53.

roles they have played in project teams, as revealed in the demographic analysis, they have learned or internalized the principles of PM. A lessons-learned repository is a required outcome of effective PM, and so the purpose of this question was to determine if project teams do in fact adhere to this guideline. The total number of responses for each Likert scale option is presented in Table 1, as well as the mean, mode, median and standard deviation. For this question, 53% of respondents chose option 4 or 5, indicating that they agree or strongly agree, and the mode response was 4. This result suggests that project teams make an active effort to document the lessons they learn through a project's lifecycle, which can then be used by future projects to assist in their

successful completion. Since the assumption was made that project workers who partook in the data-collection process understood knowledge flow within their organisations, it was necessary to test this assumption. This question aimed to determine to what extent lessons-learned repositories are used across the organisation and if they are accessible. The total number of responses for each Likert scale option is presented in Table 1, as well as the mean, mode, median and standard deviation for each response. In contrast to the previous question, only 30% of respondents chose 4 or higher, indicating that they do not agree, with 2 being the mode response. This suggests that, while project teams do document their lessons learned, they are not made available organisation wide.

While it may be understood and accepted by project workers that a lessons-learned repository is an expected outcome of project delivery, and while these repositories may be accessible to project teams, it cannot be assumed that they consult these repositories when faced with challenges. The question whether team/s consult the lessons-learned repository as a first resort to challenges, was asked to ascertain whether lessons-learned repositories are in fact used in practice, as their true value can only be realized once they are consulted for other projects. The results of this question are shown in Table 1, where it is seen that 56% of respondents chose 1 or 2, which shows that most respondents disagree or strongly disagree, with the mode response being 2.

4.2 The Constituents of Knowledge-Sharing

Respondents were asked to share their opinions about knowledge-sharing. The purpose of this question was to assess the participants' understanding of what knowledge sharing is and what it entails. The most relevant concept related to KM is "efficient handling of information". Information without context is meaningless; therefore, efficiently handling information in such a way that it is given context creates knowledge [12], which further needs to be handled or managed efficiently. Other relevant concepts include "available knowledge", "knowledge management", "best use of knowledge", "good knowledge management", "managed knowledge asset", and "improved business initiative".

The aim of this question regarding knowledge sharing was to further explore participants' understanding of KM and assess how they differentiated it with knowledge-sharing. "Exchanged knowledge" was the most relevant concept as it relates to knowledge-sharing. Knowledge-sharing is indeed the exchange of knowledge and experience between people so that they can further expand their own knowledge and ideas. Others concepts highlighted being "best practice" and "knowledge". Knowledge repositories can promote the reusability and sharing of knowledge [5], and this has been shown to improve organisational performance [2]. Respondents were asked to what extent they agree or disagree to the sharing of knowledge through repositories. The responses for each Likert scale option are presented in Table 1, as well as the mean, mode, median and standard deviation for each response. The mode response was 4, indicating that respondents agree with the statement. It should be noted, however, that, while 39% of respondents either agreed or strongly agreed, almost the same amount (36%) either disagreed or strongly disagreed. This makes the median of the responses 3 (neutral) and shows that there is much work to be done in encouraging the creation and utilization of knowledge repositories by project teams.

For knowledge-sharing to become common practice in project teams, they need to be aware of available knowledge-sharing tools and practices. The purpose of this question was to determine whether respondents are aware of the tools and practices necessary to enable knowledge-sharing. The results shown in Table 1 reflect that 64% of respondents agree or strongly agree that they are aware of knowledge-sharing tools and practices, the mode response being 4. While this result is positive, it does not reflect the extent to which these tools and practices are used in project teams.

In the pursuit of continuous improvement, project teams need to actively engage in knowledge-sharing activities, but this is not possible if there is not a knowledge-sharing culture within the team. The purpose of this question was to understand whether the teams that respondents are part of or manage do in fact have a knowledge-sharing culture. In Table 1, it can be seen that 72% of respondents agree or strongly agree that their teams do have such a culture, and the mode response is 4. While an individual project team may have a knowledge-sharing culture, the overall culture within the organisation in which it operates can play a determining factor in whether knowledge-sharing practices are encouraged or neglected in favour of project delivery and performance. This is not to say that focusing on knowledge-sharing activities can impede a project team's ability to deliver business value, but with constrained budgets and timelines, knowledge-sharing could be neglected. In a learning organisation, however, where knowledge-sharing is ingrained in the culture, such practices would be encouraged. This question related to a knowledge sharing culture aimed to establish whether the organisations the participants are employed in do in fact have a knowledge-sharing culture. For this question as depicted in Table 1, the mode response was 4, and 55% of respondents chose option 4 or 5, indicating that they agree or strongly agree with the statement. As the SECI literature has shown, an integral part of the knowledge-sharing process involves transforming tacit knowledge into explicit knowledge through codification or externalization [12]. The purpose of this question was to assess whether there is a belief among project and/or knowledge workers that knowledge can be codified. Table 1 responses reveal that 61% of respondents agree or strongly agree that knowledge can be codified, with the mode response being 4.

After providing insights into the current level of knowledge-sharing in each participants' organisation through the Likert scale questions, we wanted to provide participants with the opportunity to ideate knowledge-codification practices that could assist their organisations in adopting more stringent and purposeful KM and sharing. Responses summarizing the ways in which knowledge can be codified as a standard practice, and these include adopting knowledge-sharing structures, frameworks, processes, practices, tools, strategies, policies and/or systems; creating searchable, central knowledge repositories; adopting a knowledge-sharing culture; sharing the benefits and success stories of knowledge-sharing; stakeholder, management and executive support and buy-in; providing clarity and definition; and providing training. Two respondents did note that, while knowledge bases and codified knowledge were available to them, they were not accessed, and it took too much time for knowledge to be codified.

The most frequent suggestions for making knowledge codification a standard practice in organisations is the adoption of knowledge-sharing structures, frameworks, processes, practices, tools, strategies, policies and/or systems (mentioned 17 times), as well as

creating searchable, central knowledge repositories (mentioned 13 times). These kinds of enabling technologies would require substantial time and resources to establish and would require buy-in at a management and executive level, which was mentioned only 6 times in the collected responses.

4.3 Aspects of Knowledge-Sharing in Project Management

Having established whether project and/or knowledge workers know about knowledge-sharing tools and practices, we wanted to understand whether respondents actively partake in activities through which knowledge can be shared. The aim of this question was to determine how many of the respondents do in fact take part in knowledge-sharing activities. According to the results presented in Table 1, the mode response was 4, and 72% of respondents are involved in such activities, as they indicated that they either agree or strongly agree with the statement.

When asked what knowledge-sharing activities respondents take part in, the majority of respondents (87%) indicated that they partake in mentoring and coaching; 69% said that they partake in communities of practice, and 34% participated in lunch-and-learns. The topic of this research paper is the utilization and impact of knowledge-sharing in PM. We wanted to understand if there was a common belief among participants that codified knowledge could benefit project teams in some way to better understand the impact that such a knowledge-sharing practice could have. Table 1 shows that the mode response was 5, i.e., participants strongly agree that there are benefits to be realized by project teams through knowledge codification. Seventy percent of the responses were 4 or 5, indicating that the majority of the sample population agrees or strongly agrees with this statement.

We asked respondents to reflect on how knowledge-sharing contributed to project success. The purpose of this question was to further understand the impact and potential contributing factors that knowledge-sharing can have on project success, beyond codifying knowledge. Two respondents stated that knowledge-sharing is critical to project success. In contrast, one respondent stated that sharing knowledge does not contribute very much to project success because “people still want to not listen and only care about their own perspectives on how they see things”. One respondent also stated that not all knowledge-sharing is valuable, and some team members may benefit from it more than others. Lastly, one respondent explained that, while personal learnings can help a team, it would be more beneficial if a team could have access to enterprise knowledge and learnings. Of the responses from which a clear benefit could be extracted, there were eight standard benefits, including improving team communication, understanding and maturity; mitigating risks, dependencies, and rework; saving time and money; solving problems; upskilling; improving quality; improving alignment between teams and stakeholders; and improving decision-making. The most frequently mentioned contribution that knowledge-sharing can have from projects and project teams is that it improves a team’s communication, understanding and maturity (mentioned 19 times). Two other responses appeared more than 10 times: mitigating risks, dependencies, and rework (mentioned 15 times) and saving time and money (mentioned 14 times).

4.4 Additional Respondent Comments

To ensure that the participants of this study could capture all their insights and experiences related to the concept of knowledge-sharing in a project-management context, an open-ended question was added as the final section of the questionnaire. Previous qualitative responses have been analyzed and contextualized within the rest of the findings, and so the purpose of analysis here is to identify any contradicting or enriching statements that might support or counter the responses previously captured. There was a consensus among respondents that while knowledge-sharing may be valuable to project teams, it is currently being "underutilized" as it is "time consuming" and "admin intensive" to gather enough knowledge from enough sources and then combine it in a repository of some sort so that it can be easily accessible and searchable for all the project teams in an organisation. It was noted that currently "most projects do not budget for it". Therefore, organisations need to adopt knowledge-sharing cultures and actively invest and allocate time and budget for knowledge-sharing technologies and teams who can oversee the effective management and measurement of knowledge across projects and teams.

Project teams need to be encouraged to actively and consistently partake in knowledge-management and knowledge-sharing practices, during the entire duration of their projects as once again consensus was reached that these practices can lead to "completing projects on time and on budget", decreasing "time to value", helping to "not repeat [the] same mistakes within projects", improving quality and "delivery across the board", and nurturing "the competitive streak". Additional advantages include supporting project managers with their work and increasing their productivity, supporting team performance and development, "increasing IQ", "up-skilling and elevating team capability". Although, because KM is "often not seen as critical", the benefits of such culture changes, maturity growth and investments should be clearly communicated with decision makers and managers in an organisation. As one respondent noted, "We need to find a way to articulate the benefits so that it's part of our daily practice, not when someone leaves the team".

One respondent made the argument that, while there may be great benefit to teams who partake in knowledge-sharing processes, as it allows team members with different levels of experience to upskill themselves, these staff members then become more marketable and retention in such cases can be difficult as they may look for higher-paying jobs. Another factor that could negatively impact the effort put in by teams to document their knowledge and make it accessible to others is that different "personalities and backgrounds" in the team could lead to the practice being neglected. As noted by one respondent, "Some people are sharers and others are hoarders. Some people learn from the insights and mistakes of others, while some people are wired to learn from their own". The final observation that can be made from the open-ended responses is that many of the respondents have suggestions of knowledge-sharing tools and practices that could be used more effectively in organisations and project teams. These include using "room planning and collaboration" instead of focusing too much on tools, using "playbooks to share [knowledge and] information", capturing lessons learnt "throughout the project, not just at the end", "actively managing communities of practice", and using a tool that provides project managers with a "step by step guide" of all relevant knowledge they will need to on-board with a new team.

5 Contribution

Their four-quadrant model describes the knowledge-creation process as a cycle involving four stages: socialization (converting tacit knowledge into new tacit knowledge), externalization (articulating tacit knowledge into explicit knowledge), combination (connecting different explicit knowledge to create new explicit knowledge), and internalization (embodying explicit knowledge to make it tacit). These stages work in a continuous spiral, with each cycle expanding the existing knowledge base. In the context of project teams, project managers and knowledge workers provided insights into the activities which they partake in as they pertain to the four processes. The benefits of participation in knowledge-sharing activities include improving team communication, understanding and maturity; mitigating risks, dependencies, and rework; saving time and money; solving problems; upskilling; improving quality; improving alignment between teams and stakeholders; and improving decision-making. Further benefits extracted from the open-ended question included "completing projects on time and on budget", improving quality and "delivery across the board", supporting project managers with their work and increasing productivity, supporting performance and development and nurturing "the competitive streak".

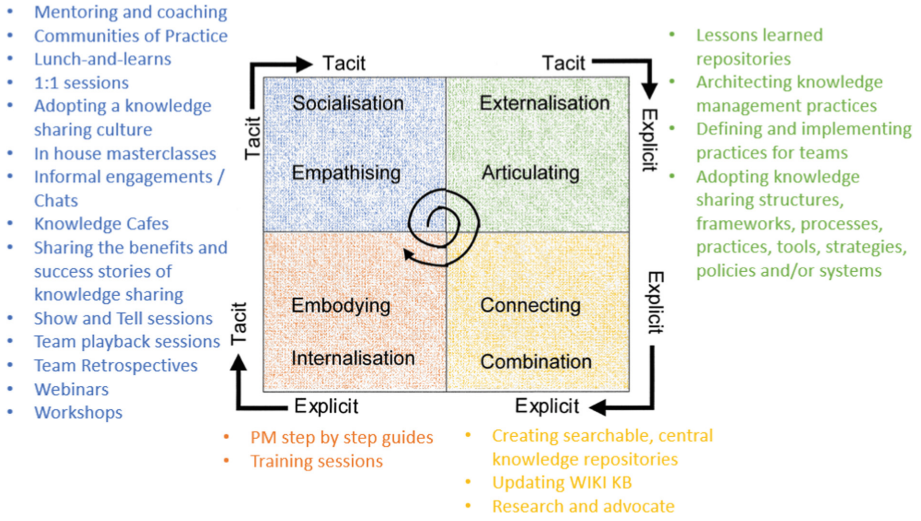

Fig. 1. The SECI model with suggested activities to enable each process

In Fig. 1, the activities which project teams and various teams within an organisation could undertake to create and share knowledge are listed next to their respective SECI process. In the socialization process of knowledge-creation process, activities include, among others, mentoring and coaching, communities of practice, lunch-and-learns, in-house masterclasses, informal engagements and chats, knowledge cafes, show and tell sessions, team retrospectives, and workshops. For externalization, activities include creating lessons-learned repositories, and adopting knowledge-sharing structures, frameworks, processes, practices, tools, strategies, policies and/or systems. Combinations can

be achieved through creating searchable, central knowledge repositories, updating wikis, and conducting research. Lastly, the internalization process would require such activities as training sessions and using step-by-step guides to get project managers onboarded with new projects and teams.

The uneven distribution of knowledge creation and sharing activities as seen in Fig. 1 is indicative of the social nature of project team interactions, and it supports too the findings that structured knowledge-sharing efforts and technologies are insufficiently budgeted for and insufficiently supported by management who make investment decisions. The transience of project teams and the nature of their objectives being business-value-focused means that there is also insufficient time to establish structured knowledge combining practices and tools, resulting in socialization being the easiest and quickest means of creating and sharing knowledge.

5.1 The Principles of Project Management

For the first theme, the ten project-management principles as prescribed by the Project Management Institute [9] in the Project Management Body of Knowledge (PMBOK guide) were referenced. The ten guiding principles include project-integration, scope, schedule, cost, quality, resource, communications, risk, procurement, and stakeholder management. The results of the data collection and analysis highlighted that 62% of respondents do know about the ten project-management principles. When defining 'project management', respondents found the concepts of "given constraint", "desired outcome", "project management", "optimal use of people", "allocated sure resource", "adhered budget constraint", and "defined project objective" to be most relevant. It can be concluded from the results that, while the principles of PM as well as the concept of a lessons-learned repository are well understood, they are not utilized to their full potential. The implication of these findings is that much time could be wasted by project teams in trying to troubleshoot challenges, whereas having access to and consulting the repositories could assist in saving both time and money.

5.2 The Constituents of Knowledge-Sharing

For the next theme, constituents of knowledge-sharing, the literature revealed that the main constituents include knowledge documenting and repositories, knowledge teams, learning organisations, and knowledge-sharing models which can be used for implementation. Through an analysis of the responses related to knowledge-sharing, the following was found:

- When respondents were asked to define 'knowledge management', they found the concepts of "efficient handling of information", "available knowledge", "knowledge management", "best use of knowledge", "good knowledge management", "managed knowledge asset", and "improved business initiative" to be most relevant.
- In defining the concept of 'knowledge-sharing', terms such as "exchanged knowledge", "best practice" and "knowledge" were ranked as most relevant.
- 39% of respondents agreed that their teams consult knowledge repositories when faced with challenges, while 36% said they did not.

- 64% of respondents claimed that they know about knowledge-sharing tools and practices.
- 72% of respondents indicated that there is a knowledge-sharing culture in their teams, whereas only 54% said there is a knowledge-sharing culture in their organisations.
- 60% of respondents believe that knowledge can be codified.
- Key suggestions made by respondents regarding the implementation of knowledge codification practices included: Adopting knowledge-sharing structures; frameworks, processes, practices, tools, strategies, policies and/or systems; Creating searchable, central knowledge repositories; Adopting a knowledge-sharing culture; Sharing the benefits and success stories of knowledge-sharing; Stakeholder, management and executive support and buy-in; Providing clarity and definition; Providing training.

The analyzed responses indicate that many participants are aware of knowledge-sharing practices and tools; however, knowledge repositories and codified knowledge are not easily accessible to project teams. Executives and management of organisations need to be educated in the benefits of knowledge-sharing so that they can transform the culture into one of knowledge and learning.

5.3 Knowledge-Sharing in Project Management

The final theme related to knowledge-sharing in PM and the literature outlined several practices which project teams can undertake, including utilizing lessons learned (an expected outcome of PM), communities of practice, lunch-and-learns, and coaching and mentoring. Analysis of the collected data resulted in the following insights:

- 72% of respondents take part in knowledge-sharing activities, with 87% indicating that they partake in mentoring and coaching, 69% partake in communities of practice, and 34% participate in lunch-and-learns.
- 70% of respondents believe that projects can benefit from codified knowledge.
- Key contributions that knowledge-sharing can make towards project success include: Improving team communication, understanding and maturity; Mitigating risks, dependencies, and rework; Saving time and money; Solving problems; Upskilling; Improving quality; Improving alignment between teams and stakeholders; Improving decision-making.

From the summarized results, it can be concluded that, while participants do actively partake in knowledge-sharing activities, these are currently being driven at an individual and team level, which can slow the learning maturity of organisations and so getting stakeholder and management buy-in is essential. Codified knowledge is believed to be beneficial for project teams but the lack of management buy-in means this practice is often neglected. Sharing the success stories and benefits of knowledge-sharing in project teams, like improved team communication, understanding and maturity, mitigation of risks, dependencies, and rework, and saving of time and money, could justify to the business why such tools and practices are necessary.

5.4 The Impact of Knowledge-Sharing in Project Management

To understand and integrate the individual concepts, the literature revealed that there are ten underlying principles in PM [21] and there are aspects of KM and sharing in each principle, especially as it relates to lessons-learned repositories. Capturing lessons learned requires the codification or articulation of tacit knowledge into explicit knowledge, which Nonaka et al. [12] describe as the process of externalization in their SECI model.

The findings from the data collection and analysis process revealed that knowledge-sharing can indeed have an impact on PM, with participants making such observations as: "Projects where there were extensive knowledge-sharing principles and repositories did far better to complete in time and on budget than those who did not have a knowledge-sharing culture and repository"; "Knowledge-sharing is one of the most powerful tools in project, programme and portfolio management. When all project teams are empowered with access to knowledge and knowledge-sharing, delivery across the board improves" and "Knowledge-sharing should be encouraged across all project teams as it complements the PM practice". Collected data also revealed that, while knowledge-sharing does have a positive impact on PM, too few organisations invest in knowledge-sharing efforts and so the conceptual model presented in Fig. 1 aimed to provide suggestions for activities that organisations can engage in to facilitate the knowledge-creation and sharing process.

6 Conclusion

The academic contribution of this study is that it has added to both the knowledge-sharing and project-management bodies of knowledge and has provided a context for knowledge-sharing in projects. The practical significance of the study is that project and knowledge workers can use the insights generated in this study to implement knowledge-sharing opportunities or initiatives in projects to ensure knowledge is retained and distributed to other teams who can adopt similar initiatives. Project teams, as well as organisations, can benefit from this, as it can provide guidance on how to make knowledge-sharing a common practice and increase the overall knowledge base of the teams and organisations who implement the suggestions made.

A possible expansion of the research presented could involve collecting the views and opinions of more C-level executives and directors since it is essentially their decision-making that influences how much time and money is invested in knowledge-management technologies and practices. Additionally, insights could be gathered from specific industries other than information technology, to assess the viability of applying knowledge-management practices in otherwise siloed organisations.

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Testing the Preliminary Model of Enhancing Organizational Memory Through Computer-Based Knowledge Repositories in Failure Learning

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Abstract. Learning from failures is crucial for organizations to prevent recurrence and enhance performance. However, the role of organizational memory in this process, particularly within computer-based knowledge repositories, remains unclear. This study aimed to develop a generalized hypothetical model of institutional memory structures in learning from failure based on a case study of a company that successfully implemented such learning practices. The model was tested using quantitative data collected through questionnaires administered to employees from both the case company and benchmark companies. A covariance structure analysis was conducted to validate the model. The results confirmed an acceptable model fit for both the case company and benchmark companies, suggesting its generalizability. This study contributes to the understanding of the relationship between organizational memory, technology use, and learning from failure, offering insights for companies struggling to establish effective learning practices. Future research should extend this model to examine the impact of organizational memory on learning outcomes and further explore the connection between recorded knowledge and human memory.

Keywords: Organizational Learning · Failure-Informed Practice · Institutional Memory · Computer-based Knowledge Repository

1 Introduction

Many recognize the value of learning from failure. Both children and adults refine their abilities through setbacks, adjusting their approaches to avoid similar mistakes. By reflecting on past errors, individuals develop strategies to prevent recurrence and improve their chances of success.

At the organizational level, however, learning from failure is more complex [1]. Even if those directly responsible reflect on their mistakes, others may still repeat them. To prevent this, organizations need a structured approach, including systematic corrective

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actions [2–4]. This involves not only personal reflection but also sharing detailed failure accounts internally and, in some cases, with external stakeholders. Analyzing these accounts helps identify root causes and implement preventive measures.

Despite these efforts, organizations often repeat failures, and acquiring failure-related knowledge is challenging. Individuals may hesitate to make mistakes, making it difficult for the organization to learn. Failures persist not just because they occur but also due to ineffective organizational memory [5].

Research suggests that computers and the Internet have altered how people remember information. Instead of recalling content, individuals focus on where data is stored, relying on quick online retrieval. This phenomenon, known as digital amnesia or the Google Effect [6, 7], has been linked to negative impacts on cognitive function [8].

Computers are widely recognized as effective tools for data storage and retrieval in organizations [5]. However, given the evidence of digital amnesia and its potential cognitive effects on individual memory, it is essential to examine how computers, organizational intranets, and emerging technologies such as artificial intelligence influence organizational memory.

This study acknowledges that organizational memory may not always function effectively, which can hinder learning from failure. Therefore, the authors aim to clarify the relationship between the use of computers, organizational intranets (as knowledge-sharing and communication infrastructures), and organizational memory.

To explore this, the authors developed a conceptual model of organizational memory in learning from failure by analyzing a company that successfully integrated computers and an organizational intranet into its learning processes. Based on this case study, they constructed a hypothetical model of organizational memory in learning from failure [9–13] and later worked on its generalization [14]. This study [14] tested the hypothetical model through statistical analysis of questionnaire data. However, direct comparisons between datasets were not always feasible due to the time gap between data collection from the case company and the subsequent generalization. This gap coincided with significant events, including the COVID-19 pandemic and rapid advancements in artificial intelligence, both of which dramatically changed firms' reliance on computers. For instance, the widespread shift to telecommuting and remote work during the pandemic, along with the growing emphasis on digital transformation, made computers even more indispensable for business operations than before.

A key limitation of previous studies was their inability to directly compare data from the case company with general data from unspecified companies under the same criteria due to differences in data collection timing. To address this limitation, the authors aimed to minimize variations in social background and ensure comparability by analyzing data collected simultaneously whenever possible. The objective of this study is to build upon the hypothetical model developed from the case company's case study and further generalize its findings.

Understanding the relationship between organizational memory and digital technologies has been a central focus of prior research. While computers and organizational intranets are generally assumed to support organizational memory, their impact on individual memory remains unclear. Given this gap, this study is significant as it investigates

how these technologies influence organizational learning from failure. Furthermore, clarifying the mechanisms of organizational memory in learning from failure is crucial, as deficiencies in organizational memory may hinder effective learning processes.

2 Constructing Hypothetical Model with Case Study

Based on a literature review, the authors developed a preliminary framework—a model of organizational memory mechanisms in learning from failure—using qualitative research. This framework emerged from a case study of a company that successfully implemented failure-based organizational learning. The model was then tested with quantitative data from employee surveys. This section first outlines the company's approach to learning from failure, followed by the preliminary model, which serves as the study's hypothetical model.

2.1 Case Introduction

Sangikyo Co., Ltd. defines operational failures—including human errors, project setbacks, and financial losses—as "failures" and addresses them through the Reflection School, a specialized task force analyzing their causes and processes to prevent recurrence and facilitate learning. Established in April 2005 under the former president's leadership, the Reflection School had reviewed 42 failure cases as of November 2021. According to the current president and executives, no identical failures have occurred since its implementation. They emphasized its role in strengthening organizational capabilities, enabling the company's shift from a subcontractor to a prime contractor.

When an accident occurs, those involved report it through a knowledge-sharing database on the company's intranet. For significant incidents, the Management Committee, including the president, decides whether to submit the case to the Reflection School based on its impact. Once approved, the person responsible for the failure leads the Reflection School, involving relevant parties and, if necessary, the quality assurance officer. The Reflection School consists of several meetings where participants confirm case details, analyze the situation, identify causes, and formulate preventive measures. The case leader then compiles a report, which is posted in the knowledge-sharing database. Employees can access these reports anytime and from any location via the intranet.

2.2 Research Evolution with Case Study

To enhance clarity, the authors summarize the evolution of their case study in Table 1, acknowledging some overlap with the preceding description. The study began in 2013, with efforts in 2014–2015 focused on understanding the company's Reflection School. An exploratory study was then conducted to identify the key success factors of this initiative [16]. Building on this, the authors developed a hypothetical model based on the assumption that leveraging a knowledge -sharing database and intranet supports organizational memory in learning from failure. This model, depicted in Fig. 1, was tested through a company-wide questionnaire [10–13]. However, results were inconsistent at the midway stage [9]. Since the model was derived from a single case, concerns arose

Table 1. Research Evolution

Year	Research Category			Method	Outcome/Findings	Limitation/Issue	Publication (Only a part of the list is shown)
2013	The series of research started						
2014–2015	Qualitative research of the case company	Case Study	Understanding the case	Interview	Assumed success factors of the failure learning initiative in the case of the company	Just an assumed finding	[15]
2015–2016	Quantitative research		Constructing hypothetical models for the case company	Discussion among the authors	Preliminary model with organizational memory	Necessity of verification	
2016–2017			Verification of the preliminary model with organizational memory	Questionnaire Survey in the case company • All employees in the case company	Conflicting results (one result indicating that the use of computers promotes organizational memory and one result indicating that it does not promote organizational memory)	Inconsistency results	[9]
2018–2024			Improve and extend the model – added the latent variable "Concern."	Questionnaire Survey in the case company • All employees in the case company	Computers indirectly promote organizational memory	Generalization of the model	[10–13]
2022–2024		Generalization	Verification of the model with unspecified multiple companies	Questionnaire Survey for anonymous monitor members in an internet survey company	Good model fitness	Comparison with the case company under the same condition	[14] and TBC
2024-		Test and Comparison	Test the model with the case company/unspecified multiple companies and Comparison	Same Questionnaire Survey for the case and anonymous companies in almost the same period	Good model fitness	Comparison in detail Time series analysis	This study

regarding over-adaptation, necessitating further generalization. To address this, data collection expanded in 2022 to include various companies. However, differences in data collection timing made direct comparisons challenging. To ensure consistency, this study gathered data under similar conditions to refine and generalize the model.

2.3 Hypothetical Model

As previously noted, the authors continuously examined the company's learning from failure practices and formulated eight hypotheses in their prior study [11]:

Hypothesis 1 (H1): Work-related concern enhances the use of a computer-based knowledge repository.
Hypothesis 2 (H2): Work-related concern increases the documentation process.
Hypothesis 3 (H3): Work-related concern improves individual memory retention
Hypothesis 4 (H4): A computer-based knowledge repository directly strengthens organizational memory.
Hypothesis 5 (H5): A computer-based knowledge repository enhances documentation activity.
Hypothesis 6 (H6): A computer-based knowledge repository improves individual memory retention.
Hypothesis 7 (H7): Documentation activity reinforces organizational memory.
Hypothesis 8 (H8): Individual memory retention strengthens organizational memory.

The authors constructed the "Organizational memory mechanism model in organizational learning from failure" [12–14] by extending a previous study's framework [11], as shown in Fig. 1.

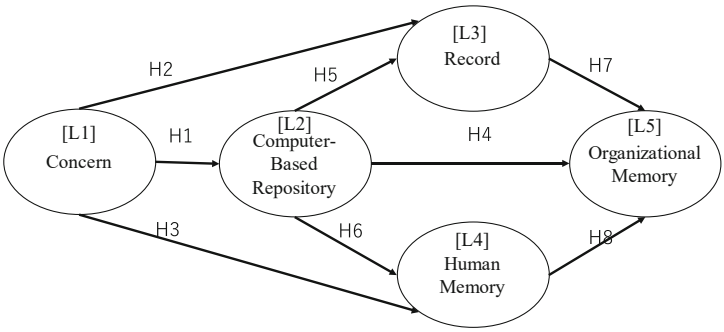

Fig. 1. Organizational memory mechanism model in organizational learning from failure [12–14].

The authors previously [12, 13] hypothesized and tested the model by analyzing quantitative data from employee questionnaires using structural covariance analysis. The findings suggest [12, 13].

- IT-based knowledge storage and sharing media do not directly strengthen organizational memory but enhance documentation and personal memory, which in turn support organizational memory.
- The level of organizational interest in documented information may influence its establishment as organizational memory through IT-based storage and sharing media.
- Computers alone do not improve organizational memory, but routines involving their use can promote it.
- IT adoption does not directly enhance organizational performance; instead, performance improves through structural developments driven by IT integration.

3 Research Methodology

This study employs a quantitative approach to test the proposed organizational memory model [12–14] for learning from failure (Fig. 1) using the latest data. It analyzes survey responses from employees of both the case company and benchmark firms. Statistical analysis is conducted on data collected through two rounds of employee surveys to compare findings and validate the hypotheses.

4 Analysis of the Case Company

4.1 Data Collection

Employee surveys for the case company were conducted via Freeasy, a web-based platform by iBridge Corporation. The survey used the same questions as Nagayoshi and Nakamura [14] in their study of other companies. Conducted between April 8 and April 23, 2024, the survey targeted approximately 700 employees, yielding 196 responses. After removing unreliable data (e.g., straight-lined responses), 190 were deemed valid for analysis.

4.2 Data Analysis

Covariance structure analysis was performed using IBM SPSS AMOS 29 to validate the hypothetical model.

The results are presented in Fig. 2.

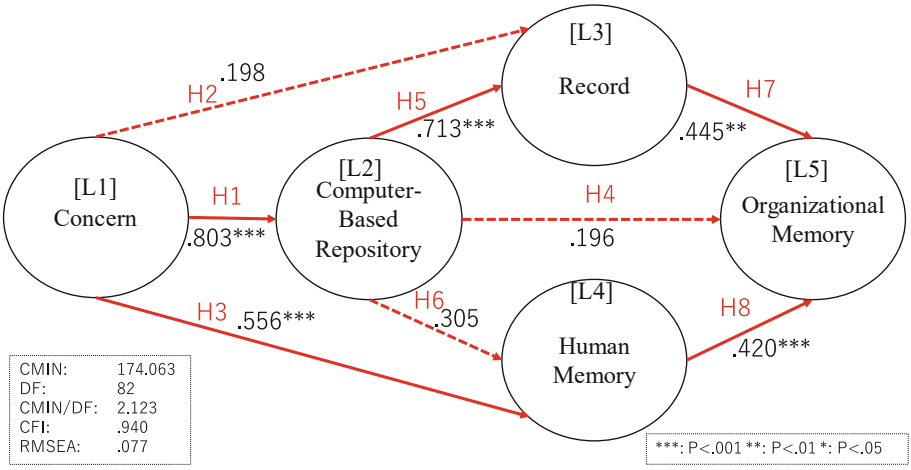

Fig. 2. Analysis results for the case company

5 Analysis of Benchmark Companies

5.1 Data Collection

The survey for benchmark company employees was conducted by iBridge Corporation, a Japanese survey firm with 13 million members, one of the largest respondent pools in Japan. The 50-question survey, identical to that used for the case company and in Nagayoshi and Nakamura's [14] study, was created via Freeasyand distributed online to iBridge's monitored members. Respondents included company employees (regular and contract/temporary), managers, executives, public officials (excluding faculty), and medical personnel. Participants were aged 20 or older.

Conducted on March 13, 2024, the survey targeted 600 respondents, with iBridge's AI-based data cleaning service used to remove fraudulent responses. The service initially collected 120% of the target sample and eliminated invalid responses (e.g., short or straight-lined answers). However, if fraudulent data exceeded 20%, some remained. A sample size of 385 was needed for a 5% data tolerance. Despite AI cleaning, additional filtering by the authors reduced usable data to 60–80% of the original sample. To compensate, they requested a larger sample of 600 responses.

After reviewing the 600 responses, the authors manually removed fraudulent data, retaining 502 valid samples for analysis.

5.2 Data Analysis

Covariance structure analysis was performed using IBM SPSS AMOS29 to validate the hypothetical model. The results are shown in Fig. 3.

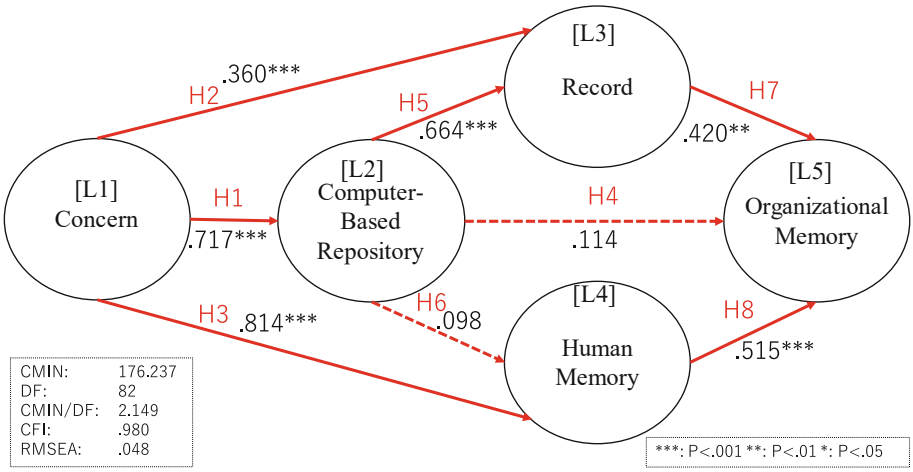

Fig. 3. Analysis results for the benchmark companies

6 Comparison and Discussion

Tables 2 and 3 show the analysis results for the case company and the benchmark companies, respectively.

Table 2. Comparison of model evaluation data and benchmark values

	Case company	Benchmark companies
Data collection term	2024, April 8–23	2024, March 13
CMIN	174.063	176.237
Degrees of Freedom (DF)	82	82
CMIN/DF	2.123	2.149
CFI	.940	.980
RMSEA	.077	.048

Notes: CMIN = Chi-square Minimum; CFI = Comparative Fit Index; RMSEA = Root Mean Square Error of Approximation.

6.1 Model Evaluation

The Comparative Fit Index (CFI) indicated that the model fit was 0.940 for the case company and 0.980 for benchmark companies. The root mean square error of approximation (RMSEA) was 0.077 and 0.048, respectively. These results suggest an acceptable fit for the case company and a strong fit for benchmark companies. The authors tested the hypothetical model using the latest data, confirming the reproducibility of the analysis.

Table 3. Hypothesis testing by comparison with benchmark values

	Path		Case company			Benchmark companies		
			Correlation	Significance	Support	Correlation	Significance	Support
H1	L1 Concern	→L2 Computer-based repository	.803	***	Yes	.717	***	Yes
H2	L1 Concern	→L3 Record	.198		No	.360	***	Yes
H3	L1 Concern	→L4 Human memory	.556	**	Yes	.814	***	Yes
H4	L2 Computer-based repository	→L5 Organizational memory	.196		No	.114		No
H5	L2 Computer-based repository	→L3 Record	.713	***	Yes	.664	***	Yes
H6	L2 Computer-based repository	→L4 Human memory	.305		No	.098		No
H7	L3 record	→L5 Organizational memory	.445	**	Yes	.420	**	Yes
H8	L4 Human memory	→L5 Organizational memory	.420	***	Yes	.515	***	Yes

This study successfully followed up on prior research and further generalized the hypothetical model derived from the company's case studies.

6.2 Hypothesis Verification

H1: [L1] → [L2]: H1 is supported because, in both the case of company and benchmark companies, the use of computers is encouraged when the topic is of interest to employees within the organization.

H2: [L1] → [L3]: It is found that, in the case of benchmark companies, recording is encouraged when the issue is of interest to employees within the organization, so H2 is supported. However, for the case company, H2 is not supported because employees are not encouraged to record when the issue is of interest to them within the organization. Further investigation is required to understand the factors behind this difference.

H3: [L1] → [L4]: H3 is supported because issues of interest within the organization evoke people's memories in both the case company and benchmark companies. However, they trigger memory more strongly in the benchmark companies than in the case company.

H4: [L2] → [L5]: H4 is not supported because the use of computers does not directly lead to organizational memory, whether in the case of company or benchmark companies.

H5: [L2] → [L3]: H5 is supported because, in both the case company and benchmark companies, computers improve documentation.

H6: [L2] → [L4]: H6 is not supported because, in both the case company and benchmark companies, human memory is not enhanced by the use of computers.

H7: [L3] → [L5]: H7 is supported because records reinforce organizational memory, which is true for both the case company and benchmark companies.

H8: [L4] → [L5]: H8 is supported because human memory reinforces organizational memory in both the case company and benchmark companies.

7 Conclusion

7.1 Summary

This study resolves a key issue from prior research, where differences in data collection timing hindered direct comparisons between the case company and benchmark companies. To address this, we minimized social background differences by collecting data as contemporaneously as possible, allowing for a more accurate generalization of the hypothetical model.

7.2 Contribution

Understanding the relationship between organizational memory, computers, and intranets has been valuable in past studies but has not fully addressed individual memory. This study helps bridge that gap. Additionally, clarifying how organizational memory functions in learning from failure is crucial, as it may not always operate effectively in this context.

7.3 Limitation

This model examines how organizational memory develops during learning from failure but does not confirm whether it directly leads to successful learning. Further research is needed to assess its applicability across different organizations. This study did not identify which types of firms the model applies to or explain the differences observed between the case company and benchmark companies.

Additionally, this study sought to address the previous study's limitation of comparing data collected at different times, which was influenced by external factors such as COVID-19. However, as this study did not compare its results to prior research, the impact of these environmental changes remains unclear.

Moreover, the model does not explore the link between recordings and human memory, despite evidence from learning science suggesting that documentation enhances recall [16].

Finally, fraudulent responses in the dataset posed a challenge. The survey company collected 120% of the target sample and used AI to filter invalid responses, but it remains uncertain whether all fraudulent data was successfully removed.

7.4 Future Study

Building on this study's limitations, further research and discussion are needed to identify the factors contributing to the observed differences between the case company and benchmark companies. Clarifying these factors would also help define the scope of the proposed model. Additionally, it is necessary to examine the impact of recent environmental changes by comparing this study's findings with those of previous research.

The authors plan to refine the model by developing an extended version that illustrates how organizational memory facilitates successful learning from failure. Specifically, a latent variable, "Effective Learning from Failure," will be incorporated into the model, followed by statistical analysis and discussion. Furthermore, a literature review on the relationship between recording and memory in learning science will be conducted. The existing model will be revised to include the pathway from the latent variable "Record" to "Human Memory," which will be tested using statistical methods. The results will be compared with the original model and analyzed.

Finally, to improve data reliability, the questionnaire design will be revised. While the current study prioritized minimizing respondent burden by reducing the number of questions, additional and dummy questions will be introduced to enhance data consistency and filter out fraudulent responses.

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Knowledge in Business and Organisation

A Digital Enterprise Architecture Framework for Supply Chain Transformation: Integrating Knowledge Management and the TOE Framework in the FMCG Industry

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Abstract. The complexity of Supply Chain Management (SCM) in the Industry 4.0 era demands digital transformation to enhance efficiency, visibility, agility, and real-time decision-making. Traditional SCM systems, hindered by manual workflows, fragmented data, and lack of predictive analytics, result in delays, stock allocation errors, and proof-of-delivery (POD) disputes, affecting operational resilience and cost efficiency. This study proposes a Digital Enterprise Architecture SCM Framework, integrating Enterprise Architecture (EA), Knowledge Management (KM), and the Technology-Organization-Environment (TOE) framework to optimize automation, interoperability, decision intelligence, and predictive capabilities. A Design Science Research (DSR) approach, structured into Preliminary Study, Model Development, and Model Evaluation, ensures systematic analysis, framework development, and empirical validation. The As-Is analysis at MSM Malaysia Holdings Berhad identified inefficiencies in order processing, inventory management, and logistics coordination, while the To-Be framework, integrating Transport Management Systems (TMS), Customer Relationship Management (CRM), AI-powered predictive analytics, and real-time dashboards, enhances supply chain agility, data synchronization, and risk mitigation. Expert validation via the Delphi Method engaged 12 supply chain and digital transformation experts to ensure scalability, industry alignment, and technical feasibility. Usability testing with six industry professionals using the System Usability Scale (SUS) evaluated system functionality, user experience, and operational efficiency, yielding a high usability score. Findings show a 48% reduction in order processing time, a 42.3% decrease in stock allocation errors, and a 70.8% reduction in POD disputes, confirming the framework's effectiveness in strengthening supply chain resilience, transparency, and cost optimization. This study contributes

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a structured, knowledge-driven SCM model that leverages AI, real-time intelligence, and enterprise-wide digital integration to foster efficiency, strategic agility, and competitiveness in the FMCG industry.

Keywords: Digital Supply Chain · Enterprise Architecture · Knowledge Management · Supply Chain Automation · TOE Framework

1 Introduction

The digital transformation of Supply Chain Management (SCM) integrates automation, real-time analytics, and enterprise-wide connectivity to enhance efficiency and resilience. Supply Chain 4.0 enables predictive planning, AI-driven logistics, and dynamic inventory control, yet many Fast-Moving Consumer Goods (FMCG) manufacturers still rely on outdated workflows and fragmented data systems, reducing agility and responsiveness to market demands [1]. These inefficiencies create operational bottlenecks, affecting cost efficiency and service delivery.

FMCG manufacturers face volatile demand, short product lifecycles, and logistics dependencies, yet manual order processing, disconnected inventory systems, and inefficient proof-of-delivery (POD) tracking hinder optimization [2]. The absence of centralized digital infrastructure restricts real-time visibility and synchronized decision-making, as seen in MSM Malaysia Holdings Berhad, where stock misallocations, truck assignment delays, and invoice disputes result from poor data integration and fragmented coordination across sales, customer service, and logistics [3].

A key barrier to SCM digitalization is the lack of structured Knowledge Management (KM), preventing effective data capture, sharing, and application across departments. KM enhances process standardization, real-time intelligence, and predictive analytics [4]. Without it, organizations struggle to automate processes, leading to reactive rather than proactive supply chain management. Embedding KM supports organizational learning, data-driven decision-making, and supply chain resilience [5].

This study applies the Technology-Organization-Environment (TOE) framework [6] to align technological adoption, organisational restructuring, and external compliance in SCM transformation. While, Enterprise Architecture (EA) provides a structured IT-business integration approach, improving process automation, system interoperability, and scalability [7]. The proposed Digital Enterprise Architecture SCM Framework integrates EA, KM, and TOE principles to enhance supply chain visibility, automation, and analytics. This study systematically develops and validates the framework, presenting a structured approach to SCM digitalization, theoretical foundations, methodology, framework design, and evaluation process.

2 Literature Review

The digital transformation of SCM in Industry 4.0 demands advanced automation, real-time visibility, and AI-driven decision-making to enhance efficiency and agility. Traditional SCM models, constrained by manual workflows and fragmented data systems,

lack scalability, interoperability, and predictive capabilities, leading to inefficiencies in inventory management, logistics coordination, and decision intelligence [8–10]. Recent advancements in digital SCM frameworks emphasize AI-driven forecasting, IoT-enabled logistics, and blockchain-enhanced transparency [11, 12]. However, many FMCG manufacturers, including MSM Malaysia Holdings Berhad, still struggle with legacy systems, fragmented digital infrastructures, and inadequate organizational readiness, hindering end-to-end supply chain integration.

2.1 Digital Supply Chain Management in Industry 4.0

The Industry 4.0 landscape presents both opportunities and challenges for SCM transformation. While AI, IoT, and blockchain facilitate automated logistics, predictive analytics, and real-time tracking, studies indicate that organizational resistance, high implementation costs, and cybersecurity risks remain significant barriers [13, 14]. Despite these challenges, research underscores the need for a structured digital enterprise framework that aligns business strategy with technological capabilities [15] (see Table 1).

Table 1. Comparative Analysis of Traditional, Digital, and AI-Driven SCM

Feature	Traditional SCM	Digital SCM	AI-Driven SCM
Data Processing	Manual	Automated	Predictive
Decision-Making	Centralized	Decentralized	AI-Optimized
Visibility	Limited	Real-Time	Self-Learning
Inventory Management	Periodic	Demand-Driven	Dynamic Optimization
Risk Management	Reactive	Predictive	Autonomous Response

While Industry 5.0 has emerged, emphasizing human-centric digitalization, sustainability, and human-AI collaboration, this study remains grounded in Industry 4.0 principles, as they align with the current technological adoption trends in FMCG supply chains. Industry 5.0 aims to enhance human involvement in digital ecosystems, whereas Industry 4.0 is focused on full automation, system interoperability, and AI-driven supply chain resilience [16]. Given that most FMCG manufacturers, including MSM Malaysia Holdings Berhad, are still transitioning towards Industry 4.0 adoption, this study prioritizes its technological integration framework for optimizing digital SCM transformation.

2.2 Theoretical Underpinning – KM, TOE Framework, and EA

This study leverages Industry 4.0 technologies to integrate EA, KM, and the TOE framework, developing a structured, AI-enhanced digital supply chain model. The framework bridges automation gaps, ensures real-time data synchronization, and streamlines order processing and logistics, enabling a scalable, intelligent SCM digitalization strategy. KM plays a pivotal role in supply chain agility by systematically capturing, retaining, and

applying operational intelligence [4]. The SECI model facilitates tacit-to-explicit knowledge conversion, supporting real-time collaboration, best practice standardization, and AI-driven learning [17]. Digital SCM relies on structured KM to eliminate fragmented knowledge flows, ensuring enhanced operational responsiveness.

The TOE framework structures SCM adoption, aligning technological advancements, organizational processes, and environmental dynamics. Technology-driven automation through TMS, CRM, AI, and real-time analytics enhances supply chain visibility and data-driven decision-making [1, 18]. Organisational process automation and enterprise-wide KM integration ensure workflow agility and collaborative intelligence [11]. Environmental factors such as regulatory compliance, sustainability, and market-driven adaptability reinforce supply chain resilience, reducing operational risks [3]. The TOE framework ensures strategic SCM digitalization, mitigating inefficiencies in manual workflows, fragmented systems, and non-standardized decision-making processes.

EA aligns IT capabilities with SCM, ensuring seamless business-technology integration and structured digital transformation [19, 20]. The business and application layers facilitate system interoperability, integrating SCM workflows with IT-driven process standardization. The data layer reinforces regulatory compliance, risk mitigation, and adaptive market response, strengthening SCM resilience. The technology layer enables end-to-end process automation through AI, TMS, and cloud-based platforms, eliminating inefficiencies in manual inventory tracking, logistics coordination, and real-time decision support. EA ensures that SCM transformation is scalable, data-driven, and aligned with enterprise-wide digital objectives.

This approach not only bridges the digital transformation gap but also provides a scalable roadmap for organizations to optimize supply chain agility in the Industry 4.0 era. The KM-SECI model optimizes knowledge flow and decision accuracy, the TOE

Table 2. The proposed Digital Enterprise Architecture SCM framework integrating KM, EA, and TOE principles

TOE Dimension	SECI Framework (KM)	EA BDAT Framework (EA)
Technology	**Combination:** Integrates structured data from CRM, IoT, and AI dashboards for predictive analytics	**Technology Layer:** Implements AI, TMS, and cloud-based platforms for system-wide automation
Organization	**Socialization & Internalization:** Fosters collaboration and organizational learning, enabling real-time decision intelligence	**Business & Application** Layers: Align SCM workflows with IT architecture, ensuring interoperability and process standardization
Environment	**Externalization:** Codifies industry best practices and compliance frameworks into structured knowledge repositories	**Data Layer:** Ensures regulatory compliance, market-driven adaptability, and risk management capabilities

framework ensures strategic digital adoption, and EA structures SCM automation and IT alignment. This holistic integration addresses key limitations in traditional supply chains, enabling agile, intelligent, and responsive SCM ecosystems that drive supply chain resilience, cost efficiency, and real-time adaptability in dynamic FMCG environments (see Table 2).

3 Methodology

This study employs a Design Science Research (DSR) approach [21] to systematically develop and validate a Digital Enterprise Architecture Supply Chain Management (SCM) Framework tailored for MSM Malaysia Holdings Berhad. DSR is selected for its structured problem-solving methodology, allowing for the design, implementation, and empirical evaluation of innovative solutions in complex organizational environments. The approach ensures both academic rigor and practical relevance, addressing SCM inefficiencies through enterprise-wide digital transformation. The research is structured into three key phases: (1) Preliminary Study, (2) Model Development, and (3) Model Evaluation, ensuring both academic rigour and practical applicability in the digital transformation of SCM (see Fig. 1).

The preliminary study phase involves a comprehensive literature review conducted using Scopus, IEEE Xplore, and Web of Science, identifying gaps in EA, SCM, and Digital Transformation within FMCG industries. A comparative gap analysis was conducted to assess deficiencies in existing frameworks, including limited interoperability,

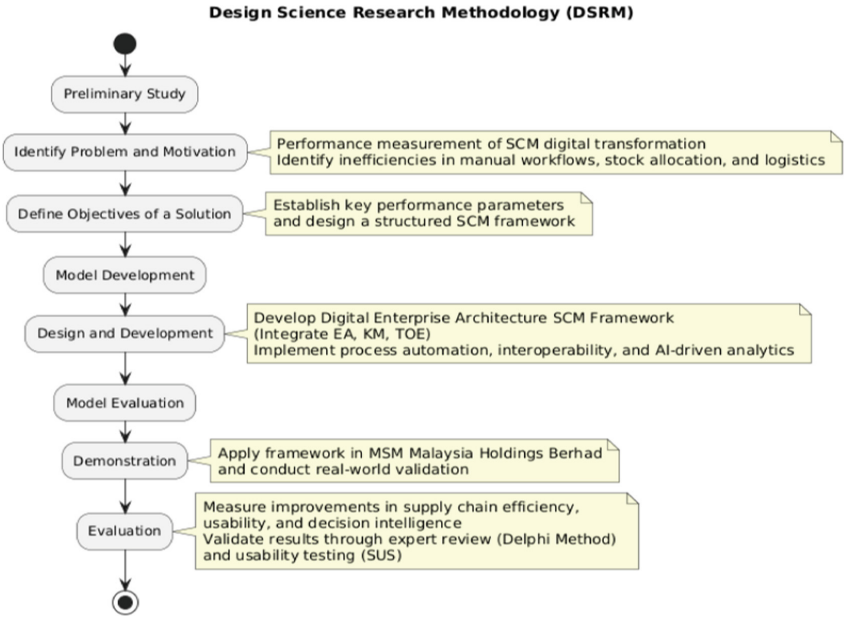

Fig. 1. Research Methodology of this Study

outdated system architectures, and inefficiencies in real-time tracking. Process documentation review, structured stakeholder interviews, and transaction log analysis were performed to validate these findings further. The As-Is workflow of MSM Malaysia Holdings Berhad was examined, revealing critical inefficiencies such as manual order processing, fragmented stock allocation, and the absence of real-time tracking, leading to delays, inaccuracies, and operational bottlenecks.

The model development phase utilizes ArchiMate modelling, a widely recognized framework for enterprise-wide architecture representation, ensuring business-IT alignment, interoperability, and process optimization. While BPMN and UML are common in business process modelling, ArchiMate was selected because it maps the relationships between the layers of business, application, and technology. This phase involves mapping the current "As-Is" workflow using stakeholder inputs and transaction data, followed by designing the "To-Be" framework, which integrates TMS, CRM, and a centralized dashboard, all synchronized with Infor M3 ERP to enhance automation, real-time data flow, and decision-making. This structured framework ensures seamless system interoperability, supply chain visibility, and process standardization, addressing the key inefficiencies identified in the preliminary study.

The model evaluation phase applies a mixed-methods approach, combining Delphi-based expert validation, thematic analysis, and usability testing to assess the framework's effectiveness, scalability, and usability. A purposive sampling strategy was employed to select 12 experts with domain expertise in SCM, EA, digital transformation, and enterprise systems implementation. The Delphi Method [22] facilitated iterative feedback collection, ensuring expert consensus on the framework's practical feasibility and strategic alignment. Thematic analysis [23] was conducted using NVivo software, with Krippendorff's Alpha ensuring inter-rater reliability in coding expert insights. The System

Table 3. Selection Criteria for Expert Panel

Criteria	Details
Domain Expertise	Specialized knowledge in SCM, logistics, enterprise architecture, digital transformation, and project management
Industry Relevance	Expertise in FMCG, healthcare, supply chain digitalization, and enterprise systems implementation
Academic Background	Industry certifications or researchers with peer-reviewed publications in enterprise architecture or supply chain management
Years of Experience	Professional experience ranging from 13 to 30 years in relevant fields
Diversity of Perspectives	A mix of academic and industry professionals to ensure a balanced evaluation
Geographical Representation	Includes experts from Southeast Asia and international regions for global perspectives

Usability Scale (SUS) [24] was applied to measure the framework's usability, efficiency, and adoption feasibility, confirming its practical utility for real-world SCM operations. The expert panel was selected based on predefined domain expertise, industry relevance, and years of experience, as outlined in Table 3.

4 Analysis and Findings

Developing and evaluating the Digital Enterprise Architecture SCM framework for MSM Holdings Berhad follows a rigorous DSR methodology, ensuring both theoretical validity and practical applicability. This structured approach systematically identifies inefficiencies, develops a digital integration framework, and conducts empirical validation to enhance automation, real-time tracking, and system interoperability in the FMCG industry. With increasing digital transformation demands, the study prioritizes operational transparency, process efficiency, and data-driven decision-making to mitigate supply chain bottlenecks.

The study is structured into three phases: analyzing the current (As-Is) workflow through literature review, stakeholder interviews, and transaction log analysis to identify inefficiencies; developing a digitally integrated (To-Be) framework incorporating automation, system interoperability, and process optimization; and empirically evaluating the model through expert validation and usability assessments to measure feasibility, scalability, and effectiveness. This structured approach balances theoretical rigour and practical implementation, reinforcing the framework's viability in real-world SCM operations at MSM Holdings Berhad.

4.1 Analysis of the Current Order Processing Workflow (As-Is)

The As-Is order processing workflow analysis at MSM Holdings Berhad reveals significant inefficiencies across key operational stages, including order creation, stock allocation, truck assignment, fulfilment, and proof of delivery. These inefficiencies stem from manual processes, fragmented data flows, and a lack of real-time tracking, leading to operational delays, miscommunication, and financial discrepancies. Process documentation reviews, stakeholder interviews, and transaction log analyses highlight the absence of automation and system interoperability, resulting in stock misallocations, delivery delays, and invoice disputes. Table 4 summarizes these workflow bottlenecks, emphasizing the critical need for process optimization.

Manual order placement via email or verbal communication leads to tracking inconsistencies, missing orders, and duplication errors. Stock allocation depends on manual SKU verification, increasing processing delays and inventory inaccuracies. The truck assignment process remains disconnected from warehouse operations, causing scheduling inefficiencies and extended delivery times. The lack of real-time fulfilment tracking also prevents customer service teams from monitoring deliveries, delaying invoicing and dispute resolution. The proof of delivery (POD) system, still reliant on paper-based documentation, exacerbates reconciliation delays, contributing to 18.2% of invoice disputes and financial discrepancies (see Fig. 2).

Table 4. Key Issues in Current (As-Is) Order Processing Workflow

Process Stage	Identified Issue	Impact on Efficiency
Order Creation	Sales request orders via email/verbal communication	Lack of order tracking and miscommunication
Stock Allocation	Manual SKU verification due to errors in warehouse data	Delayed order processing, increased errors
Truck Assignment	Manual truck allocation process	Increased logistics delays
Order Fulfillment	No real-time tracking of deliveries	Lack of visibility, delays in invoicing
Proof of Delivery (POD)	Paper-based documentation, missing PODs	Invoice disputes, reconciliation delays

The absence of automation and digital integration significantly hampers supply chain efficiency, reinforcing the necessity for a structured digital transformation strategy. The TOE framework highlights the importance of technological adoption, organizational process optimization, and compliance with evolving business environments. The workflow lacks seamless IT-business alignment, requiring an enterprise architecture-driven approach for structured process integration. TOGAF ensures system-wide interoperability, enhancing order processing efficiency, stock accuracy, and logistics coordination.

Beyond automation, KM is crucial in improving decision intelligence and operational agility. The SECI model supports structured knowledge sharing and real-time insights, minimizing workflow inefficiencies caused by data silos and manual intervention. Implementing an EA-driven framework integrated with KM principles will enhance real-time visibility, system standardization, and predictive decision-making, addressing MSM Holdings Berhad's supply chain inefficiencies. The fragmented and inefficient As-Is workflow underscores the necessity of transitioning towards a technology-driven, data-integrated SCM framework. The findings justify a shift towards digital SCM, incorporating enterprise-wide process automation, AI-driven analytics, and real-time data visibility to optimize supply chain performance, reduce errors, and improve financial reconciliation.

4.2 Development of the Proposed Framework (To-Be)

The proposed Digital Enterprise Architecture SCM framework resolves inefficiencies by integrating automation, system interoperability, and real-time tracking, ensuring streamlined data flow and cross-functional collaboration. Built on EA principles, it employs Business Process Modeling (BPM) and ArchiMate modelling to enhance transparency, efficiency, and data-driven decision-making. Key components include TMS for automated logistics, CRM for systematic order tracking, a centralized dashboard for real-time analytics, and Infor M3 integration for seamless synchronization across inventory, logistics, and sales. These integrations eliminate manual errors, enhance operational agility, and optimize supply chain responsiveness.

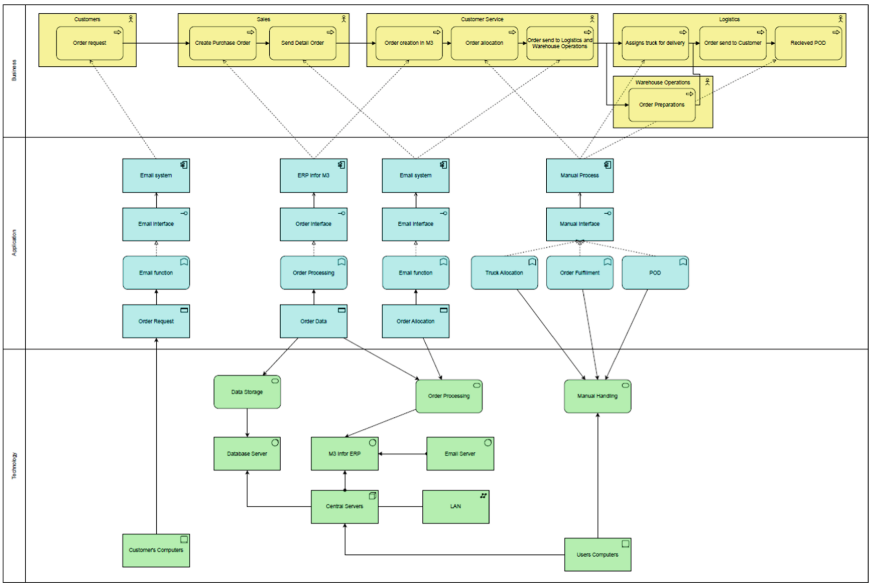

Fig. 2. Current (As-Is) Order Processing Workflow (*Refer to this link for a detailed diagram* https://bit.ly/scm-as-is).

A comparative pre- and post-automation performance analysis confirms substantial improvements (see Table 5). The automated framework reduces stock allocation errors by 42.3%, truck assignment delays by 34.6%, and proof-of-delivery (POD) disputes by 70.8%, validating real-time tracking and digital documentation as critical enablers of accuracy and efficiency. The system accelerates order processing by 48%, reinforcing enterprise-wide integration as a primary driver of cost reduction, process standardization, and supply chain resilience. These advancements position MSM Holdings Berhad for enhanced decision-making, increased visibility, and sustainable digital transformation.

Table 5. Projected Performance Improvements with the To-Be Framework

Process Stage	As-Is (Manual Process)	To-Be (Automated System)	Improvement (%)
Order Processing Time	4.8 h per order	2.5 h per order	48.0% faster
Stock Allocation Errors	12.3%	7.1%	42.3% reduction
Truck Assignment Delays	2.6 h per order	1.7 h per order	34.6% faster
Proof of Delivery (POD) Issues	18.2% of invoices disputed	5.3% of invoices disputed	70.8% reduction

The framework embedding these elements strengthens MSM Holdings Berhad's agility, efficiency, and competitiveness in an evolving supply chain landscape. The structured digital integration model, (see Fig. 3), presents a seamless transition from the inefficient As-Is workflow to an optimized, automation-driven To-Be framework.

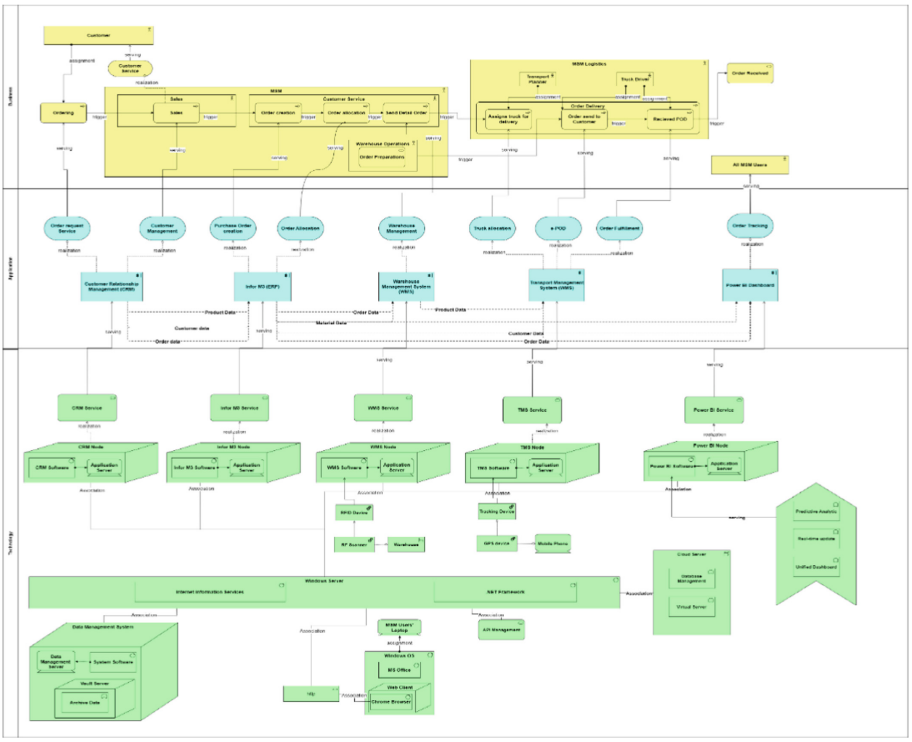

Fig. 3. Proposed (To-Be) Order Processing Workflow (*Refer to this link for a detailed diagram* https://bit.ly/scm-to-be).

Aligned with the TOE framework, the proposed solution ensures technological adoption, organizational readiness, and environmental compliance. Automation via TMS, CRM, and real-time dashboards addresses inefficiencies in data entry, fragmented workflows, and limited operational visibility. Predictive analytics and digital record-keeping improve risk management, while enterprise-wide KM principles facilitate continuous learning, structured data utilization, and real-time decision intelligence This transformation ensures supply chain processes are fully interconnected, responsive, and resilient, reinforcing MSM Holdings Berhad's capability to meet dynamic market demands with precision and efficiency.

4.3 Framework Evaluation and Validation

The Digital Enterprise Architecture SCM framework underwent rigorous validation to assess its effectiveness, usability, and scalability in addressing operational inefficiencies.

A mixed-methods approach, integrating expert evaluation through the Delphi Method and usability testing via the System Usability Scale (SUS), ensured comprehensive assessment. The Delphi method engaged twelve experts facilitating structured feedback collection, iterative refinement, and validation of technical feasibility and business alignment. Thematic analysis using NVivo confirmed consistency, with Krippendorff's Alpha (KA = 0.82) indicating high inter-rater reliability. The framework was evaluated against five key criteria—process efficiency, system integration feasibility, scalability, operational usability, and strategic applicability, demonstrating strong consensus on its effectiveness.

Delphi expert evaluation results indicated high confidence in the framework's ability to enhance supply chain operations, with 91% supporting improvements in process efficiency and 85% validating system integration feasibility. Recommendations emphasized strengthening API-based interoperability, expanding predictive analytics, and optimizing cloud infrastructure for scalability. These insights reinforce the framework's strategic fit for digital transformation, ensuring seamless adoption and long-term operational efficiency. Integrating automation and real-time analytics was critical for improving responsiveness, visibility, and decision-making in SCM. The expert feedback is summarized in Table 6.

Table 6. Delphi Expert Feedback Summary

Evaluation Criteria	Positive Response (%)	Key Suggested Improvements
Process Efficiency	91%	Improve workflow automation
System Integration Feasibility	85%	Enhance API-based interactions
Scalability	78%	Strengthen cloud infrastructure
Operational Usability	82%	Improve data visualization tools
Adherence to Industry Best Practices	87%	Expand predictive analytics

Usability testing through SUS further validated adoption potential, yielding an average score of 75.71, classified as "Good Usability." While Experts 5 and 6 rated usability above 80, indicating strong adoption potential, Expert 4's lower score 52.5 highlighted areas requiring refinement, particularly in workflow simplification and user interface design. These findings align with prior usability research, underscoring the need for iterative design improvements to enhance user experience and streamline system interactions. The results confirm that the framework is well-positioned for enterprise adoption, with targeted refinements ensuring enhanced functionality, ease of use, and industry alignment before full-scale implementation. This is summarised in Table 7.

$$SUS\ Score = \left(\sum(odd\ items\ score - 1) + \sum(5 - even\ items\ score)\right) \times 2.5$$

Table 7. System Usability Scale (SUS) Scores

Expert ID	SUS Score	Usability Rating
Expert 1	77.5	Good Usability
Expert 2	75.0	Good Usability
Expert 3	75.0	Good Usability
Expert 4	52.5	Needs Improvement
Expert 5	80.0	Excellent Usability
Expert 6	90.0	Excellent Usability
Average SUS Score	**75.71**	**Good Usability**

4.4 Managerial Implications of Findings

The findings provide actionable insights for supply chain leaders seeking to enhance operational resilience and efficiency through Industry 4.0-driven digital transformation. Strategic agility is improved as enterprises can minimize stock misallocations and proof-of-delivery disputes by leveraging automated data synchronization, ensuring real-time visibility and accuracy in inventory tracking and logistics coordination. Operational efficiency is strengthened through AI-driven demand forecasting and real-time dashboards, enabling better supply-demand alignment while reducing order processing delays and inefficiencies associated with manual workflows.

Decision intelligence is enhanced as KM repositories and predictive analytics empower organizations to mitigate manual errors, improve decision accuracy, and implement proactive risk management strategies. The integration of structured knowledge management fosters a data-driven culture that optimizes SCM operations and enhances responsiveness to disruptions. Scalability is ensured through the EA-driven digital transformation framework, allowing FMCG firms to seamlessly integrate future technological advancements such as blockchain, IoT, and AI-based automation, ensuring long-term adaptability and competitiveness in evolving supply chain ecosystems.

By implementing these strategic insights, organizations can accelerate their digital maturity, optimize supply chain processes, and enhance decision-making capabilities. This structured approach ensures that firms transition from reactive problem-solving to proactive, data-driven supply chain management, fostering agility, resilience, and sustained growth in an increasingly digitalized market landscape.

5 Conclusion

This study develops a Digital Enterprise Architecture Supply Chain Management (SCM) framework, integrating Enterprise Architecture, Knowledge Management, and the Technology-Organization-Environment framework to drive supply chain digital

transformation. Addressing inefficiencies in manual order processing, fragmented data flows, and limited supply chain visibility, the framework leverages automation, system interoperability, and real-time decision intelligence to enhance operational efficiency and strategic agility. Enterprise Architecture ensures business-technology alignment and scalability, while Knowledge Management strengthens knowledge codification and process optimization, facilitating data-driven decision-making.

Empirical validation through Delphi expert reviews and System Usability Scale testing confirms the framework's feasibility, usability, and adaptability. Expert feedback highlights process automation as a key enabler of workflow optimization, while IT integration enhances cross-functional collaboration and operational efficiency. The System Usability Scale score of 75.71 reinforces the framework's strong usability, with further enhancements recommended for API-based interoperability, user experience design, and AI-driven predictive analytics. The structured Technology-Organization-Environment framework approach ensures that digital adoption aligns with technological readiness, organizational restructuring, and compliance requirements, supporting enterprise-wide SCM transformation.

Beyond MSM Malaysia Holdings Berhad, the framework demonstrates cross-sector adaptability, making it applicable to industries with complex supply chain ecosystems, such as automotive, healthcare, and retail. Its scalable AI-driven capabilities, including automated logistics, predictive analytics, and intelligent decision support, allow organizations at various stages of digital maturity to adopt and expand SCM automation. Furthermore, the Knowledge Management-driven learning approach provides a replicable model for industries that rely on real-time data access and standardized decision-making, reinforcing its potential as a universal strategy for supply chain optimization.

This study provides a scalable roadmap for enterprise-wide SCM digitalization, reinforcing Enterprise Architecture as a strategic enabler of intelligent, knowledge-driven supply chains. Future research should explore advanced AI-driven predictive analytics, blockchain-enabled order tracking, and expanded automation strategies to further enhance supply chain transparency, security, and adaptability in rapidly evolving business environments.

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The Data Empowerment of Different Stakeholders in Organisations During Digital Transformation

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Abstract. Digital transformation has become an important focus point for organisations striving to adapt and thrive in today's dynamic and digital business environment. At the core of this transformation is data democratisation, which aims to make data more readily accessible and usable across various organisational levels for data driven decision making. This systematic literature review (SLR) explores the impact of data democratisation on different stakeholders, including c-suite executives, managers, and general employees, during the digital transformation journey. The research problem identified is how data democratisation empowers stakeholders, and the challenges encountered in this process. This study employed a rigorous selection process to analyse peer-reviewed articles, case studies, journal articles, conference papers and industry reports. Through the systematic analysis of 30 papers covering the topics of "Data Democratisation", "Digital Transformation" and "Stakeholders" 3 main themes and 10 sub themes of stakeholder empowerment were identified. This synthesis highlights success case studies and areas for improvement in implementing data democratisation initiatives. This systematic literature review (SLR) contributes to advancing knowledge on how data democratisation empowers stakeholders during digital transformation, offering valuable insights for organisations seeking to leverage data-driven approaches for sustainable growth and competitive advantage.

Keywords: Data democratisation · Digital Transformation · Organisations · Stakeholders · Empowerment

1 Introduction

In the digital age in which we now live, data is increasingly understood as one of the most important assets within organisations and society as a whole [1, 2]. The correct utilisation of this asset to attain valuable insight can allow organisations to attain a competitive advantage [3], by providing insightful information on key indicators such as customer behaviour, market trends and operational efficiencies [4]. Data Democratisation is defined as the provision of organisational data assets to all employees in an organisation while having reasonable limitations on legal confidentiality and security [5]. Understanding the impact of data democratisation is important for organisations

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striving to stay agile [2] in a rapidly evolving business landscape. Business agility can be defined as an organisation's ability to adequately respond to external changes to seize market opportunities and mitigate threats in a timely manner [6, 7].

Digital transformation (DT) often generates vast amounts of data which is regarded as an important asset for the digital transformation process itself to occur [8]. The digital transformation journey involves the integration of digital technologies into an organisation's value creation processes and results in a restructuring of the organisation's strategy [9], this encompasses all aspects of an organization [10]. Digitisation in digital transformation is thus transformative for business and a key determinant for the competitiveness and sustainability of the organisation, especially for Small and medium enterprises (SMEs) [11].

DT thus fundamentally changes an organisation's operations which causes improvements to products, services, competitive advantage, customer experiences, business model innovation and business processes [12]. In addition to transforming business operations, digital transformation also changes the way organisations hire employees by integrating digital tools and data-driven analytics which enable better hiring decisions by human resource executives [13]. Although there is high potential for data to be used as a strategic asset, many organisations struggle to leverage its value due to two barriers: limited data literacy among employees and restricted access to organisational data [2]. Limited data literacy among employees reduces their ability to understand the data they have been given and reduces their ability to find meaningful trends and patterns which may be useful for making strategic decisions. Restricted access to organisational data also has the problem of potentially reducing the context necessary for making meaningful connections and deriving impactful insights from the data which would limit a user's ability to make strategic decisions from the incomplete data The limiting of data makes its usefulness to its users limited [14]. As such this highlights the importance of democratising this data to derive meaningful insights and drive strategic decisions so that it is not limited and so make it useful.

Due to the increased importance of data democratisation, this systematic literature review addresses the following research question, "*How does data democratisation empower different stakeholders within organisations in accomplishing their tasks and objectives during digital transformation?*". This study specifically focuses on the impact on stakeholders such as executives, managers, and general employees on analysing how access to democratised organizational data influences their decision-making capabilities and operational effectiveness during the organisation's digital transformation journey.

In the second section the background on the existing literature on this topic is discussed. In the third section, the research methodology is discussed. In the fourth section the findings are presented. In the fifth section of this paper is then a discussion on the findings, highlighting important insights. In the sixth section of this paper is then a conclusion on how the findings answer the research question initially proposed.

2 Literature Background

Digital transformation allows organisations to leverage digital technologies in their value propositions and this creates large amounts of data that once shared can be utilised by different stakeholders in the organisation and value creation be better achieved [8]. Data

democracy in the organisation can encourage an understanding of shared responsibility at all organisational levels [15] as data is shared and silos are restricted allowing a broader perspective of the organisation for everyone.

In the next section, an in-depth explanation of the history and relevance of data democratisation, digital transformation and stakeholder empowerment and their interrelationship will be discussed.

2.1 Digital Transformation

Digital transformation research has received particular attention in recent years [16, 17], yet there is little agreed understanding surrounding the concept as it is synonymously interchanged with digitisation and digitalisation [18], and it has many definitions depending upon perspectives and perceptions [19]. It generally entails the use of digital technologies in transforming the business model and value offering given by a company. These technologies include data analytics, cloud computing, the internet of things and social media [8].

Implementing digital transformation changes into an organisation requires a change in mindset and an openness in the organisational culture this is because hierarchies and silos are understood to be one of many major stumbling blocks for the digitisation of an organisation [8]. Secondly, structural rigidness and poor synergy play a role in restricting an organisation to change [8]. Having a digitally transformed company causes more data to exist within the company and in most companies the ability to analyse it is left to a few data scientists [3].

2.2 Data Democratisation

Data democratisation refers to providing broader access of data to technical and non-technical data users to empower them from being data users but data scientists who can provide valuable insights [14]. The quick access to data and decision-making support that data democratisation allows, are important elements for a business to grow [20].

The value creation opportunities that arise from data being adequately analysed and accessed are significant, it is for this very reason that organisation's view data democratisation as a high priority [2].

According to [21], there are 3 main pillars for data democratisation which are: share data, share data skill, and share data responsibility. Share data refers to the data analytics tools, mainly used by a data science team to analyse data. Share data skill refers to the skills required for using these tools to extract patterns from the data. Shared data responsibility refers to taking care of the risk and security related issues of the data [21]. Data democratisation looks at empowering stakeholders of all levels with the ability to analyse and draw insight from the data they have been given, it is not merely placing datasets in an open shared drive, nor when the data seekers have very limited technical skills [21]. As such, it is important to understand the extent of users' familiarity with the data and data processing tools, as successful data democratisation and digital transformation also entails user engagement [22, 23].

2.3 Stakeholder Empowerment

Stakeholders, as defined by Hill and Jones [24: p. 133], are "constituents who have a legitimate claim on the firm." In the context of this paper, stakeholders refer to individuals or parties operating in the internal environment of an organisation, who are directly affected by its success or failure. This includes both executives and general employees. For stakeholders to be empowered with data, they must be trained to know how to use it [4]. A benefit of data sharing is that, data scientists in organisations are relieved of low-level tasks and are enabled to use their expertise on tasks which require deeper technical understanding [14]. Since data democratisation increases a sense of data responsibility throughout the organisation, non-technical employees are empowered to collect high quality data [14], which is an important factor for business decisions to be made [25]. Organisational management is empowered with a more analytically proficient workforce as requisite analytical skills are expected to be in shortage, for example in America [14]. A data literate workforce of analytically equipped employees allows business value to be created from data [26]. Additionally, addressing knowledge gaps among stakeholders can help reduce one of the common causes of failure in digital transformation efforts [27].

3 Research Method

The research method the researcher has applied for this study is a systematic literature review (SLR). An SLR entails formulating a research question, searching the extant literature, screening the literature found for inclusion in-line with the formulated research question. Assessing the quality of studies found, extracting data, and analysing the data [28]. The following section explains the process followed for analysing and reviewing the literature used in this literature review and this is graphically depicted using the Prisma Flowchart diagram in Fig. 1. Using the search terms of "Digital Transformation", "Data Democratisation" AND "Stakeholders" a total of 168 terms were found from the Google Scholar search engine. Making use of the Emerald, ProQuest, AIS e-library, Elsevier, and Scientific research publishing databases these papers were identified. An additional 14 papers related to Data Democratisation, critical success factors for digital transformation and stakeholder engagement in data democratisation were found. The 183 papers found were reviewed for duplicate copies, after this review, 58 papers were discarded.

Eligibility was reviewed on accessibility and relevance to data democratisation and digital transformation. In this stage of review, papers found to require payment for access were discarded. Papers with a particular focus on data governance were discarded as irrelevant to the main area of focus for this research report. Finally, papers which focused on cloud computing or were unrelated to data democratisation or digital transformation were discarded.

Papers which were included and used in this research report focused on digital transformation and its relationship with data democratisation and stakeholders in organisations, this included peer reviewed journal articles and conference proceedings and only papers published from 2010 onwards to ensure relevance.

To ensure that the papers included in this research report are relevant and insightful to answering the research question proposed, the following criteria was used to assess

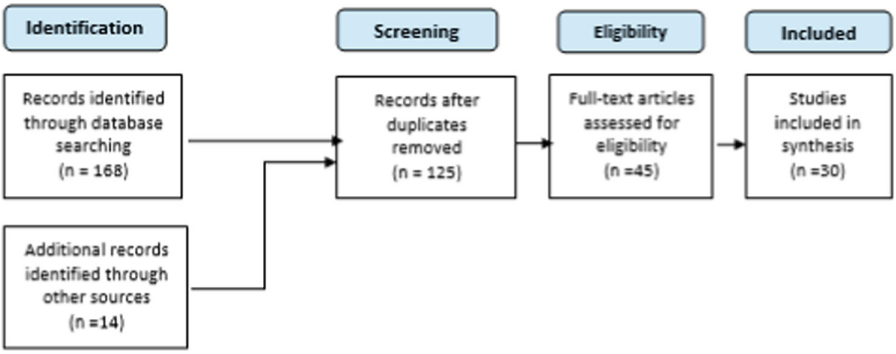

Fig. 1. Prisma Flowchart

the quality of these papers: the extent to which the research methodology and data analysis techniques used were discussed in the paper, relevance of the paper to digital transformation, data democratization or both, whether the findings were concise and provided actionable insights. The extent to which the papers met the criteria above resulted in their inclusion in the report.

Data extraction was the process of attaining relevant themes and sub-themes found from reading the main articles and transcribing key quotes that arose from the papers found which had a direct correlation with the main theme in the papers.

Thematic analysis is a method in qualitative data analysis where the patterns of meaning are identified and interpreted [29]. This Systematic literature review made use of thematic analysis on pre-existing qualitative literature on data democratisation, digital transformation, and stakeholder empowerment. Thematic analysis is widely used for analysing qualitative data [30].

4 Findings

The objective of this paper was to identify the means in which stakeholders are empowered by data democratisation during the digital transformation process in organisations. Through an extensive analysis of the existing literature, 3 main themes were discovered along with sub themes related to these themes. These findings were documented in Table 1. The "Main Theme" column outlines the main benefits derived from data democratisation while the "Sub-Themes" column provides further elaboration on the main theme, in how it directly relates to stakeholders. The "Literature References" column shows some of the literature which supports the main themes indicated and the "Stakeholders Empowered" column highlights which stakeholders in the organisation benefit from having more data-driven capabilities in the context of the sub theme for that row.

Table 1. Thematic breakdown of research findings

Main Theme	Sub Themes	Literature References	Stakeholders affected/empowered
Improved decision making	Better analytical capabilities	[2, 20, 31]	All organisational stakeholders
	Improved knowledge sharing	[21]	All organisational stakeholders
	Job enrichment	[31]	Non-technical staff
	Increased data-driven insights	[4, 14]	Non-technical staff and all organisational stakeholders
Increased Operational Efficiency	Increased data literacy in workforce	[4, 26]	All organisational stakeholders
	Reduced reliance on data experts for data access	[14]	Non-technical staff
	Data-driven culture	[6, 8, 15, 32]	All organisational staff
	Shared Organisational vision	[33, 34, 35]	All organisational stakeholders
	Improved organizational processes		
Business agility	Adaptability to market changes	[2, 6, 16, 36]	Top management

5 Discussion

The following sections present the sub themes identified in Table 2 and also highlights the barriers to stakeholder empowerment.

5.1 Improved Decision Making

Access to more data regarding business processes, business context and consumer behaviour allow all levels of stakeholders in an organisation to make decisions that are contingent on the overall business strategy rather than only focusing on that stakeholder group's particular departmental or divisional goals.

An example of the successful implementation of data democracy to drive decision making is found in Airbnb's Data University as detailed by [14], whereby all levels of employees made decisions more in-line with business goals as they were exposed to high level machine learning tools and frameworks. All employees were empowered with data access, data education and the necessary data tools which resulted in all employees

including those with low technical expertise using dashboards and SQL queries to answer questions they encountered in their job tasks. This kind of increase in role responsibility and diversity of skillset required to perform one's tasks in their job role is regarded as job enrichment. This case study highlights that a barrier for improved decision making due to data democratisation is the extent to which technical and non-technical employees are educated about the data and the tools they are using to interact with the data.

Another case study which shows that data education, users of the data being aware of what the data means and from where it comes and how it can be used is found in the case study of Viacom's Science Central initiative where it was found that although the data scientists knew how to manipulate data in an extensive manner, they did not understand the nuances of how to make a show that consumers would enjoy, but other employees in the organisation would know how to extract more insight from show data so as to make better shows for Viacom. Due to democratising the data in Viacom, directors and producers who understood their consumer base better were able to make better decisions from the data due to their expertise, this resulted in more effective marketing campaigns being produced.

5.2 Increased Operational Efficiency

From the case study of data democratisation in Airbnb by [14] it was found that when data had been democratised to all levels of employees in the organisation, Airbnb's specialist data scientists had received a 50% decrease in ad hoc queries and requests for data processing. As such data democratisation allows data scientists to be able to focus on more difficult queries and data-oriented business problems [4], in empowering all stakeholders with data access and data literacy, operational resources such as analytical skills are more distributed and operationalised which can result in a better value proposition in the company's value chain.

Another example of data democratisation improving operational efficiency is found in the case study of a Swedish Bank analysed by [3] in which it was found that the efficiency of the work produced by employees in the bank was improved due to more actors in the organisation being more data driven in their tasks as compared to relying on intuition. This has the effect of fostering a data driven culture in an organisation in which decisions and actions for all organisational stakeholders can be explained by data. This aids in creating a shared outlook on the organisation for all stakeholders.

However a barrier to increased operational efficiency due to data democratisation is a lack of data governance policies and frameworks in an organisation, as it is understood that data democratisation does not entail all data being shared to all stakeholders in an organisation [21] but in the right people having access to the correct data they require as was discovered in the survey results of the Swedish bank case study. It is thus important to manage the risk that comes with democratising data which can only be achieved by creating governance protocols.

5.3 Business Agility

Successful data democratisation is an enabler for more innovative solutions as gaps can be identified across the organisation in an integrated manner, this permits organisations

to react to market changes in a timely fashion. Knowledge sharing across the organisation entails, for example, the accounting department being aware of the human resources department's statistics, in the short term these statistics may seem inconsequential however due to the data being shared across the organisation, connections and correlations can be established over time which results in the data being of great value [31]. An example of this is with Walmart's data café as researched and presented by [14]. It was found that pricing miscalculations which had occurred in a stage of the supply chain resulted in products being sold for a higher price than intended which caused a significant reduction in customer sales, this issue was able to be solved because data for all processes of the supply chain were available, as such Walmart was able to respond timely and reduce a loss in its competitive advantage. A key barrier that can be identified in this case study is that data silos and data fragmentation are key hindrances for data democratisation being a useful tool for business agility and timely responses to market changes.

5.4 Conceptual Contribution

Successful data democratisation in an organisation equips all levels of stakeholders with data literacy and the ability to analyse data to make meaningful decisions for the organisation at all levels, which is what increases operational efficiency and business agility. In order to operationalize the findings, the DIKW pyramid was used to categorize the findings.

The DIKW pyramid is an appropriate model which shows that when data is processed, it becomes information. This information allows further analysis which can show insightful trends and patterns, this insightful information leads to knowledge, and when this knowledge is acted upon by stakeholders, it is wisdom. The DIKW pyramid is shown in Fig. 2.

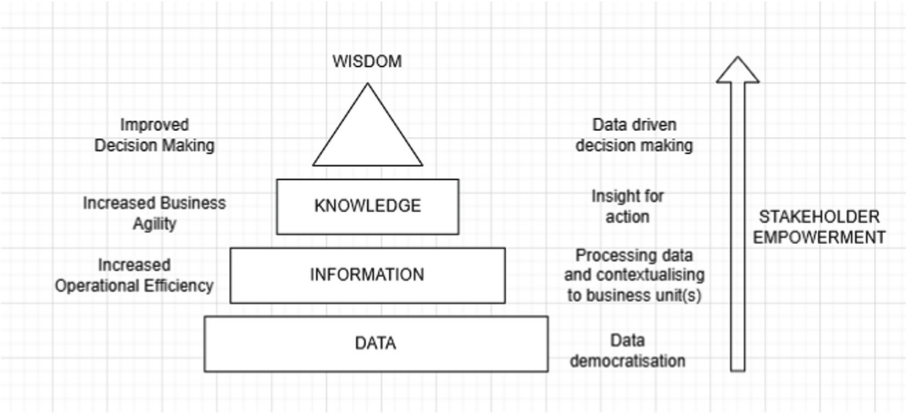

Fig. 2. The DIKW Pyramid

By democratising data, all stakeholders in an organisation are equipped with the lowest level of the pyramid, however as this research report has highlighted, successful

data democratisation entails being able to make use of and make sense of the data, which results in stakeholders processing the data to derive meaningful contextual insights from it. This information empowers stakeholders with knowledge and allows them to make decisions of their business area within the wider context of the organisation, this ability to act upon this contextualized information is wisdom. As such, by democratising data to all stakeholders in an organisation, there is an increase in the organisation's capacity for wisdom in all organisational levels which also results in increased business agility and improved competitive advantage.

6 Conclusion

The aim of this paper was to investigate and discover the means in which stakeholders in an organisation undergoing digital transformation are empowered by data democratisation. 3 main themes and 10 sub themes were discovered that showcased stakeholder empowerment. A key insight discovered was that all levels of employees are better empowered when data democratisation occurs in an organisation to make data driven decisions. Companies that make use of data-driven approaches have been reported to perform better than those which work on intuition [21] as such, the importance of data democratisation lies in all levels of the organisation not working on intuition, but data, a key finding thus, through this systematic literature review is that data democratisation is beneficial for an organisation but faces risks, it is thus crucial to create data governance frameworks and policies in an organisation so as to reduce data leaks or security compromise.

Digital transformation is not well understood in Information systems [16] particularly due to the complexity of the many conceptual variables that encompass the digital transformation process. Secondly the term of an organisation being "data driven" is still very vague for employees [3] and no core definition is understood for what constitutes a data drive culture in an organisation, as there is no definition yet or little understanding [8]. Future research can focus on defining these key terms in the context of data democratisation through creating a governance reference framework detailing the key drivers for how data is meant to be stored, accessed and by whom, so that it is still democratised but not available to all stakeholders of the organisation.

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Product Repurchase Decision in the Offline-to-Online Business Model: A Mental Accounting Theory Perspective

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Abstract. This study explores consumers' offline-to-online repurchase intentions. The offline-to-online model captures consumers who experience and understand product features at a sales or physical location before making purchases on an e-commerce platform or through a live streaming platform. Bathroom water hardware products have unique qualities, and consumers often prefer to make a purchase after experiencing them in person. The research participants comprised consumers who attended the physical special sale organized by the Water Hardware Association in Taiwan or visited the physical stores of bathroom companies. Subsequently, these consumers purchased bathroom water hardware products through e-commerce platforms or via Facebook live streaming provided by the Water Hardware Association or the companies. Our analysis of 107 consumers regarding bathroom water hardware products within the offline-to-online model reveals that quality, price, epistemic, online conditional, and offline conditional values positively influence the offline-to-online repurchase intention. Financial and privacy risks show no impact on offline-to-online repurchase intention, nor do electronic word of mouth. However, physical experience has a positive impact on consumers' offline-to-online repurchase intention.

Keywords: O2O model · Offline to online · Online to offline · Repurchase intention · Bathroom water hardware products

1 Introduction

Some products have a marketing model that is well-suited for the offline-to-online approach. Initially, a physical store allows consumers to explore and verify the product's functionality and design. While consumers may not make an immediate purchase, they might decide to buy online after a short or extended period. Bathroom water hardware products serve as a prime example of this model. These products, which primarily include faucet-related items used in kitchens and bathrooms, are ubiquitous in daily life and present unlimited business opportunities. Therefore, this study explores the offline-to-online repurchase intention specifically for bathroom water hardware products.

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According to Rampell [1], who first coined the term "O2O commerce," the goal was to find customers online and bring them to real-world stores. The rationale is that although e-commerce could replace a large part of traditional physical retail, certain elements of physical shopping cannot or should not be replicated digitally. Integrating e-commerce with physical retail is the core of O2O [2]. According to Agrawal. [3], O2O commerce—that is, online-to-offline commerce—connects service providers with consumers through online platforms or smartphone applications. Hwang and Kim [4] pointed out that O2O commerce can proceed in two directions: offline-to-online and online-to-offline. Offline-to-online commerce refers to the extension of offline retail stores' products or services to online platforms. Through a online sales channel, vendors aim to meet the needs of consumers spontaneously and eventually gain profitability. A common model is for consumers to scan a QR code in a physical store or on an advertisement to access an online product webpage where they place their orders and pay for the products [5]. By contrast, online-to-offline commerce is a new business model that enables online consumers to fulfill time-sensitive and location-specific needs offline. The O2O model bridges the gap between online and offline to attract potential consumers. The concept of localization allowed O2O store operators to proactively market their products and services to specific consumers, with benefits such as distinct profit models, precise targeting of consumer segments, traceability of transactions, and reduced logistics costs [6]. O2O can be further categorized as (1) online to offline, (2) offline to online, (3) offline to online to offline, or (4) online to offline to online. For example, the offline to online to offline model allows the consumer to visit a physical store to experience the product, go to an online shopping site to purchase the product, and subsequently pick up the product at an offline physical store. Online to offline to online encompasses the process of purchasing a product on an online shopping site, picking it up at an offline store, and returning to the online shopping site to leave a comment or rating.

Currently, O2O commerce attracts consumers by offering discounts, real-time information, and booking services, thereby converting potential customers on the Internet into real customers in physical stores [6]. Many physical stores are establishing online platforms due to common cross-channel shopping behaviors among consumers [7], For example, after experiencing a product in a physical store, a consumer might go online to read reviews or buy it online; thus, online and offline channels complement each other [7]. In the past, research has heavily favored the online-to-offline business model, leaving the offline-to-online business model relatively underexplored.

Bathroom water hardware products are essential in daily life, and consumers may want to confirm the appearance and function of the products in physical stores. Therefore, the O2O model in this study refers to the offline to online model, where consumers experience and understand product features on-site at special events or physical stores before purchasing on e-commerce or live streaming platforms. This study is guided by the following research question: *What factors affect consumers' repurchase intention of bathroom water hardware products from an offline to online platform?* To construct the influencing factor model, this study adopts the perspective of mental accounting theory to explore the effects of product value, online payment experience, and merits of the deal on the repurchase intention of bathroom water hardware products.

2 Literature Review

2.1 O2O Commerce

According to Chen et al. [6], O2O applications can be categorized into three types: (1) Short-term campaigns: marketing campaigns are usually short-term, one-time events. Social marketing is mainly used with check-in or QR codes to quickly offer store awareness, such as seasonal sales or new product sales. (2) Service application: This type of application typically allows enterprises to extend their services to online platforms. (3) Connecting providers and consumers through platforms: Third-party suppliers establish specific network platforms to serve specific target groups of consumers and providers and to create a sharing economy, such as Airbnb and Uber. RohPark [8] described integrated O2O industry applications that include transportation (e.g., car rental and carpooling), space (e.g., accommodation, offices, rental apartments, and parking spaces), food (e.g., product delivery for grocery stores, meal delivery, food delivery, recipe packs, and ingredient delivery), loans, pawnshops, online employees, real estate agents, house cleaning, laundry services, hair salons, driver services, flower delivery services, and pop music videos.

From the perspective of consumer decision-making behavior, Hsu and Lin [9] considered O2O applications to be of two types. Task-oriented apps are used to increase the efficiency of customer online searches, evaluate selection options, purchase products/services or make payments, and visit physical stores to understand the functions of the products. Entertainment-oriented apps increase the joy and fun of consumer gaming, provide opportunities for social activities, and guide consumers to physical stores to make purchases. Existing empirical studies have focused on examining consumers' satisfaction with O2O services [4, 6], O2O loyalty [10], satisfaction with O2O App [11], the intention of using O2O app [8, 12], the intention for continuous use of O2O [9, 13, 14], dissatisfaction toward O2O website [15], and purchase intention in O2O commerce [16]. Most of the studies did not distinguish between online-to-offline consumers and offline-to-online consumers, with the exception of the study conducted by [6], who explored the satisfaction and behavioral intentions of Taiwanese O2O platform users (including satisfaction with the entire transaction process, online platform, and physical stores). Huang et al.'s [7] interview and focus group findings suggest that influencing factors and their intensity might vary across different channels. For example, for an online channel, price may be the main factor, while for a consumer who chooses an offline channel, physical experience and cost savings may be the main determinants of purchase.

2.2 Mental Accounting Theory

Mental accounting theory explains a person's decision making under uncertain conditions and risks from the perspective of maximizing value [17]. Value and utility connote the same meaning and are often used interchangeably [18]. When purchasing physical goods online, people are often concerned about whether the goods they buy meet their needs, and there is uncertainty about their quality. The buyer makes the purchase decision after evaluating the acquisition utility and the transaction utility. Therefore, this study

concludes that mental accounting theory is suitable for understanding the repurchase decisions of O2O consumers. According to this theory, as shown in Fig. 1, two types of utility—acquisition utility and transaction utility—affect the buyer's purchase decision. Antecedents affecting the utility of an acquisition include the value of the product and the payment, while antecedents affecting the utility of the transaction include the merits of the deal, such as financial and non-financial benefits. The financial benefits are obvious, while the non-financial benefits include saving time, energy, and transaction certainty [18].

Before purchasing a product, some consumers typically seek others' opinions of the product on the internet (i.e., electronic word-of-mouth marketing), while others may visit a physical store to try out and touch the product (i.e., the physical experience), which may help minimize uncertainty and offer the benefits of the transaction. Uncertainty aversion is very common in the choices made by consumers [19]. The quality of a product is one of the most important factors in acquisition utility [20]. In economic theory, a good value is obtained by, for example, paying a low price for a good-quality product [20]. A prior study suggested that consumers are influenced by the value system in adopting O2O services [8]. Therefore, this study also considers product value and perception of payment as antecedents of acquisition utility. Sellers provide customer experiences in physical storefronts or positive reviews by other buyers on the Internet, and these strategies are designed to enhance buyers' perceptions of the transaction or the value of the transaction. Thus, this study treats the merits of the deal as antecedents of transactional utility.

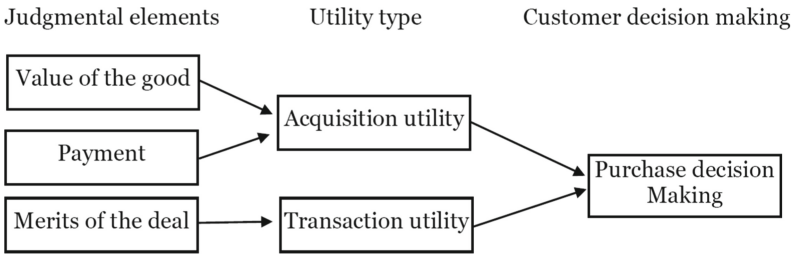

Fig. 1. Conceptual framework of mental accounting theory [18]

3 Research Model and Hypotheses

3.1 Research Model

This study is based on mental accounting theory, in which product value and online payment experience are antecedents of acquisition utility, and merits of the deal are antecedents of transaction utility. Product value includes quality value, price value, epistemic value, online conditional value, and offline conditional value. Online payment experience includes financial and privacy risks. Merits of the deal include physical experience and electronic word-of-mouth. The research model is shown in Fig. 2.

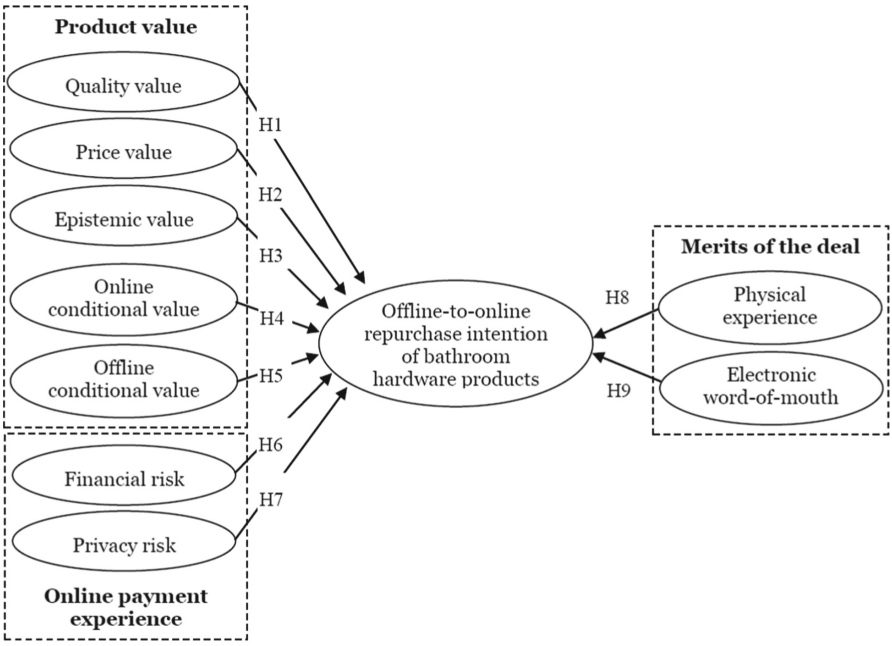

Fig. 2. Research model

3.2 Research Hypotheses

Quality value refers to the perceived utility that consumers derive from the quality performance of a product [21]. Consumers feel that high quality can establish personal shopping value and enhance purchasing intention [22]. Experiencing high-quality value in physical stores can have a positive impact on consumers' intentions to repurchase bathroom water hardware products in the offline-to-online process.

H1: *There is a positive relationship between quality value and intention to repurchase bathroom water hardware products through offline-to-online transactions.*

Price value refers to the perceived utility that consumers obtain from the price performance of a product, such as the value for money [21]. The consumer's perception of how much money a product should spend is important, as it can affect the perceived customer value of a product [23, 24]. This, in turn, will affect the final purchasing decision. Prior studies have found that price value positively affects consumers' continued intention to use O2O services [13]. If offline-to-online consumers perceive the price value as high, their intention to repurchase bathroom water hardware products from offline to online may increase.

H2: *There is a positive relationship between price value and intention to repurchase bathroom water hardware products through offline-to-online transactions.*

Epistemic value is defined as the utility that consumers derive from the novelty of a product that arouses curiosity, provides novelty, and satisfies consumer knowledge

[25]. Five consumption values—functional value, social value, emotional value, epistemic value, and conditional value—are considered, with epistemic value defined as the curiosity and pleasure that influence consumer choice behavior [25]. The physical or online advertisements, promotions, videos, etc. provided by bathroom water hardware products can arouse consumer curiosity and satisfy their curiosity and desire to acquire knowledge. If consumers feel curious, they may go offline to experience the bathroom water hardware product, which has a positive impact on their offline-to-online product repurchase intention. Hence, we propose the following hypothesis:

H3: *There is a positive relationship between epistemic value and intention to repurchase bathroom water hardware products through offline-to-online transactions.*

Online conditional value is defined as the functional or social value added by the consumer as a result of some online contingency, such as promotional activities and web advertising [25]. When consumers find themselves in special situations, they may appreciate the convenience of the Internet. As a result, bathroom water hardware companies can leverage online advertising, videos, and promotions to capture consumers' attention. Common online promotion strategies include direct promotions, coupons, bundles, quantity discounts, and gift offerings [26]. These promotional activities and web advertisements may encourage consumers to visit physical stores to experience bathroom water hardware products firsthand, positively influencing their offline-to-online product repurchase intentions. Hence, we propose the following hypothesis:

H4: *There is a positive relationship between online conditional value and intention to repurchase bathroom water hardware products through offline-to-online transactions.*

The offline conditional value refers to the functional or social value that consumers associate with offline contingencies, such as promotional activities and product demonstrations [25]. Non-monetary promotions, such as gift offerings [26], are typically provided through offline channels. This is particularly relevant for bathroom water hardware products, which possess distinct functional and aesthetic features. Physical displays allow consumers to evaluate the products' suitability more effectively. This study hypothesizes that the higher the offline conditional value provided by physical stores, the higher the offline-to-online repurchase intentions of consumers for bathroom water hardware products.

H5: *There is a positive relationship between offline conditional value and intention to repurchase bathroom water hardware products through offline-to-online transactions.*

Financial risk is defined as a consumer's awareness that an existing financial service would result in a potential monetary loss, such as cyber fraud [27]. The security of the payment system is a factor that determines the overall quality of a shopping site [28]. Most O2O services provide a payment system that is convenient to users while exposing them personal financial information to risk [4]. In this study, financial risk is defined as the concern regarding the potential harm to personal financial information when making online payments, such as in cases of account compromise or overpriced products. Financial risk is one of the most significant concerns that can negatively affect attitudes toward O2O technology [29]. This study hypothesizes that consumers who perceive online payments as being associated with high financial risks will have a reduced

intention to repurchase bathroom water hardware products through offline-to-online channels.

H6: *There is a negative relationship between financial risk and intention to repurchase bathroom water hardware products through offline-to-online transactions.*

Privacy risk is defined as the perception that consumers might lose control of their personal information, such as when personal information was used without their permission [27]. Privacy is a key factor in evaluating online and offline services [4]. Privacy risk in this study refers to concerns about harm to personal information when shopping online, such as leakage or misuse of personal data. In physical stores, using mobile phones to join official accounts, downloading and registering official apps, and using in-store augmented reality technology are ways of collecting personal information, which might cause consumers to worry about personal information being accessed, tracked, and used [30, 31]. Filling in personal information when making an online payment may also lead to data leakage. Therefore, this study hypothesizes that if offline-to-online consumers perceive a high privacy risk, it will reduce their intention to repurchase offline-to-online bathroom water hardware products.

H7: *There is a negative relationship between privacy risk and intention to repurchase bathroom water hardware products through offline-to-online transactions.*

Physical experience refers to the extent to which consumers are provided with the opportunity to test products or understand the scope of services in a physical store [32]. Physical storefronts offered sellers a unique opportunity that the vast majority of their online platform competitors could not, and that was the ability to provide consumers with a unique in-store customer experience [33]. The biggest difference between O2O commerce and pure e-commerce was the physical experience, as the user experience affected the purchasing behavior [5]. The provision of a physical product display of bathroom water hardware products enables consumers to inquire about product functions, product after-sales services, which can make consumers feel satisfied to purchase. Thus, an offline customer experience has a positive impact on the product repurchase intention of bathroom water hardware products online. Therefore, we propose the following hypothesis:

H8: *There is a positive relationship between physical experience and intention to repurchase bathroom water hardware products through offline-to-online transactions.*

Electronic word of mouth refers to a positive or negative opinion of a product that a consumer obtained from a potential or actual experienced buyer and published to others via the Internet [34]. Electronic word of mouth can occur in a variety of ways, such as forums, blogs, social networking sites, news, and website reviews, to learn about the positive or negative aspects of a product [34]. O2O e-commerce platforms facilitate a flow of information between buyers and sellers through online reviews [35]. This study hypothesizes that consumers' interaction with online reviews impacts product ratings and perceptions, which in turn influence their intentions to repurchase bathroom water hardware products both offline and online.

H9: *There is a positive relationship between electronic word-of-mouth and intention to repurchase bathroom water hardware products through offline-to-online transactions.*

4 Research Methodology

4.1 Data Collection and Participants

This study focuses on consumers who participated in the physical special sale organized by the Water Hardware Association in Taiwan or who visited the physical stores of bathroom companies. After experiencing and gaining an understanding of the product functions at the physical venue, these consumers engaged with live streaming on e-commerce platforms or Facebook fan pages provided by the Water Hardware Association or the companies. Subsequently, as respondents of this study, these consumers either made purchases on e-commerce platforms or bought products during Facebook Live sessions. A total of 107 consumers completed the post-purchase questionnaire, all of which were valid. Among the 107 valid questionnaire respondents, 57 were female, accounting for 53.3%. There were 50 males, accounting for 46.7%. Only one (0.9%) of the respondents indicated the age range 21–30. Among the others, 22 (20.6%) were aged 31–40, 33 (30.8%) were aged 41–50, 32 (29.9%) were aged 51–60, and 19 (17.8%) were aged 60 or above.

4.2 Measurement

This study developed a questionnaire based on the past literature. Four experts conducted a pre-test to review the appropriateness and suitability of the question items in the English translation for the research scenario. After conducting a small sample test, the formal questionnaire was confirmed to be suitable. The small sample pilot test used an online questionnaire and invited 30 consumers who had purchased bathroom water hardware products online to fill out the questionnaire. After the pilot test, reliability and validity tests were conducted to revise questions with poor reliability and validity. The measurement of independent variables in the research model adopted a 5-point Likert scale, with 1 = strongly disagree, 2 = disagree, 3 = ordinary, 4 = agree, and 5 = strongly agree. The dependent variable was offline-to-online repurchase intention, which was defined as the motivation and willingness of consumers to purchase the company's bathroom water hardware products again in the future [36]. The measurement scale was a 5-point scale: 1 = not at all likely, 2 = not likely, 3 = somewhat likely, 4 = very likely, and 5 = extremely likely. Appendix A provides the questionnaire items.

5 Results

5.1 Reliability and Validity

SmartPLS 3 was used to examine the reliability of the measurement model and the structural model composed of each variable. The path coefficients and significance were calculated using the bootstrap resampling method with 5000 repetitive samples. In terms of reliability testing, composite reliability and Cronbach's alpha were used to evaluate

whether the measurement items of all variables reached internal consistency. The minimum threshold value for composite reliability was 0.7 [37] and suggested threshold value for Cronbach's alpha was 0.7 [38]. As shown in Table 1, the composite reliability and Cronbach's alpha of all variables met the requirements. Confirmatory factor analysis (CFA) was used to measure whether each construct had convergent validity and discriminant validity. Table 2 shows the table of correlation coefficients, where the average variance extracted (AVE) was greater than 0.5. Appendix A presents the factor loadings for each question and confirms convergent validity because the AVE was greater than 0.5 and the factor loadings were greater than 0.5 [37]. As shown in Table 2, the square root of the AVE between the variables was greater than the correlation coefficients between the other constructs, indicating that this scale has discriminant validity.

5.2 Hypotheses Testing

In this study, structural model analysis was used for hypothesis testing. The path coefficients and significance are shown in Fig. 3, which illustrates the positive relationship between quality value and offline-to-online repurchase intention of bathroom water hardware products (path coefficient = 0.150, t = 2.434, $p = 0.015$), thus supporting Hypothesis 1. We also observed a positive relationship between price value and offline-to-online repurchase intention for bathroom water hardware products (path coefficient = 0.159, t = 2.095, $p = 0.036$), thus supporting Hypothesis 2. The relationship between epistemic value and offline-to-online repurchase intention of bathroom water hardware products was also positive (path coefficient = 0.166, t = 2.942, $p = 0.004$), thus supporting Hypothesis 3. Online conditional value and offline-to-online repurchase intention for bathroom water hardware products had a positive relationship (path coefficient = 0.218, t = 2.905, $p = 0.004$), supporting Hypothesis 4. Confirming Hypothesis 5, we found a positive relationship between offline conditional value and offline-to-online repurchase intention for bathroom water hardware products (path coefficient = 0.201, t = 2.439, $p = 0.015$). There was no negative relationship between financial risk and intention to repurchase bathroom water hardware products from offline to online (path coefficient = 0.004, t = 0.080, $p > 0.05$), thus rejecting Hypothesis 6. Further, contrary to Hypothesis 7, we found no negative relationship between privacy risk and repurchase intention of bathroom water hardware products from offline to online (path coefficient = −0.016, t = 0.313, p > 0.05). There was a positive relationship between physical experience and offline-to-online repurchase intention for bathroom water hardware products (path coefficient = 0.198, t = 2.687, p = 0.007), thus supporting Hypothesis 8. We found no positive relationship between electronic word-of-mouth and the intention to repurchase bathroom water hardware products from offline to online (path coefficient = 0.073, t = 1.235, p > 0.05), contrary to Hypothesis 9.

Table 1. Reliability analysis

Variables	Number of items	Composite reliability	Cronbach's alpha
Quality value	3	0.930	0.886
Price value	3	0.940	0.905
Epistemic value	3	0.941	0.906
Online conditional value	3	0.943	0.909
Offline conditional value	3	0.922	0.872
Financial risk	3	0.938	0.901
Privacy risk	3	0.886	0.814
Physical experience	4	0.922	0.887
Electronic word of mouth	4	0.902	0.854
Offline-to-online repurchase intention	1	1.000	1.000

Table 2. Discriminant validity

	1	2	3	4	5	6	7	8	9	10
1. Quality value	**0.903**									
2. Price value	0.688	**0.917**								
3. Epistemic value	0.310	0.456	**0.918**							
4. Online conditional value	0.701	0.682	0.377	**0.920**						
5. Offline conditional value	0.635	0.623	0.398	0.617	**0.893**					
6. Financial risk	-0.296	-0.180	-0.150	-0.369	-0.365	**0.913**				
7. Privacy risk	0.100	0.102	0.202	0.137	0.028	0.288	**0.849**			
8. Physical experience	0.628	0.580	0.450	0.627	0.588	-0.281	0.110	**0.864**		
9. Electronic word of mouth	0.484	0.584	0.463	0.506	0.635	-0.210	0.031	0.560	**0.835**	
10. Offline-to-online repurchase intention	0.748	0.766	0.566	0.775	0.756	-0.323	0.110	0.752	0.662	**1.000**

Note. The diagonal elements (in bold) represent the square roots of the average variances extracted (AVEs).

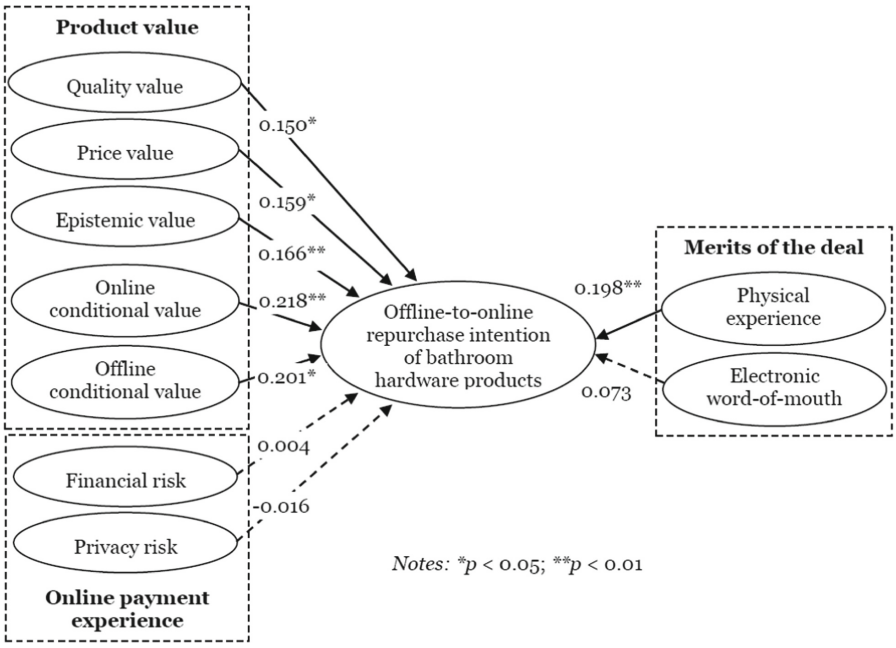

Fig. 3. Structural model results

6 Conclusion

The bathroom water hardware industry is actively undergoing digital transformation and establishing the Changhua Water Hardware Brand Alliance. In addition to traditional storefronts and displays, it has also developed online shopping platforms and marketed its products to end consumers, hoping to replicate the commercial miracle of Dingfanpo, an important water hardware settlement. This study explores the factors that affect the repurchase intention of offline to online consumers of bathroom water hardware products after the extension of the bathroom water hardware industry to online platforms. The research results show that five variables in the product value dimension—quality value, price value, epistemic value, online conditional value, and offline conditional value—have a positive impact on the repurchase intention of bathroom water hardware products through an offline-to-online process. Further, the findings indicate that the physical experience has a positive impact on the intention to repurchase bathroom water hardware products offline-to-online process transactions. However, electronic word-of-mouth has no impact on intention to repurchase bathroom water hardware products from offline to online. The possible reason is that although electronic word-of-mouth may affect repurchasing decisions because the bathroom water hardware products in this study are functional products, when the product functions or on-site experiences have been confirmed in physical stores, electronic word-of-mouth may not have an impact on the intention to repurchase bathroom water hardware products through an offline-to-online process. Notably, two variables in the online payment experience—financial risk and privacy risk—have no impact on the intention to repurchase bathroom water hardware

products through an offline-to-online process. A possible explanation is that consumers transition from offline physical to online purchases, have already learned about the company's products in physical stores or display areas or trust the company based on commentaries and are therefore more likely to trust online activities, such as online data registration and online payments.

This study offers three academic and practical contributions. First, this study explores bathroom hardware products and consumers who initially visit physical stores before purchasing online, that is, consumers in the offline-to-online mode. Second, this study finds that product value and physical experience are important factors in the decision to repurchase for offline-to-online consumers, which, in order of relative importance, are online conditional value, offline conditional value, physical experience, epistemic value, price value, and quality value. Third, we show that the online payment experience has no impact on the intention to purchase again. This may be due to the experience of physical stores, and the risk of a subsequent online payment experience will be ignored. Similarly, electronic word-of-mouth has no impact on the intention to purchase. Hence, it is possible that after experiencing physical stores, the evaluation of bathroom water hardware products is determined by product values, so consumers are less affected by other comments and opinions.

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Appendix A. Variables and Items

Variable	Item	Factor loading	Average variances extracted	Source
Quality value	1. I think the product has good quality	0.894	0.815	[21]
	2. I think the product is very well made	0.914		
	3. I think the product meets acceptable quality standards	0.901		
Price value	1. I think the price of the product is reasonable	0.910	0.840	[21]
	2. I think the product is very cost-effective	0.924		
	3. I think the product is worth the money	0.915		

(*continued*)

(*continued*)

Variable	Item	Factor loading	Average variances extracted	Source
Epistemic value	1. I saw the product advertisement that caught my attention	0.921	0.842	Developed based on [25]
	2. I want to have a better understanding of the product	0.919		
	3. I have a curiosity about products	0.913		
Online conditional value	1. Online promotional activities that attract my attention	0.921	0.847	Developed based on [25]
	2. Seeing webpage advertisements increases my desire to purchase	0.911		
	3. Seeing video introductions online increases my desire to purchase	0.928		
Offline conditional value	1. The promotional activities provided by the company's physical exhibition area attracted my attention	0.862	0.797	Developed based on [25]
	2. Seeing the advertisement DM in the physical display area increases my desire to purchase	0.928		
	3. Seeing product displays in the physical display area increases my desire to purchase	0.886		

(*continued*)

(*continued*)

Variable	Item	Factor loading	Average variances extracted	Source
Physical experience	1. I can view products in the physical display area	0.849	0.747	Developed based on [5]
	2. I can confirm the quality and performance of the product in the physical display area	0.855		
	3. I can test the product in the physical display area to see if it meets my expectations	0.840		
	4. I can learn about the scope of after-sales service in the physical display area and see if it meets my expectations	0.912		
Electronic word of mouth	1. To ensure that I choose the right company products, I often read reviews by other buyers online	0.811	0.697	[39]
	2. Before deciding to purchase a company's products, I often gather opinions from other buyers online	0.889		

(*continued*)

(*continued*)

Variable	Item	Factor loading	Average variances extracted	Source
	3. If I haven't seen any reviews from other buyers online, then I will worry about my decision to purchase the product	0.841		
	4. When I make a purchase, positive comments on the Internet give me confidence in deciding to make a purchase	0.795		
Financial risk	1. Payment online may cause financial losses	0.875	0.834	[27]
	2. Online payments may result in account theft and fraud	0.938		
	3. Making payments online may make my products more expensive to purchase	0.925		
Privacy risk	1. Using online and offline interactive technologies (such as downloading apps, AR interaction) or online payments may cause my personal information to leak out	0.875	0.721	Adapted from [27]

(*continued*)

(*continued*)

Variable	Item	Factor loading	Average variances extracted	Source
	2. The use of online and offline interactive technologies (such as downloading apps and AR interactions) may result in my personal information being used without my knowledge	0.844		
	3. Using online and offline interactive technologies (such as downloading apps and AR interactions) may cause my credit card data to leak out	0.828		
Offline-to-online repurchase intention	How willing are you to purchase the company's products again in the future?	1.000	1.000	[36]

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The Impact of Telework on Subjective Well-Being and Knowledge Management Among Aging Workers in Japan and the United States: A Conceptual Framework

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Abstract. The COVID-19 pandemic has accelerated the adoption of telework, fundamentally altering work environments worldwide. This paper explores the impact of telework on subjective well-being, work-life balance, job satisfaction, job performance, and knowledge management among aging workers in Japan and the United States. Given demographic shifts and the increasing presence of older employees in the workforce, understanding how remote work affects this population is essential.

Drawing upon cultural, psychological, and knowledge management theories, this conceptual paper develops a set of propositions regarding the interplay between telework and key workplace outcomes. We argue that cultural differences, digital literacy, and telecommuter self-efficacy significantly shape telework adaptation for older employees. Our propositions highlight variations in work-life balance, job satisfaction, and the effectiveness of knowledge-sharing practices, particularly regarding tacit vs. explicit knowledge transfer in different cultural settings. Furthermore, the study emphasizes the role of organizational support, digital training, and hybrid work models in mitigating telework challenges. These propositions provide a foundation for future empirical research to refine telework policies and enhance the experiences of aging workers in remote environments.

Keywords: Telework · aging workforce · knowledge management · well-being · Japan · United States

1 Introduction

With the COVID-19 pandemic now under control, telework has transitioned from a temporary necessity into a permanent feature of the global work landscape. In both Japan and the United States, telework—initially driven by the need to maintain operations during lockdowns—has become a widely embraced option, particularly in knowledge-based industries. In Japan, where telework was less common before the pandemic, its adoption has significantly expanded, especially in urban areas. By 2023, approximately 25% of full-time employees in Japan were engaged in telework, a notable rise from pre-pandemic levels (MLIT 2024). In the United States, telework has become a fixture of the

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post-pandemic work environment, with 35% of workers whose jobs can be performed remotely working from home full-time (Parker 2023).

Telework offers numerous benefits, including improved work-life balance, greater job flexibility, and reduced commuting time. However, it also presents distinct challenges, particularly for older workers, who often struggle to adapt quickly to new digital tools and remote work environments (Magnier-Watanabe 2024b). Many aging employees lack experience with remote technologies, increasing their risks of social isolation, diminished subjective well-being (SWB), and difficulties in managing and sharing knowledge remotely (Czaja & Lee 2007). Workforce diversity components, such as age, significantly influence teleworking outcomes. Age-related factors impact job performance and adaptability to remote settings, with older workers often requiring more support to thrive in telework environments (Hamouche & Parent-Lamarche 2023). Additionally, reduced self-efficacy—the belief in one's ability to perform tasks successfully—exacerbates these challenges, particularly for older workers who may lack confidence in their ability to meet the demands of telework (Bandura 1997; Raghuram et al. 2003). Studies suggest that tailored support systems, such as targeted digital literacy programs, can play a critical role in enhancing older workers telework experiences. These interventions address specific challenges related to self-efficacy and knowledge management, enabling older employees to adapt more effectively and maintain productivity in remote work environments (Scheibe et al. 2024; Magnier-Watanabe 2024b).

In both Japan and the United States, the demographic shift toward aging workforces adds urgency to understanding how telework affects older workers. In Japan, over 29% of the population is aged 65 or older, placing increasing pressure on businesses to adjust to the needs of older employees (United Nations 2024). Similarly, in the United States, approximately 18% of the population is aged 65 or older, creating its own set of challenges as organizations contend with an aging workforce (United Nations 2024). These demographic trends—driven primarily by the aging baby boomer generation—are reshaping labor markets in both countries. Older workers, who possess a wealth of experience and institutional knowledge, are essential for sustaining organizational productivity. However, their adaptation to telework is often hindered by technology-related stress, the loss of traditional face-to-face communication, and disruptions in tacit knowledge-sharing practices, which are crucial for organizational knowledge management (DeLong 2004; Nonaka & Takeuchi 1995).

Cultural differences also play a crucial role in shaping the telework experiences of older employees in Japan and the United States. Japan's work culture traditionally emphasizes long working hours, physical presence, and face-to-face communication. As a result, many Japanese companies have been slow to adapt to telework, and older workers may struggle with the rapid digital transformation that telework demands (Iwasaki, Takahashi, & Nakata 2006). The shift away from tacit knowledge-sharing practices, central to Japanese business culture, further complicates this transition for older employees (Nonaka & Takeuchi 1995). In contrast, the United States has a more established culture of flexible work arrangements, yet older workers there still face challenges, particularly in terms of technology use, social isolation, and maintaining work-life balance (Allen et al. 2015).

In addition to cultural factors, the organizational culture and support available to older workers can significantly influence how successfully they adapt to telework. Japanese companies, with their hierarchical structures and emphasis on group cohesion, may provide less support for telework adaptation, particularly in terms of technological training (Kazekami 2020). However, research suggests that hybrid work arrangements can bridge this gap, fostering collaboration while retaining the flexibility and productivity benefits of telework (Simeli et al. 2023). In contrast, U.S. organizations, particularly those with experience in flexible work policies, often provide better technological support and training, which can help mitigate the challenges faced by older workers adapting to remote work (Maruyama & Tietze 2012). Studies show that telework can enhance job satisfaction, job performance, and retention if employees are provided with the necessary resources, such as adequate technology support and training (Oakman, Kinsman, Stuckey, Graham, & Weale 2020; Wang et al. 2021).

This research aims to investigate the impact of telework on subjective well-being and knowledge management among older workers in Japan and the United States. By comparing these two countries, the study provides a cross-national analysis of how cultural, organizational, and technological factors shape older employees' adaptation to telework. The findings are expected to offer actionable insights to organizations seeking to better support aging workers in telework settings, with the ultimate goal of improving employee satisfaction, retention, and productivity.

This paper makes three key contributions. First, it develops a comparative conceptual framework that integrates cultural, psychological, and knowledge management perspectives to understand how telework affects aging workers in Japan and the United States. Second, it highlights critical factors—such as digital literacy, telecommuter self-efficacy, and organizational support—that influence well-being, job satisfaction, and knowledge-sharing outcomes in remote work settings. Finally, by presenting a series of theoretically grounded propositions, this study provides a foundation for future empirical research, offering practical insights for policymakers and organizations seeking to optimize telework policies for an aging workforce.

2 Literature Review

2.1 Telework and the Aging Workforce in Cultural Context

Telework, also referred to as telecommuting or remote work, is a work arrangement where employees perform their duties outside traditional office settings, often relying on information and communication technologies (ICT) to stay connected with colleagues and supervisors (Nilles 1998; Gajendran & Harrison 2007). The rapid acceleration of telework, spurred by the COVID-19 pandemic, has introduced both opportunities and challenges for the aging workforce—workers typically aged 55 and above (U.S. Bureau of Labor Statistics 2023). The demographic shift driven by increased life expectancy and declining birth rates (DeLong 2004) necessitates organizational adjustments to meet the specific needs of older workers, who face unique challenges such as adapting to new technologies and maintaining knowledge-sharing practices while working remotely.

Cultural differences, particularly between high-context and low-context cultures (Hall 1976), significantly influence how older workers experience and manage telework.

In high-context cultures like Japan, communication relies heavily on implicit messages, non-verbal cues, and shared experiences. These cultures prioritize group cohesion, hierarchical relationships, and tacit knowledge-sharing—knowledge that is deeply embedded in personal experience and difficult to formalize (Polanyi 1966; Nonaka & Takeuchi 1995). In contrast, low-context cultures like the United States favor explicit communication and individualism, potentially facilitating a smoother adaptation to telework (Hofstede 1980; Sharma & Liu 2023). These cultural distinctions play a critical role in shaping how older employees navigate the complexities of remote work.

2.2 Impact of Telework on Key Outcomes

Subjective Well-Being (SWB). Subjective well-being (SWB), defined as an individual's self-assessment of happiness and life satisfaction (Diener et al. 1999), is a key predictor of job performance and retention. Telework can positively impact SWB by reducing commuting stress and offering greater flexibility in managing work schedules (Allen et al. 2015). However, it may also result in social isolation and increased stress, particularly for older workers who struggle with technology (Czaja & Lee 2007; Kazekami 2020). Recent studies suggest that older teleworkers who adopt segmentation strategies—such as creating distinct physical and temporal boundaries between work and non-work domains—report improved SWB outcomes (Scheibe et al. 2024). These strategies are especially beneficial in mitigating the psychological toll of blurred work-life boundaries, a common telework challenge. In Japan, the loss of face-to-face interaction, which is central to work culture, may further decrease SWB among older employees (Nonaka & Takeuchi 1995). In contrast, in the U.S., telework aligns with cultural values of autonomy and flexibility, which may improve SWB, although digital literacy remains a key factor in successful adaptation (Hofstede 1980; Gajendran & Harrison 2007).

Knowledge Management (KM). Knowledge Management (KM) refers to the processes of creating, sharing, utilizing, and retaining organizational knowledge to maintain competitive advantage (Nonaka & Takeuchi 1995; Magnier-Watanabe & Senoo 2008). Telework disrupts spontaneous office interactions, which are crucial for sharing tacit knowledge—informal, experience-based knowledge that is difficult to communicate through digital platforms (Polanyi 1966). Studies indicate that digital tools alone cannot replicate the nuanced knowledge transfer mechanisms present in in-person collaboration (Scheibe et al. 2024). Organizational interventions such as fostering job crafting and hybrid work systems have been shown to improve KM outcomes during telework (Mansour & Mohanna 2024). Older workers, who often serve as repositories of institutional knowledge, may face difficulties using digital collaboration tools, hindering their participation in KM activities (Czaja & Lee 2007). In Japan, where tacit knowledge-sharing and high-context communication are essential, telework poses even greater challenges to maintaining effective KM (Magnier-Watanabe 2024a). Older employees, who frequently act as repositories of organizational knowledge, face challenges in using digital platforms to share their expertise. However, introducing hybrid work arrangements and job crafting strategies—allowing workers to tailor their roles to better fit remote contexts—has been shown to mitigate KM-related challenges (Mansour & Mohanna 2024). Conversely, in the U.S., where explicit knowledge-sharing through digital platforms is

more common, older workers' digital literacy and technology support remain critical factors in ensuring effective participation in KM processes (Czaja & Lee 2007). Moreover, the emphasis on individual productivity in U.S. workplaces highlights the importance of self-directed learning and technology adoption to maintain KM effectiveness in remote contexts (Hamouche & Parent-Lamarche 2023).

Telecommuter Self-efficacy. Telecommuter self-efficacy refers to an individual's belief in their ability to manage the demands of remote work. High self-efficacy is essential for older workers adapting to telework, as they often face less structured environments and reduced supervision compared to traditional office settings. Employees with strong telecommuter self-efficacy are more likely to engage in proactive behaviors such as task structuring, time management, and maintaining productivity despite potential distractions (Bandura 1997; Raghuram et al. 2003). Moreover, self-efficacy supports resilience, motivation, and the ability to navigate work-life boundaries, which are critical for success in remote work (Bandura 1997). Without strong self-efficacy, older workers may experience difficulties in managing the complexities of telework, negatively affecting their well-being, job performance, and ability to share knowledge.

Work-Life Balance (WLB). Work-life balance (WLB) refers to an individual's ability to balance work responsibilities with personal life demands (Greenhaus & Beutell 1985). Telework has the potential to improve WLB by offering flexible work schedules and eliminating commuting time (Gajendran & Harrison 2007). However, it can also blur the boundaries between work and home life, leading to increased stress and potential burnout (Carlson et al. 2000). In Japan, cultural expectations around long working hours and family responsibilities can exacerbate the difficulties of achieving balance in a telework setting (Kazekami 2020; Simeli et al. 2023). Conversely, in the U.S., where individualism and autonomy are more valued, older workers may find telework conducive to a better WLB, provided they have the necessary digital skills and support (Allen et al. 2015).

Job Satisfaction. Job satisfaction, defined as a positive emotional state resulting from an individual's appraisal of their job (Locke 1976), is closely linked to productivity and retention (Judge et al. 2001). Telework can enhance job satisfaction by providing workers with greater autonomy and control over their work environment (Gajendran & Harrison 2007). However, for older workers who experience technological difficulties or struggle with the lack of face-to-face interactions, job satisfaction may decline due to frustration and feelings of isolation (Czaja & Lee 2007). In Japan, where interpersonal relationships and in-person collaboration are valued, older workers may experience a greater drop in job satisfaction (Kazekami 2020). In the U.S., the alignment of telework with cultural preferences for flexibility may lead to higher job satisfaction, provided older employees are comfortable with the required technologies. Indeed, U.S. employees often report higher job satisfaction in telework contexts, particularly when supported by effective training and access to technological resources (Oakman et al. 2020).

Job Performance. Job performance refers to how effectively employees fulfill their job responsibilities (Campbell et al. 1993). Telework can improve performance by reducing workplace distractions and allowing employees to tailor their work environment to their preferences (Gajendran & Harrison 2007). However, technological challenges and a lack of training can hinder the job performance of older workers, particularly those

less familiar with digital tools (Czaja & Lee 2007). Adequate technology support is crucial to ensure that older workers perform effectively in a telework environment (Wang et al. 2021). Age significantly moderates the relationship between teleworking and job performance, with older workers often experiencing unique challenges and benefits in remote settings. Hamouche and Parent-Lamarche (2023) emphasized the importance of tailored organizational strategies to address these age-specific dynamics. In Japan, where teamwork and face-to-face collaboration are central to work culture, older workers may experience declines in performance if telework reduces opportunities for interpersonal interactions and collective problem-solving (Nonaka & Takeuchi 1995). In contrast, older workers in the U.S. may face fewer barriers to telework adaptation due to the cultural acceptance of independent work and generally higher levels of digital literacy. Nevertheless, disparities in access to technology and social isolation can still impact their performance. Research highlights the importance of fostering collaborative digital environments and implementing clear communication protocols to mitigate these challenges (Oakman et al. 2020; Wang et al. 2021).

Retention. Retention refers to an organization's ability to retain employees over time, minimizing turnover (Hausknecht et al. 2009). Telework can positively influence retention by offering flexibility that meets older workers' needs, potentially delaying retirement (DeLong 2004). However, technological difficulties, decreased job satisfaction, or challenges with knowledge-sharing due to telework can negatively impact retention among older employees (Golden 2006). In Japan, disruptions to traditional work practices and barriers to effective technology use may reduce retention among older workers (Kazekami 2020). In contrast, in the U.S., supportive telework policies and adequate technological support may enhance retention by aligning with preferences for flexibility and autonomy (Allen et al. 2015).

Organizational Culture and Support. The experience of telework among older workers is heavily influenced by organizational culture and the level of support provided. Policies that emphasize inclusivity—such as training programs to address digital literacy gaps—have been shown to significantly increase older workers' commitment to their organizations (Scheibe et al. 2024) and KM in teleworking environments (Magnier-Watanabe 2024b). These interventions are particularly crucial in industries where aging workers constitute a large portion of the workforce, ensuring continuity in expertise and institutional knowledge. Japanese companies, characterized by hierarchical structures and an emphasis on group cohesion, may provide less support for telework adaptation, particularly for older workers who may struggle with technology (Ouchi 1981; Kazekami 2020). The emphasis on face-to-face communication and long working hours in Japan may conflict with the flexibility and autonomy that telework offers. In contrast, Western companies, particularly those in the U.S., often embrace flexible work structures and provide better technological support and training, facilitating a smoother transition to telework for older employees (Maruyama & Tietze 2012). These companies are likely to have more experience with telework policies and may prioritize technology training to help older workers overcome digital literacy challenges.

3 Conceptual Propositions

The following propositions were developed based on an extensive review of telework, knowledge management, and cultural psychology literature. These propositions are informed by prior empirical findings on digital adaptation, remote work dynamics, and the aging workforce (e.g., Kazekami 2020; Scheibe et al. 2024). While these statements remain conceptual, they serve as testable hypotheses for future research, guiding empirical studies that explore the differential impact of telework on aging employees across Japan and the US.

3.1 Proposition 1: Telework and Subjective Well-Being

Telework's effects on subjective well-being (SWB) are influenced by cultural expectations of workplace interactions. In individualistic cultures, such as the U.S., remote work enhances well-being by increasing autonomy, flexibility, and work-life balance (Gajendran & Harrison 2007). In contrast, in collectivist cultures like Japan, traditional face-to-face interactions and workplace hierarchy play a more significant role in shaping well-being (Nonaka & Takeuchi 1995). Older Japanese employees, who are accustomed to structured office environments, may struggle with social isolation and blurred work-home boundaries, leading to higher stress and lower SWB (Kazekami 2020).

Proposition 1: The impact of telework on the subjective well-being (SWB) of older workers is moderated by cultural expectations of workplace interactions. Older workers in the U.S. will experience higher SWB due to increased autonomy and work-life balance, while older Japanese workers will experience lower SWB due to the disruption of traditional work routines, reduced social cohesion, and work-home boundary blurring (Hofstede 1980; Nonaka & Takeuchi 1995; Kazekami 2020; Parker 2023).

3.2 Proposition 2: Telework and Job Satisfaction

Job satisfaction in telework settings is shaped by workplace flexibility and perceived autonomy (Bloom et al. 2015). U.S. employees tend to view telework as a means to enhance job control and reduce workplace stress (Allen et al. 2015). However, in Japan, telework challenges traditional workplace norms, where in-person visibility is often equated with productivity and commitment (Yang et al., 2019). This difference suggests that job satisfaction among older teleworkers in Japan may be lower due to a perceived lack of workplace inclusion.

Proposition 2: The relationship between telework and job satisfaction is moderated by cultural perceptions of workplace flexibility. Older U.S. workers will report higher job satisfaction due to increased autonomy, while older Japanese workers will report lower satisfaction due to disrupted workplace norms and social integration challenges (Bloom et al. 2015; Yang et al., 2019).

3.3 Proposition 3: Telework and Knowledge Sharing

Knowledge-sharing practices are strongly influenced by organizational culture and communication structures (Choi & Lee 2003). In the U.S., explicit knowledge transfer through digital platforms is common, whereas in Japan, tacit knowledge—which relies on informal socialization—is central to workplace learning (Nonaka & Konno 1998). Telework may create barriers to tacit knowledge exchange in Japan, reducing knowledge-sharing effectiveness.

Proposition 3: Telework negatively impacts knowledge sharing among older Japanese workers due to a reliance on tacit knowledge exchange, whereas older U.S. workers will be less affected as they are more accustomed to explicit knowledge-sharing mechanisms (Nonaka & Konno 1998; Choi & Lee 2003).

3.4 Proposition 4: Digital Literacy and Telework Adaptation

Older workers' ability to adapt to telework depends significantly on digital literacy levels (Czaja et al. 2006). Research indicates that Japanese employees, particularly in traditional industries, tend to have lower digital literacy than their U.S. counterparts (OECD 2021). This gap suggests that telework adaptation may be more challenging for older Japanese workers.

Proposition 4: Older workers with higher digital literacy will experience better telework adaptation. Due to lower digital literacy levels, older Japanese workers will face greater challenges in telework settings compared to older U.S. workers (Czaja et al. 2006; OECD 2021).

3.5 Proposition 5: Telecommuter Self-efficacy and Performance

Self-efficacy plays a crucial role in telework performance (Staples et al. 1999). U.S. employees generally exhibit higher confidence in independent work settings, whereas Japanese employees rely more on structured feedback and team-based decision-making (Ouchi 1980). As a result, self-efficacy will have a greater impact on telework effectiveness in Japan than in the U.S.

Proposition 5: Telecommuter self-efficacy will be a stronger predictor of telework effectiveness for older Japanese workers than for older U.S. workers, due to differences in workplace autonomy and hierarchical support structures (Staples et al. 1999; Ouchi 1980).

3.6 Proposition 6: Organizational Support and Telework Success

The level of organizational support influences telework success (Parker et al. 2020). In the U.S., companies provide more structured telework policies, including IT support and flexible work arrangements (Bailey & Kurland 2002). In contrast, Japanese firms have been slower to formalize telework policies, creating challenges for older workers unfamiliar with remote work technologies.

Proposition 6: Organizational support plays a crucial role in telework success. Older Japanese workers will be more dependent on company-provided telework support than their U.S. counterparts (Bailey & Kurland 2002; Parker et al. 2020).

3.7 Proposition 7: Work-Life Balance and Stress Management

Research suggests that telework improves work-life balance but can also blur work-home boundaries, leading to stress (Kossek et al. 2006). Japanese workers are more likely to experience difficulty in separating work and personal life, contributing to higher stress levels than U.S. teleworkers.

Proposition 7: Older Japanese teleworkers will experience higher stress due to blurred work-life boundaries, whereas older U.S. teleworkers will benefit from greater flexibility in managing work-life balance (Kossek et al. 2006; Shockley & Allen 2010).

3.8 Proposition 8: Social Isolation and Telework Loneliness

Telework can reduce workplace social interactions, leading to feelings of isolation (Golden et al. 2008). This is particularly problematic in Japan, where workplace belonging is culturally significant (Hofstede 1980). As a result, Japanese teleworkers may experience greater loneliness than their U.S. counterparts.

Proposition 8: Telework-related social isolation will be more pronounced among older Japanese workers than older U.S. workers, due to differences in workplace socialization norms (Golden et al. 2008; Hofstede 1980).

3.9 Proposition 9: Trust in Virtual Teams and Collaboration

Trust is essential for effective virtual team collaboration (Jarvenpaa et al. 1998). U.S. employees, accustomed to flat organizational structures, may find it easier to build trust remotely. In contrast, Japanese workplaces emphasize face-to-face relationships, making virtual collaboration more challenging.

Proposition 9: Older Japanese workers will experience greater difficulties in building trust in virtual teams compared to their U.S. counterparts (Jarvenpaa et al. 1998; Fukuyama 1995).

3.10 Proposition 10: Productivity and Task Performance in Telework

While telework can boost productivity, task complexity and job type play a role (Dutcher 2012). Japanese workers, who often rely on collaborative decision-making, may struggle more with independent remote tasks than U.S. workers.

Proposition 10: Older Japanese workers will experience lower productivity in telework settings due to the reliance on collaborative decision-making, whereas older U.S. workers will adapt more easily to remote work (Dutcher 2012; Ouchi 1980).

3.11 Proposition 11: Long-Term Career Implications of Telework

Telework can influence career advancement opportunities (Kim 2020). Japanese firms emphasize physical presence for promotions, potentially disadvantaging teleworkers. This effect may be less pronounced in the U.S., where performance is often evaluated independently of office presence.

Proposition 11: Telework will have a greater negative impact on career advancement for older Japanese workers than for older U.S. workers (Kim 2020; Yang et al., 2019).

4 Conclusion

This conceptual paper has examined the impact of telework on subjective well-being, work-life balance, job satisfaction, job performance, and knowledge management among aging workers in Japan and the United States. By drawing on cultural, psychological, and organizational theories, we developed a series of propositions that highlight how cultural norms, digital literacy, telecommuter self-efficacy, and organizational support shape the experiences of older teleworkers in both countries.

Our analysis underscores that telework does not affect all workers equally—while U.S. employees may benefit from greater autonomy and flexibility, Japanese employees may struggle due to cultural preferences for in-person communication, hierarchical decision-making, and tacit knowledge-sharing. These cultural factors impact how aging workers adapt to telework technologies, manage work-life boundaries, and engage in knowledge-sharing activities. Moreover, while digital literacy and self-efficacy play a crucial role in determining telework success, organizational interventions—such as hybrid work models and structured training programs—can help mitigate telework-related challenges for older employees, particularly in Japan.

This study contributes to the broader understanding of aging workforce dynamics in remote work environments by demonstrating that successful telework implementation must consider cultural and organizational factors. Companies seeking to retain older employees should develop targeted policies that enhance digital literacy, improve telework self-efficacy, and foster knowledge-sharing mechanisms tailored to cultural work norms. In Japan, hybrid models and structured telework adaptation programs may help older workers transition more effectively, whereas in the U.S., expanding digital training and flexible policies can further optimize remote work outcomes.

Future research should empirically test these propositions to provide data-driven insights into the long-term effects of telework on aging employees. Comparative studies that track longitudinal changes in well-being, job performance, and retention among older teleworkers will be particularly valuable. Additionally, examining the role of industry-specific telework adaptations can further refine strategies for supporting aging employees across different sectors.

As telework continues to reshape global labor markets, organizations must proactively address the challenges and opportunities it presents for older workers. By fostering inclusive and well-supported remote work environments, companies can ensure that aging employees remain engaged, productive, and satisfied in an increasingly digital work landscape.

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Exploration into the Digital Skill Development Needs and Challenges of Older Workers

(Case Study of Slovak Ageing Work Force)

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Abstract. The paper focuses on the analysis of the digital skills gaps in the ageing workforce and factors considered by the ageing workforce as the most important for them to remain competitive in the labor market. As the ageing workforce struggles to adapt to a new, fast-changing environment, especially in the use of digital technologies, their training and education are crucial. This is an important concern in Slovakia, where the workforce in the 50–64-year age group represents 18.70% of the workforce.

The paper is based on original data collected from a representative sample of 150 respondents from Slovakia in this age group in fall 2024. The paper explores key digital skills identified by respondents as ones that they need in the workplace and need to improve. These include digital tools for office use, cybersecurity, use of video and teleconference tools, visualization and analytical tools, effective digital file management, and knowledge about AI and its use in the office environment.

The lack of such competencies is also observable in the DESI index, where Slovakia ranked 23rd out of 27 EU members in 2022. The original research conducted by the authors clearly indicates that this demographic group is lagging behind in both using and understanding digital technologies.

Keywords: Digitalization · Ageing workforce · Digital Skills · Slovakia

1 Introduction

During the past few decades, the nature of jobs has substantially changed with the gradual transition to a fluid, dynamic, and at times unpredictable job market. In the past, most workers worked for the same organization throughout their entire careers. This ensured a clear and linear career track where one could accumulate experience steadily and make their way up within the company. The switch from economies focused on production and manual labor to those relying on knowledge, where value is created through intellectual capital and innovation, has tremendously altered employment opportunities. This shift has been powered by rapid technological growth and the emergence of digital technologies, along with the integration of global markets. These developments have contributed to the transformation of skills needed by workers for them to remain competitive in the labor force.

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In recent years, technological development based on automation, artificial intelligence (AI), and information technology (IT) has resulted in a reduced demand for routine and manual tasks and an increased demand for cognitive, creative, and problem-solving skills (Schwab 2016).

Machines and algorithms can do many tasks that were previously done by humans—for example, in manufacturing or data entry and clerical office work. More and more jobs require critical thinking, adaptability, and the capacity to lead. Employees need to be digitally literate and have the ability to engage with technology (Brynjolfsson & McAfee 2014).

Globalization has also been instrumental in fostering this trend. With markets open globally, where capital goods along with labor can move across borders, this has led to an increase in competitive pressure within industries. Companies now seek talent from around the world, often prioritizing the most skilled and adaptable workers regardless of their location. This has led to increased flexibility in labor markets and pressure on workers to make transitions between jobs, industries, and, in some cases, countries before they can find job opportunities (Autor 2019).

The ability to learn new skills and respond to technological disruptions is what makes an individual employable. This implies that lifelong learning has become necessary for workers who need to remain relevant in a labor market that is steadily evolving, where employees are supposed to update their skills regularly to meet the changing demands of employers and industries. Workers are expected to have and apply their digital skills, in particular, data analysis, programming, and the capacity to work with and manage digital resources, in their daily activities (Brynjolfsson & McAfee 2014). Employees who are able to use technology to enhance their productivity, creativity, and effectiveness are highly sought after in every sector of the economy.

At the same time, hard skills such as the ability to program and code, analyze data mathematically, and use AI and machine learning have been rising in importance. Companies look for employees who can work well in cross-functional teams and are also able to lead them, handle complex relationships, and manage conflicts in an effective as well as productive way (Deming 2017). These soft skills are often considered a differentiating factor between workers in a competitive job market.

For older workers, particularly those over the age of 50, these changes bring both challenges and opportunities. Many older workers have found themselves at risk of becoming obsolete in a rapidly evolving labor market where the need to reskill or upskill has become critical, especially for those workers who did not grow up with digital technologies (Schwab 2016). However, the training of older workers should be seen not only as a technical requirement but as a holistic process that requires, in addition to technical skills, the ability to work with people.

Two aspects of the current environment need to be addressed – population aging and the process of digitalization. Automation and digitalization of production processes might have a positive effect on performance, as automation and digitalization compensate for the lower physical abilities of older workers (Stojković Zlatanović & Jovanović 2023). At the same time, these changes in the labor market require policy and regulatory interventions to shift the skills and competencies of the aging workforce towards the digital aspects. In this respect, the transition of educational systems and the adoption

of training programs for employees is crucial for the digital, green, and sustainable transformation of economies.

The importance of lifelong learning for older employees is highlighted by Goštautaitė and Šerelytė (2024), who found a negative relationship between age and employability, while this effect was higher in cases where there was a higher perceived risk of automation in an occupation. However, lifelong learning might mitigate this issue, and the negative relationship is not characteristic of lifelong learners.

Learning and improving digital skills among employees seems to be insufficient. Considering the current development and spread of AI, employees need to understand and work with AI. Access to generative AI tools has been shown to increase productivity by 14% (Brynjolfsson, Li & Raymond 2023). Studies have shown that the highest impact of AI use was among new and low-skilled workers, while its effect on the productivity of highly skilled workers was minimal. These results suggest that AI is very useful for providing best practices, solutions, and processes from more capable and skilled workers to low-skilled workers, resulting in their increased productivity.

These tendencies have also affected Slovakia. Based on data collected among older economically productive people with full secondary or tertiary education, the research underlying this paper explores the needs and challenges faced by these employees regarding their upskilling and reskilling.

The main objective of the paper is to identify factors affecting the lack of digital competencies among the ageing workforce. To meet this objective, a survey of the ageing workforce was conducted. The objective relates to finding the crucial factors causing the Slovak ageing workforce to fall behind in digital competencies.

2 Literature Review

Older workers face challenges that are unique given the rapid evolution of the job market, which is also rooted in social perceptions and systemic biases that make their situation even worse. Age-related barriers, coupled with the undervaluation of their experience and the fast pace of technological change, have placed older workers at a disadvantage despite the wealth of knowledge and skills that they possess.

One of these pressing issues for older workers is age discrimination. Although legislation exists in many countries that prohibits bias against someone based on their age, older individuals often find it hard to get hired for jobs because people have certain perceptions about them and their abilities. Management might consider them less adaptable or open to change and may view them as more expensive in terms of salary expectations compared to younger employees. This age-related bias can be a barrier and leave these workers on the sidelines of a job market (Ng & Feldman 2012). This bias is compounded by the tendency of hiring processes in innovation- and tech-driven sectors to favor younger candidates, who are better aligned with new trends and tools (Swift et al. 2017).

Although older workers may have abundant experience, employers might observe that their skills are too specific and suited for previous periods, which makes it difficult for these workers to effectively market themselves (Cappelli & Novelli 2010). However, it should be remembered that experience is in high demand in roles requiring mentorship

or strategic oversight (Coughlin 2018). The barrier that results from the disconnect between older workers' experience and the skills that contemporary employers demand is a critical issue for their employment.

Another major obstacle for older workers is the rapid pace of technological progress. Many older people developed their careers in industries or roles where required skill sets changed substantially over time. For instance, sectors like manufacturing, finance, and healthcare have experienced large-scale adoption of digital tools as well as data analytics and automation. Workers who have not continually updated their skill sets may find themselves at a disadvantage because, in recent years, employers have looked for candidates who can use new technologies efficiently (Frey & Osborne 2017).

Older workers have also been unequally affected by the digital divide, since a significant number of them joined the workforce before computers and the internet became widely used. On the other hand, younger generations have grown up in a digital world and have integrated new technologies into their daily lives. Therefore, older workers are more likely to struggle to adapt to these changes, especially if they have not had access to upskilling opportunities. The result is a mismatch between their skills and the skills that modern jobs require (McQuaid et al. 2019).

Unemployment or underemployment among older workers has significant economic and social consequences for these individuals and for society as a whole. For individuals, prolonged unemployment can lead to financial instability, especially for those close to retirement who have not accumulated sufficient savings or pension benefits. This can force them to seek employment in an age-discriminatory market and delay their retirement (Roscigno et al. 2007).

Additionally, underemployment is a situation in which individuals are forced to accept jobs below their skill level or pay grade, which also has a detrimental effect on their economic well-being and self-esteem. Many older workers are looking for full-time, stable employment but find it challenging, and therefore they take up part-time or temporary work that does not fully utilize their skills or does not provide adequate pay. This can result in feelings of frustration, making these workers feel underappreciated and underused despite their extensive experience.

Moreover, in societies where identity and self-worth are often tied to professional success, older workers who are pushed out of the workforce may experience lower life satisfaction (Lahey 2010).

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As technology continues to reshape industries and the global economy, the ability to navigate digital tools and platforms is essential. Digital skills are essential not only for maintaining productivity but also for fostering innovation and problem-solving in an increasingly virtual work environment (McKinsey 2021). The 2023 report by the World Economic Forum highlights that nearly 50% of all employees will need reskilling by 2025 due to increased digitalization (World Economic Forum 2023).

Companies that foster a culture of lifelong learning and encourage digital upskilling are better equipped to adapt to changing market conditions. The most successful professionals will be those who continuously refine their technical skills while also cultivating soft skills that enable them to work effectively in teams, lead others, and drive innovation (Morphoses 2024).

Human resources systems need to adapt to this new environment as well. To achieve Industry 5.0, those systems must be designed to find the balance between automation and human skills and to promote adaptability and inclusivity tailored to the diverse needs of older workers (Ranasinghe, Grosse & Lerher 2024).

A focus on reskilling programs that integrate experience with new competencies can ensure that older workers remain an essential part of the workforce. Furthermore, age discrimination becomes more pronounced as workers reach retirement age, and this affects their job opportunities in the labor market (Roscigno et al. 2007). Therefore, the digitalization trend not only changes the structure and nature of jobs but also makes digital competencies a valuable resource for work (König 2022).

Training in digital technologies for the ageing workforce aims to motivate workers to stay employed, and employers may use the knowledge and experiences of older workers. Thus, organizing digital technology-related content in training programs brings success in aging within the workforce (Sheng et al. 2022).

This conclusion regarding the necessity of training programs organized by employers was confirmed by Wang and Fang (2020), as well as by Xie et al. (2023).

If older workers lack the required digital skills, reskilling programs need to be developed to overcome this deficiency. Reskilling programs can ensure that such workers have the competencies needed to remain competitive while also reducing the financial burden on social welfare systems and boosting overall economic productivity.

Also, older adults who continue working are more likely to report higher levels of life satisfaction and better mental well-being (Lahey 2010).

These programs can be implemented within companies, but the public sector can also support such initiatives, especially for small and medium-sized enterprises, which may have limited resources to spend on reskilling their employees.

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Several governments have implemented national policies to help reskill their older workers. For example, Singapore's SkillsFuture initiative has extended lifelong learning and workforce development for people of all ages, including those above 50 years old. It is considered a successful example, with high participation rates from older workers and a significant contribution to higher job satisfaction and employability (https://www.skillsfuture.gov.sg).

In Germany, several programs have been launched by the government to address the skills gap of older workers, such as "WeGebAU" (Weiterbildung Geringqualifizierter und beschäftigter älterer Arbeitnehmer in Unternehmen), a reskilling initiative specifically targeted at older workers. This scheme subsidizes firms to train older workers so that they can continue to work in industries that are heavily technologically disrupted.

In the private sector, many companies recognize the value of retaining their experienced employees, such as AT&T in the United States, which has invested $1 billion in

employee reskilling (https://www.aspeninstitute.org/of-interest/upskilling-news-att-invests-1-billion-employee-reskilling).

There are also public-private partnerships used to reskill older workers. In Finland, the National Skills Program (https://okm.fi/etusivu) is a collaborative effort between the government, employers, and educational institutions, ensuring that workers of all ages have access to relevant skill training.

One part of this program is "Fit for Digital Work", which offers government-funded training vouchers for older workers to take courses provided by private technological firms and universities, with a focus on small and medium-sized enterprises (SMEs).

Employers must also implement measures to address the challenges of an aging workforce. A survey of Dutch employers (van Dalen, Henkens & Schippers 2010) reveals that only a small minority of employers are taking measures to enhance productivity and organize training programs.

In the last few years, online learning platforms have reinvented how individuals can access education and training. Learners can now upskill themselves, learn, and even get certified from the comfort of their homes or workplaces.

This transition was triggered by technological advancements, such as the widespread availability of high-speed internet and the emergence of online learning platforms and intuitive educational software.

These changes have not only provided greater flexibility in education but also democratized it. Coursera, edX, LinkedIn Learning, and Udemy are some of the most popular platforms that offer a variety of courses ranging from programming to data science, leadership, and other soft skills.

Very often, these platforms collaborate with universities, industry experts, and companies to create content that is relevant and affordable for learners.

Online learning platforms also prove to be highly effective tools for upskilling and reskilling individuals, making them an essential resource for those seeking success in the labor market, including older employees.

Unlike younger demographic groups, older people may face more challenges using e-learning technologies, which may require adjustments to online courses and training to better suit their needs.

A focus on reskilling programs that integrate experience with new competencies can ensure that older workers remain an essential part of the workforce. Furthermore, age discrimination becomes more pronounced as workers reach retirement age, and this affects their job opportunities in the labor market (Roscigno et al. 2007). Therefore, the digitalization trend not only changes the structure and nature of jobs but also makes digital competencies a valuable resource for work (König 2022).

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Unlike younger demographic groups, older people may have more challenges using e-learning technologies, and that may require adjustments to the online courses and training to better fit their needs.

This overview points to the digital skill deficiencies of older workers, specific skills that were found to be critical to be developed for their continued active and successful employment, as well as challenges and opportunities to overcome this lack of skills. Next, we reflect upon these issues from the point of view of older employees in Slovakia.

Slovakia is performing relatively well in the measurement of the quality of life using the Human Development Index. HDI reached a value of 0.855 in 2022, which places Slovakia in the 45th position. In comparison, the first place in 2022 belongs to Switzerland with an HDI value of 0.967 (UNDP 2024).

The UNDP analysis of HDI for 2023/2024 also includes digitalization issues in the report, with an analysis of its impact on products, services, regions, and the labor market.

Considering that Slovakia started at a value of 0.716 in 1995, the improvement is not as visible as in some other countries, which have developed at a higher pace.

Relating to the sub-index of schooling, the expected years of schooling have changed from 12.15 in 1995 to 14.72 years in 2022. However, the mean years of schooling are lower and have developed over the same period from 8.40 to 13.01 years.

In this aspect, we might see an improvement in the educational process in Slovakia.

3 Methodology

The necessity of educating the ageing workforce in Slovakia is crucial since individuals aged 55 and over constitute 18.70% of the total active population in the Slovak Republic as of the second quarter of 2024. This proportion is even higher in certain Slovak regions. The urgent necessity to focus training and the development of digital skills on the ageing workforce is easily demonstrated by the pyramid of the Slovak population. The development in the composition of different age groups within the Slovak population clearly evidences the aging of the population and the shift of the population from younger to older generations. The age pyramids compare the distribution by age in 2020, 2024, and a prediction for 2030. If we went further into historical data, we would see an even younger population (Fig. 1).

The survey was conducted in Slovakia on a sample of 150 respondents aged 50 to 64 during the period from 24.6.2024 to 26.6.2024 (the questionnaire and data are at disposal upon request from the authors). It was carried out by the professional company MN Force. The sample is sufficient to provide reliable insights into the needs of the ageing workforce. The sampling technique of stratified random sampling was used to gather responses from the ageing working population. This method ensured that the sample included representatives of different demographic, regional, or social respondents within the ageing workforce.

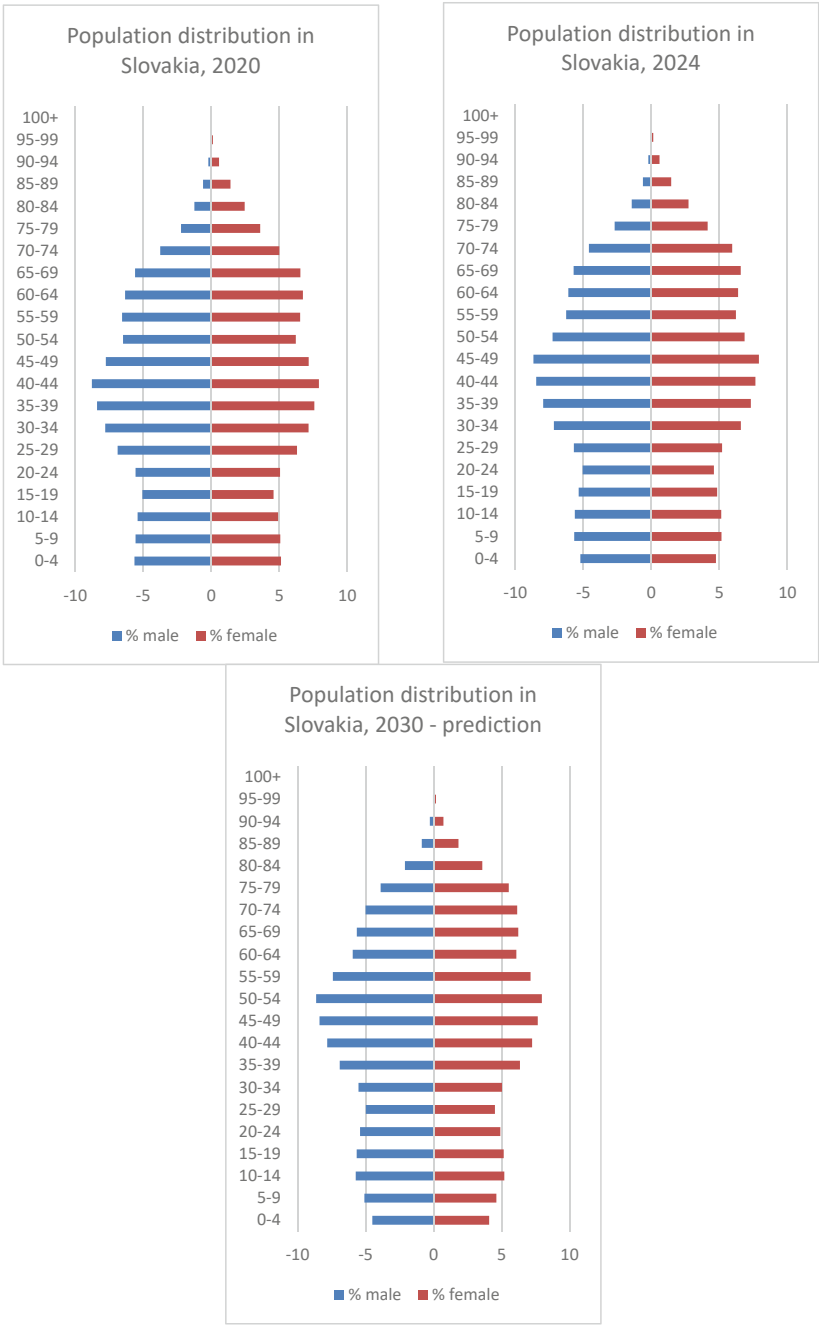

Fig. 1. Age Pyramids for Slovakia, 2020, 2024 and 2030. Source: United Nations, Data Portal Population Divison. Available at: https://population.un.org/dataportal/data/indicators/46/locations/703/start/1993/end/2025/table/pivotbylocation?df=b97deb22-d17b-495f-a2a2-32127594134b; and PopulationPyramid.net. Available at https://www.populationpyra-mid.net/slovakia/2030/

To ensure the reliability and validity of the survey, questions were designed and scaled in a way that allows us to identify the real needs of the ageing population in digital skills. At the same time, it allows us to minimize biases and improve the accuracy of the collected data. The content validity of the survey was ensured by specific questions designed to identify gaps in digital knowledge, skills, and competencies.

The questionnaire was divided into several sections, which were specifically devoted to different digital knowledge, skills, or competencies. Descriptive statistics were used to analyze the main characteristics and scope of the data. Based on these characteristics, we were able to find and reveal trends and patterns in responses from the target group. This enabled us to define the key characteristics relating to digital skills needs as well as to draw general conclusions that can be applied to the overall ageing workforce in the Slovak Republic.

The results of calculating the sufficiency of the sample of 150 respondents from the active population of 516,100 workers aged 55+ are presented in Table 1. This result allows us to consider the sample representative and to provide conclusions that might be generalized to the overall 55+ economically active population.

With a confidence level of 95%, the Z-score is given as 1.96. The Z-score relates to the distribution of data and defines the probability that the mean of the sample falls within a given range. In other words, it demonstrates how much the mean of the sample can vary compared to the mean of a normal distribution.

Under this assumption, the margin of error of the sample used is only 8%.

Table 1. Justification of the reliability of the sample.

Indicator	Level
Sample size (n)	150
Total population size (N)	516.100
Confidence level	95%
Z-score corresponding to the confidence level (Z)	1.96
Assumed proportion, maximizing the margin of error (p)	0.5
Margin of error	8,00%
Confidence Interval	[42.00%–58.00%)

The survey consists of 31 questions. These were developed to identify gaps in the digital knowledge, skills, and competencies of the ageing workforce. The questionnaire is divided into seven parts: 1) socio-economic, 2) digital skills, 3) cybersecurity and data protection, 4) specific digital skill competencies, 5) soft skills, 6) motivation and training needs, and 7) continuous improvement and learning. The paper deals with responses related to parts 2, 3, 4, and 6, as these are devoted to digital skills.

An important aspect of the survey is the respondents' structure, as it allows for unbiased results and conclusions about the ageing workforce. The respondent pool is almost evenly divided between males (49%) and females (51%). The average age of respondents is 55.6 years, with a median age of 55 years. Within the age groups, most

respondents (53%) fall within the 50–55 age range, 26% are from 55–59, and 21% are from the 60–64 age group. In terms of regional representation, the sample is distributed almost evenly across Slovak regions.

The level of education plays an important role in assessing the needs of the ageing workforce, as it is assumed that more educated workers possess more knowledge and skills compared to those with lower levels of education. In this manner, the needs of workers with higher education may differ from those of workers with lower levels of education. Respondents completed full secondary or higher education.

4 Results

4.1 The Level of Digital Skills

Slovakia does not perform well in the field of digitalization. In the 2022 DESI ranking, Slovakia was ranked 23rd out of 27 EU Member States (European Commission 2022a), while it ranked 22nd in 2021. Thus, Slovakia performs below the EU average. Moreover, in recent years, the pace of digitalization in the EU has been increasing faster than in Slovakia. In addition, even though Slovakia ranked 20th in 2017—which is also not a strong performance—the rank has continuously decreased, resulting in a drop of 3 places by 2022. This means that Slovakia is not improving sufficiently, and other countries are advancing in digitalization more effectively than Slovakia.

The breakdown of the DESI index indicates that Slovakia is able to achieve a similar level to the EU average only in the Human Capital dimension but has been falling behind in all other areas of the DESI index. With particular relevance to this paper, a report on Slovakia highlights that digital skills across the population, from primary school students to adults, need to improve in order to successfully address the challenges of digital transformation. Improving digital skills takes time, and measures need to be implemented systematically (European Commission 2022a).

The indicator of basic digital skills has declined since 2021 from 55% to 51%, while the EU average is 55%. Special attention is needed for basic digital skills among people aged 55 to 64 (38%) and 65 to 74 (19%) (European Commission 2024). Improvement in the ageing workforce is necessary, and the performance of this age group must increase to achieve the national target set by Slovakia for basic digital skills at the level of 70% of citizens. However, even this goal is lower than the EU target of 80% of citizens having specified digital skills.

4.2 Identification of Digital Skill Gaps

– *Digital Skills*

The main goal of the survey devoted to digital skills was to assess the level of digital skills, comfort in the use of digital technologies, and understanding of these tools among the ageing workforce, as well as to identify areas for improvement.

For employers, a key goal is ensuring that employees feel comfortable using new digital tools and software. This leads to higher labor productivity and better company

performance. Therefore, the focus is on comfort in using new digital tools. Most employees feel comfortable or neutral when using new tools. This might be the result of the frequency with which they use various software or applications. If digital tools are used regularly, it can be assumed that workers have a higher level of digital skills and knowledge.

According to the survey, only 5% of employees do not use digital tools at work at all, and 10% use them rarely. In contrast, 42% use software or other digital tools often, and 28% use them very often.

To use digital tools effectively, regular training to enhance digital competencies is needed. This training can be initiated by employers, knowing that digitally skilled labor leads to increased productivity. However, the survey indicates that one-fifth of employees have not received any digital skills training from their employers, and almost one-fifth have received only minimal training. About another fifth reported receiving some training, but it was not sufficient. Comprehensive and sufficient training was provided to only 27% of employees. These results clearly show the need for more employees to receive proper training to understand and use digital tools.

The use of new and modern technologies, applications, or software is very common for office work, as most documents and files are now in digital format, so effective management is crucial. In this context, most respondents rate their skills in managing digital files at a medium level (36%). Additionally, 24% consider themselves skilled, and 20% consider themselves very skilled. While this self-assessment seems adequate, there is a need to enhance the efficiency of managing digital files, particularly for those who are not skilled or only slightly skilled.

The COVID-19 pandemic led to a rise in online meetings, which have become more frequent recently. Online meetings offer many advantages, and it is expected that employees should be able not only to participate in but also to prepare, organize, plan, launch, and manage such meetings. The more online meetings employees successfully plan and complete, the more experienced they become.

The survey shows that 18% of respondents do not use these tools at all, 20% use them rarely, and 36% use them sometimes. It seems that the shift towards remote work and online meetings has peaked, and more employers are now preferring on-site work without the need for video conferencing software.

Similar to working with digital files, the storage of data and information has also become digital. Due to the increase in digital file usage, we would expect that the use of cloud services would also increase. However, only 11% of respondents use cloud-based services very often, and only 17% use them often. Meanwhile, 23% of respondents use them rarely, and even 18% have never used them.

The reasons for not using cloud services might be explained by discomfort with storing personal data or by distrust and concerns about security, especially if data is stored in the cloud rather than physically or electronically within a company's secured locations. 51% of respondents indicated that they feel neither comfortable nor uncomfortable with the idea of personal data being stored on cloud servers. However, 31% feel slightly uncomfortable or uncomfortable, while only 18% feel somewhat or very comfortable. This suggests that there is a need to educate people about the security of data stored

on cloud servers and the adequate and robust security measures that should be taken in order to prevent the misuse of stored data.

Moving to a more advanced level, some companies may already be using AI for administrative or management processes. The rapid pace of AI development and its use in the workplace means that not all employees are familiar with this technological concept.

Based on the survey, there was no respondent who considered themselves to be very familiar with generative AI, and only 9% were familiar. The highest number of responses fell into the "somewhat familiar" category, making up 36% of the answers. Most importantly, 29% of respondents were unfamiliar, and 26% were very unfamiliar with generative AI and its application in the workplace.

As more than half of the respondents are unfamiliar with AI, it is essential for the ageing workforce to address this gap by improving their knowledge and skills in this area, as it is becoming a crucial competence for success and competitiveness in the labor market.

– *Cybersecurity and Data Protection*

The use of digital technologies and tools, including digital files and online communication, is highly effective but also introduces new threats that were not present or recognized in traditional "onsite" environments. Many individuals or companies have had their data lost, compromised, or misused. However, many of these incidents could be avoided, as online attackers often exploit vulnerabilities caused by improper use of digital tools, such as breaching login credentials to gain control of digital services, including social media accounts, email accounts, or even bank accounts.

Starting with the key question regarding respondents' familiarity with cybersecurity, the majority of responses were neutral, with 41% indicating they were neither familiar nor unfamiliar. Only 2% reported being very familiar, while 25% were somewhat familiar. On the other hand, 9% were not familiar at all, and 23% were not very familiar. This highlights that cybersecurity needs to be a priority area for the ageing workforce. They must understand and learn how to protect themselves against these modern, and for many, previously unknown, digital threats.

In terms of protecting against cyber threats, multiple methods of security are necessary. Therefore, most digital tools now offer, or even require, two-factor authentication. The survey shows that 12% of respondents still never use two-factor authentication, 11% rarely use it, and 18% use it only sometimes.

As mentioned above, cyber attackers often exploit people's mistakes or lack of awareness, taking advantage of opportunities when they arise. The survey results are quite reassuring, as only 1% of respondents reported being either not cautious at all or only sometimes cautious when opening emails or clicking on links from unknown senders.

– *Specific Digital Skill Competence*

Specific digital skills competence refers to employees' ability to use digital technologies and tools effectively and practically in their work. The application of digital tools in the workplace often focuses on office software, online communication (e.g., emails), and data analysis and visualization. An essential aspect of developing digital

competence is the learning process, as different workers require varying amounts of time to understand and begin using digital tools efficiently.

When adopting and learning new technologies and tools, understanding them is the first step, followed by practical usage. As the ageing workforce is assumed to use fewer digital technologies than younger generations, their confidence in learning and applying new technologies is often presumed to be lower. However, the survey results suggest otherwise. Seventeen percent of respondents always feel confident using new technologies, and 44% often feel confident. Once digital tools or software are understood and put into use, competence grows.

For both personal and professional use, proficiency in office software, such as Microsoft Office or Google Workspace, is particularly important. The survey revealed that most respondents consider themselves competent in using office software.

Another significant aspect of office work is the ability to manage correspondence, particularly through email. Effective email management involves organizing emails, filtering and sorting them, and utilizing advanced features of email software. According to the survey, the ageing workforce is generally comfortable with email management. Only 13% find it very difficult or struggle to manage emails effectively.

Modern tools provide numerous opportunities to present data and results effectively and engagingly through attractive presentations and data analysis. These skills are critical for creating presentations that attract potential customers, suppliers, or investors. Proficiency in software such as Microsoft Excel, SPSS, or Tableau is essential for leveraging these opportunities. The survey shows that 38% of respondents possess moderate skills in data analysis and visualization, while 23% use these tools effectively almost always. Conversely, a significant proportion of respondents lack proficiency and do not use these tools effectively, with 10% unable to use such tools and 27% having only limited skills.

This group of ageing workers should be identified and provided with adequate training to enhance their data analysis and visualization capabilities, making them more competitive in the labor market.

– *Motivation and Training Needs*

People often fear change. Many workers prefer to continue using familiar processes, software, and tools, resisting changes that may disrupt their routines. However, as the environment evolves, adapting to new digital technologies and tools becomes essential and change is necessary. Workers are often afraid of changes due to fears of inefficiency with new technologies and the effort required to learn them. They may consider only a short-term perspective, focusing only on the immediate costs of learning and adopting new technologies. One way to enhance the adoption of new technologies and tools is by motivating workers. Motivation is critical in overcoming the initial fear of change. The motivation would be addressed in various forms, such as higher salaries, bonuses, or promotions. Motivation can be also intrinsic, coming from personal interest and a desire to familiarize with new technologies. However, some workers are not motivated to learn new technologies.

Thus, identifying the reasons behind this lack of motivation is crucial. According to the survey, 51% of respondents are motivated to adopt new technologies by their personal interest, 23% due to higher salary, and 7% by the opportunity for promotion. However,

16% reported being not motivated to learn new technologies. Among the 3% who cited other motivations, responses included: improving work efficiency, necessity for the job, facilitation of tasks, personal development, or acquiring new skills. Clearly, adopting new digital technologies can be stressful, especially when workers are unfamiliar with their features and capabilities. The survey revealed several common fears (multiple answers were allowed). The most frequently reported afraid of workers was making mistakes (66 responses), followed by the fear of being dismissed for an inability to use digital technology (39 responses). These fears reflect a negative perspective, as workers often associate mistakes with failure and potential job loss.

To alleviate stress and fear associated with adopting and using new technologies, effective training programs are essential. Training can be delivered in various formats, and preferences vary among workers. The survey allowed respondents to choose multiple options for preferred training methods. Practical examples were the most popular choice (86 responses), followed by onsite training (84 responses) and online video tutorials/training (53 responses). Written manuals were the least preferred option, with only 23 responses. Practical examples were particularly favored among the ageing workforce as they provide hands-on experience, allowing trainees to understand features and possibilities while testing the technology or tools directly. Similarly, onsite training was highly preferred, likely due to the physical presence of the trainer, who can address questions immediately and provide personal interaction.

The study examines the digital skills gap in Slovakia. We have found that the elderly aging workforce in Slovakia is facing a lack of digital competencies. At the same time, lifelong learning for the elderly workforce is not sufficient and needs to improve. The main gaps we have identified are working with and managing digital files, the use of cloud services, the understanding and use of AI, cybersecurity tools, data analysis and visualization software or applications, and inadequate training provided to the workforce. On the other hand, motivation and the effort to learn new things are very high, driven by intrinsic motivation.

We are fully aware that the drawn conclusions originate from the implemented survey among the ageing workforce and might not represent the overall aging workforce population. The main limitation of the study is the size of the sample. It is sufficient, but a larger sample would increase the validity and reliability of the obtained results. In addition, a repeated survey (e.g., yearly) would give researchers insight into the development of digital competencies among the elderly workforce. To conclude, regular surveys (e.g., annual) would bring valuable data not only for researchers but also for company representatives and policymakers to set, adjust, or optimize the learning process related to digital knowledge, skills, and competencies.

To mitigate the gap in digital competencies, we suggest several measures be adopted. The first and most important is the alignment of the education system with current needs. The educational system needs to be transformed to encourage the use of digital tools, software, and applications, as well as to provide learners with the capacity for continuous learning. As we are witnessing today in the case of rapid AI development, the necessity of continuously learning new topics is crucial to remaining competitive in the labor market. This issue needs to be addressed for the aging workforce as well.

Elderly workers need to improve their digital skills through various tools such as workshops or online and onsite training. Policymakers recognizing this necessity should focus on transforming the educational system, including courses related to digital skills and AI in curricula from elementary school to universities, as well as in lifelong learning programs. In addition, non-formal education provided by employers must be supported. Countries should require employers to provide regular training for elderly workers to ensure their skills remain up to date with current developments. The involvement of educational institutions, including regulatory and governing bodies, in digital transformation is essential to ensure the well-being of workers and to achieve social and economic improvements.

5 Conclusions

The rapid development of the labor market due to technological progress puts older workers aged over 50 in a specific position. This study was conducted to assess the existing capacities and specific difficulties of older workers in Slovakia. This paper presents the main results of the analysis of digital skills gaps. The study reveals a substantial gap in digital skills among employees over 50 in Slovakia that forms a barrier for older workers preventing them from using tools and technologies required for work in a modern workplace.

This paper reveals that a significant share of older workers has low skills in basic digital capabilities that curb their capacity for effective work performance and also restrict access to employment requiring intermediate levels of tech skills. The generational "digital divide" places added pressure on aging workers to be able to keep up with the fast-paced technological aspects of their work.

One of the major challenges for older employees is cybersecurity. Digitization being carried out by organizations increases the need for proper cybersecurity measures. However, many older workers do not even understand that phishing attacks exist, that they should set strong passwords, or that they should enable two-factor authentication. This lack of cybersecurity awareness not only threatens their personal data but also the data security of their organizations. Our study indicates that a high percentage of older workers are not acquainted with cybersecurity practices.

In a wider context beyond elementary digital literacy and cybersecurity is the adoption of recently developed technologies like artificial intelligence and machine learning, which are reshaping industries by automating routine tasks. In this respect, these AI tools also remain out of reach for older workers, who generally have little knowledge of how these tools can be integrated into their working environment. The study discloses that many older workers are not acquainted with artificial intelligence and also lack confidence in their ability to learn and adapt to these advanced technologies. This can become a critical issue in sectors where artificial intelligence has become part of day-to-day operations.

The findings indicate that a substantial share of older workers does not receive sufficient training on digital tools and technologies. Thus, older workers need tailored and comprehensive training programs in digital tools, data management, cybersecurity, and emerging technologies such as artificial intelligence. The introduction of these training programs is important to mitigate the increasing gaps in digital skills. In addition,

most older workers have not come across services such as cloud computing, video conferencing, or data systems, which are common in most businesses today.

Learning preferences among older workers also differ significantly from those of younger ones. Research demonstrates that the older population learns best by experiencing and engaging.

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Enterprise Architecture Readiness and Knowledge Management Integration: A Case Study of the Ministry of Rural and Regional Development

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Abstract. This study investigates the readiness for Enterprise Architecture (EA) and its integration with Knowledge Management (KM) within the Ministry of Rural and Regional Development, Malaysia. The primary objective is to assess the current state of EA readiness and the potential for integrating KM practices within the ministry. This involves identifying gaps, challenges, and opportunities to inform the development of a strategic roadmap for EA and KM integration. The methodology employed is a qualitative approach, focusing on the Ministry of Rural and Regional Development. Data collection methods include quantitative surveys, with data collected from 150 responses and analysed using SPSS to gather insights on existing EA practices and KM initiatives. The Cronbach's Alpha indicated that the questionnaire items were valid and reliable in measuring the intended constructs. The study also utilizes a readiness assessment model to evaluate the ministry's readiness for EA implementation and KM integration. The findings reveal that while there is a foundational understanding of EA and KM concepts within the ministry, significant gaps exist in terms of infrastructure, stakeholder engagement, and alignment of EA and KM strategies with organizational goals. Key challenges include limited resources, resistance to change, and the need for capacity building among staff. The significance of this research lies in its contribution to the body of knowledge on EA and KM integration in public sector organizations, particularly in the context of rural and regional development. The findings from this research can help create a detailed plan for the ministry to use EA and KM to enhance service delivery and achieve lasting development goals. This study also offers practical recommendations for policymakers and practitioners aiming to enhance organizational readiness for EA and KM integration.

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Keywords: Readiness Assessment · Enterprise Architecture · Knowledge Management · Digital Transformation · Public Sector

1 Introduction

The integration of Enterprise Architecture (EA) and Knowledge Management (KM) has become an essential strategy for improving operational efficiency, decision-making, and innovation in today's organisational management. Enterprise Architecture offers a systematic framework for aligning business processes, information systems, and technological infrastructure, whereas Knowledge Management emphasises the generation, dissemination, and use of knowledge inside an organisation. The integration of these two domains can substantially augment an organisation's capacity to adjust to evolving circumstances, boost service delivery, and attain strategic goals [1, 2].

The Ministry of Rural and Regional Development (KKDW), Malaysia exemplifies a relevant case study for analysing the combination of EA and KM. The KKDW is a government agency tasked with fostering rural development and regional advancement. It operates within a complex and dynamic environment that necessitates robust architectural frameworks and effective knowledge-sharing mechanisms. The readiness of an organisation's EA is a critical factor in its capacity to effectively incorporate the KM approach. EA readiness includes the maturity of architectural processes, the alignment of IT and business strategy, and the organisation's ability to handle change [3].

The readiness of EA is crucial for the successful implementation of KM practices within an organisation. EA readiness involves evaluating factors such as organisational culture, existing IT infrastructure, leadership support, and resource availability [4]. When an organisation is prepared for EA, it can effectively align its business processes, information systems, and technology infrastructure, creating a conducive environment for KM practices. This alignment facilitates the efficient creation, use, distribution, and transfer of knowledge, which are core components of KM [5]. By integrating EA with KM, organisations can ensure that their knowledge assets are systematically managed and leveraged to support strategic objectives, enhance decision-making, and improve overall performance [5].

This research article looks at the relation between EA readiness and KM integration inside the KKDW, aiming to identify factors that facilitate or impede this integration. Based on current literature, the study asserts that a robust EA establishes the essential framework for efficient KM, facilitating the uninterrupted exchange of information and knowledge throughout the organisation [6]. The lack of a developed EA can result in disjointed knowledge systems, inefficiencies, and lost possibilities for innovation.

This work is significant for its contributions to both academic and practical fields. It significantly enhances the discussion on the convergence of EA and KM by offering empirical evidence from a public sector environment. The findings provide practical insights for policymakers and organisational leaders aiming to improve the integration of EA and KM in comparable contexts. The research conducts a quantitative study to assess KKDW's EA readiness and KM integration initiatives. The significance of EA readiness cannot be overstated. Readiness assessments are vital to ensure a seamless transition

through the various phases of EA implementation, including planning, analysis, design, development, and maintenance. The research questions are i. What readiness assessment model is available to measure EA readiness in the organisation? ii. What is the level of readiness for EA implementation in the organisation iii. How knowledge management can transform EA implementation in the organisation?

This research highlights the necessity of synchronising EA and KM techniques to attain organisational excellence. This study seeks to illuminate the problems and opportunities encountered by the KKDW in integrating these two essential disciplines, providing significant insights for other organisations facing comparable complications. The paper begins by contextualising EA's role in public sector digitalisation, followed by an exploration of KKDW's current EA journey, the challenges encountered, the methodologies employed in this study, and the concept of EA and KM integration.

2 Background

This section provides the literature review done on the topic. It consists of three subsections as follows.

2.1 Enterprise Architecture

Enterprise Architecture (EA) is a holistic approach to planning, designing, and managing an organisation's IT systems and infrastructure. It aligns business strategies, processes, and IT infrastructure to achieve a unified and efficient system. EA facilitates informed decision-making by analysing the current (as-is) and desired (to-be) states of IT systems and identifying gaps to bridge them. The four main domains of EA—business, information, application, and technology—are critical to achieving these objectives.

Research by [7, 8] highlights EA as a blueprint for IT and business alignment, emphasising its role in interoperability and addressing challenges within public sector implementations. EA not only enhances IT systems but also aligns technological infrastructure with business goals, offering strategic benefits like improved e-government functions [9]. Furthermore, EA supports organisations in adapting to changes by providing a structured and iterative framework for managing technological evolution.

The conceptual evolution of EA has led to its recognition as a key enabler of organisational transformation. EA frameworks like TOGAF and Zachman provide methodologies to design, implement, and govern architectures effectively, ensuring that both business and IT objectives are met. Additionally, studies by [10] emphasize the importance of achieving interoperability in e-government systems, a critical factor in public sector digitalisation efforts.

2.2 EA Establishment

Establishing EA requires understanding organisational contexts, stakeholder readiness, and attitudes toward change. Frameworks such as the Zachman Framework and The Open Group Architecture Framework (TOGAF) provide structured approaches to implementation [11, 12]. These frameworks address challenges like resource allocation, alignment with business goals, and the iterative process of architecture development. For

instance, TOGAF's Architecture Development Method (ADM) emphasises continuous improvement through iterative cycles of planning, implementation, and evaluation.

Research by [13] highlights that organisational culture, leadership commitment, and stakeholder engagement are critical factors influencing the successful establishment of EA. Without adequate readiness, organisations may encounter resistance to change, inefficiencies in resource utilisation, and misalignment between strategic goals and IT capabilities. Establishing EA within an organisation, therefore, demands comprehensive planning, stakeholder collaboration, and the adoption of best practices tailored to organisational needs.

EA adoption in Malaysia's public sector is gradually gaining traction but still faces significant challenges. Initiatives like MyGovEA, introduced in 2014, aim to provide a standardised framework for EA implementation. However, according to [4, 14], adoption rates remain low, with only a limited number of government agencies fully integrating EA practices into their operations. [15] highlight several barriers to EA implementation, including a lack of awareness, inadequate training, and insufficient top management support. These challenges have resulted in fragmented adoption efforts and a limited impact on digital transformation objectives. Furthermore, cultural, and organisational resistance to change exacerbates these issues, making it difficult for agencies to fully embrace the principles and practices of EA.

EA represents a comprehensive framework designed to align an organisation's business processes, data, applications, and technology with its strategic objectives. Within the Malaysian Public Sector (MPS), EA is recognised as a foundational element of the digital transformation agenda. The Ministry of Rural and Regional Development (KKDW), a key player in advancing rural and regional development in Malaysia, has embarked on its EA journey since 2022. Currently in the Definition Phase of the MyGovEA framework, KKDW's adoption of EA underscores its commitment to enhancing service delivery and operational efficiency.

Despite these challenges, success stories like the Employees' Provident Fund (EPF) showcase the potential of EA to drive operational efficiency and improve service delivery. By adopting a hybrid approach that combines MyGovEA with tailored methodologies, EPF has been able to streamline processes, enhance decision-making, and align IT investments with business goals [11]. These examples highlight the importance of context-specific strategies in overcoming barriers to EA adoption. The Malaysian Public Sector Digitalisation Strategic Plan (DSP) underscores the need for greater collaboration and resource sharing among agencies to achieve a unified e-government ecosystem. However, the lack of a comprehensive readiness assessment framework remains a significant barrier. Without a clear understanding of organisational readiness, agencies risk investing in EA initiatives that fail to deliver the desired outcomes. Addressing this gap through targeted research and the development of tailored assessment models is critical to enhancing EA adoption in Malaysia.

2.3 EA Readiness Assessment

EA readiness is a critical determinant of successful implementation, particularly in complex environments like the public sector. The EA Readiness Assessment Model

(EARAM), illustrated in Fig. 1, provides a structured framework for evaluating an organisation's capacity to adopt EA practices. It categorises readiness into four key elements: Catalyst Enabler, People, Process, and Technology.

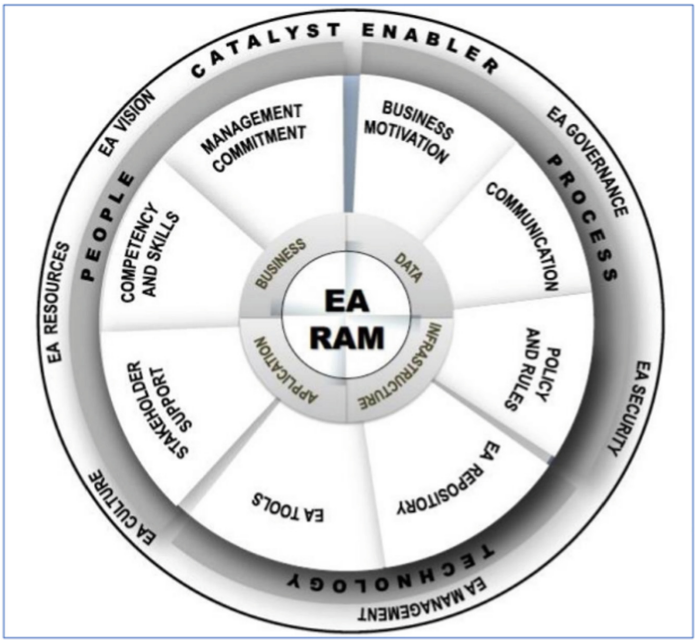

Fig. 1. EA Readiness Assessment Model [13]

The study by [13] emphasises that readiness assessments must go beyond technical capabilities to include factors such as governance structures, leadership commitment, and cultural alignment. By addressing these dimensions, organisations can identify potential barriers and develop targeted strategies to enhance readiness.

The readiness levels for each factor are evaluated using indicators, as shown in Table 1. These indicators provide a nuanced understanding of an organisation's strengths and weaknesses, enabling a focused approach to capacity building and resource allocation.

Research also highlights the importance of continuous readiness assessments to ensure alignment with evolving organisational needs. [10] propose a dynamic model that integrates feedback mechanisms to adapt readiness strategies over time. This approach is particularly relevant in the Malaysian context, where varying levels of maturity and resource availability necessitate flexible and iterative assessment processes.

Table 1. Assessment Indicator [13]

Median	Readiness Indicator
1	Low Needs substantial work before proceeding
2	Fair Needs some work before proceeding
3	Acceptable Some readiness issues exist, no showstoppers
4	Good Relatively minor issues exist
5	High No readiness issues

3 Methodology

A quantitative research design was used in this study to explore if the Ministry of Rural and Regional Development (KKDW) is ready to implement Enterprise Architecture (EA). The structured approach enables the identification of key factors influencing readiness and the measurement of current readiness levels across multiple organisational dimensions.

3.1 Instrument Development

The instrument that was used in this research is a questionnaire. A five-point Likert scale is suggested in this study to represent the responses of the respondents [23]. All the sub-factors and items used in this study are shown in Table 2. The questionnaire was developed based on validated models, EARAM, and tailored to the Malaysian public sector context. Key sections of the survey included:

1. Demographics: Capturing respondent details such as department, role, and years of experience.
2. Readiness Assessment: Assessing factors across the Catalyst Enabler, People, Process, and Technology categories.

3.2 Sample and Data Collection

The survey was administered using Google Forms, ensuring accessibility and ease of response. This study found a minimum total sample of 248 to be drawn from a population of 700 KKDW staff [21]. A total of 150 responses out of 248 were targeted to ensure statistical significance. The survey was simple, concise, and specific, and included instructions for completing the questionnaire. The instructions also mentioned that the respondent's answers were anonymous and were advised to answer the questions as honestly as possible.

1. The collected data were analysed using descriptive and inferential statistics using SPSS. The descriptive statistics were performed to analyse the demographic respondent's profile and data scores for each element. Afterward, the inferential statistics were performed to analyse the median scoring and Reliability Analysis. The definitions of median scoring and Reliability are as follows: Median Scoring: Evaluating readiness levels based on the indicators in Table 1. The median score was used to evaluate the overall readiness level of the ministry. This approach provided a robust measure of central tendency, minimising the impact of outliers and skewed data distributions.
2. Reliability Analysis: The reliability of the questionnaire was assessed using Cronbach's Alpha, ensuring the consistency and validity of the measurement items. Table 2 summarises the reliability analysis for all sub-factors. This test ensured that the questionnaire items were valid and reliable in measuring the intended constructs.

Table 2. Reliability Analysis for each element.

Element(s)	Sub-factor(s)	Number of Sub-factor items	Observations	Cronbach's Alpha
Enterprise Environmental	Vision	6	33	0.984
	Culture	4	33	0.907
	Change Management	5	33	0.905
	Resources	3	33	0.900
	Governance	3	33	0.990
People	Stakeholder Support	3	33	0.959
	Competency and Skills	3	33	0.941
	Management Commitment	4	33	0.970
Process	Business Motivation	2	33	0.989
	Communication	3	33	0.960
	Policy and Rules	3	33	0.958
Technological	EA Repository	2	33	0.954
	EA Tools	2	33	0.935
	Security	2	33	0.942

The results of the analysis were used to develop actionable recommendations for enhancing EA readiness within KKDW. This structured methodology ensures reliability and relevance in assessing the organisation's readiness for successful EA implementation. The response rate of collected data for this study is 60.5%. The benchmark response rate for organisational (individual) research studies is 52.7% or higher is good [18]. Therefore, the response rate of 60.5% can be reasonably accepted and adequate to generalize the population of the research context.

4 Results and Findings

This section presents the results and findings of the readiness assessment of Enterprise Architecture (EA) implementation at the Ministry of Rural and Regional Development (KKDW). A total of 150 respondents participated in the study, representing a broad spectrum of roles across the ministry.

The findings are categorised into descriptive statistics, reliability tests, hypothesis testing, and readiness scores to provide a detailed understanding of the ministry's preparedness for EA implementation.

The survey revealed a diverse range of working experiences among respondents. The majority (26.5%) had 11–15 years of experience, followed by those with 16–20 years (22.5%). Participants with less than 5 years accounted for 17.9%, while 20.5% had 5–10 years of experience. Those with over 20 years of experience comprised 12.6% of respondents, reflecting a balanced mix of new and tenured staff.

Most participants (57.0%) had a basic understanding or casual acquaintance with EA, while 24.5% were competent in the subject. Only 2.0% had advanced knowledge, and 16.6% were entirely unfamiliar with EA. Furthermore, formal EA training was notably lacking, with 81.5% of respondents reporting no prior training. Of the trained respondents, certifications such as TOGAF and CITAF were common, emphasising the need for a more strategic training plan.

4.1 Readiness Score

Figure 2 visually depicts KKDW's EA readiness across the four key elements: Enterprise Environment, People, Process, and Technology. Each element achieved a readiness score of 4.0, indicating that KKDW is well-prepared for EA implementation with minor areas for improvement.

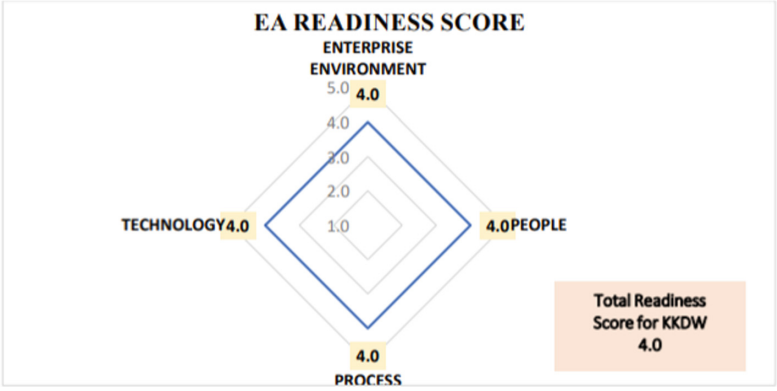

Fig. 2. Readiness Score for KKDW

4.2 Detailed Factor Analysis

A breakdown of readiness scores by individual factors is illustrated in Fig. 3. Each factor achieved a score of 4.0, reflecting consistency across dimensions such as governance, stakeholder support, and EA tools.

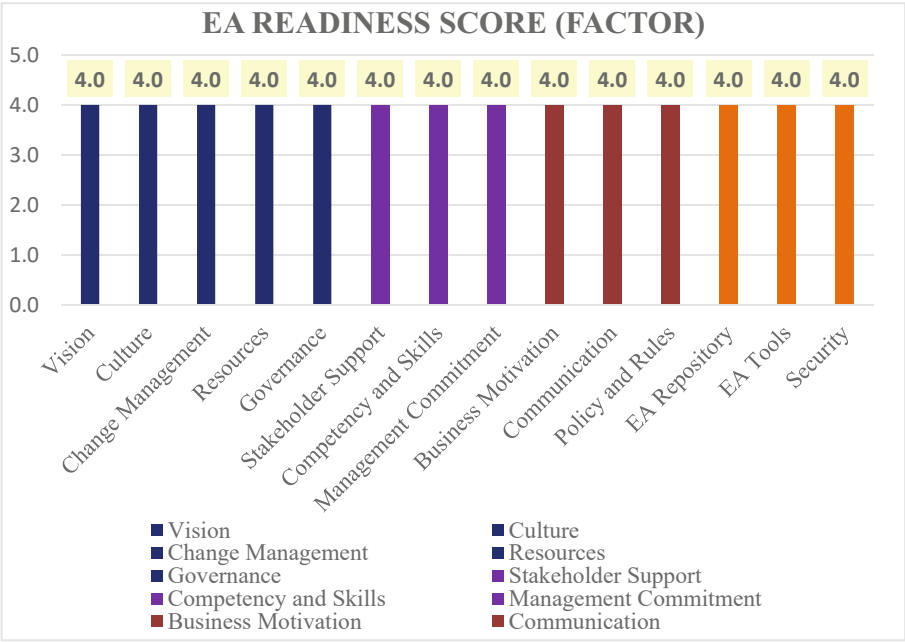

Fig. 3. Readiness Score by Factor

1. Enterprise Environment

The enterprise environment achieved a score of 4.0, signifying strong readiness in areas such as vision, culture, and governance. Collaborative efforts have established a shared vision, while governance structures, including an EA committee, support effective implementation.

2. People

The "People" element also scored 4.0, highlighting the importance of stakeholder support, competency development, and management commitment. In this case, KM should be implemented in KKDW as one of the initiatives for EA readiness as the integration amplifies both respective strengths: EA creates the infrastructure and frameworks necessary for KM to operate effectively, ensuring scalability, interoperability, and alignment with enterprise goals. Meanwhile, KM concentrates on capturing, organising, and disseminating knowledge to enhance decision-making, foster collaboration, and drive innovation. Hence, initiatives like the IDEA@KKDW platform and targeted training programs have enhanced awareness and engagement among staff.

3. Process

With a score of 4.0, the process element underscores the effectiveness of business motivations, communication strategies, and policies in guiding EA implementation. KKDW's adherence to systematic digitisation policies ensures consistency and alignment with organisational goals.

4. Technology

The technology element scored 4.0, reflecting robust infrastructure, tools, and security measures. The adoption of ISO/IEC 27001 standards for information security and the establishment of a centralised repository underscore KKDW's commitment to a secure and efficient technological foundation.

Thus, the factor analysis shows that the EA approach can be used to manage knowledge by focusing on four factors: culture, competency and skills, communication, and repository. These factors bolster the SECI model by Nonaka & Takeuchi [2], facilitating the transformation of tacit knowledge into explicit knowledge [17]. This will accelerate the digital transformation at KKDW (Fig. 4).

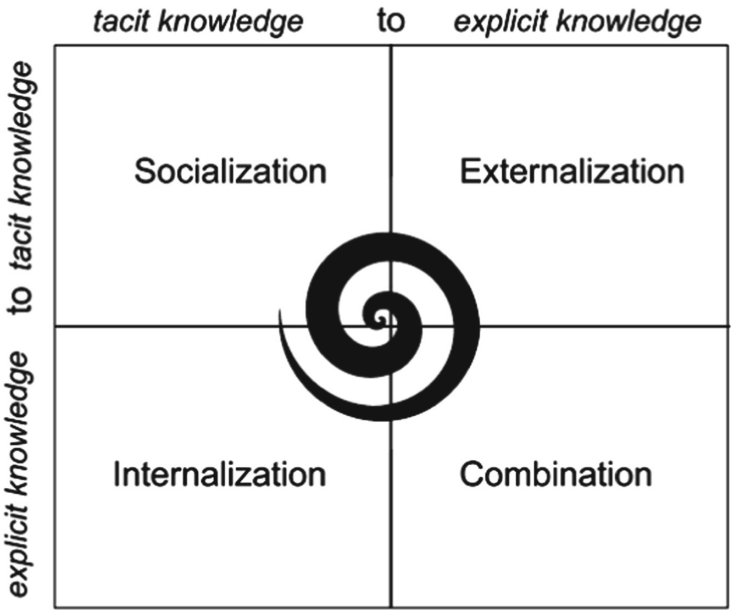

Fig. 4. SECI Model [2]

The enterprise environment attained a score of 4.0, indicating robust readiness in aspects such as vision, culture, and governance. Collaborative initiatives have created a unified vision, while governance frameworks, such as an EA committee, facilitate efficient implementation.

The SECI model enables the transformation of tacit knowledge into explicit knowledge, crucial for organizational learning and readiness. The enterprise environment

theme score of 4.0 indicates that transformation facilitates the EA readiness assessment by systematically capturing and utilizing knowledge to guide strategic decisions [19, 20].

From the technology theme, the integration of modern technology with the SECI model enhances knowledge management processes, which in turn supports the technological infrastructure required for EA readiness. This synergy enables organizations to adapt to changes and drive innovation [19, 20] and by aligning these models, organisations can enhance their readiness for change and innovation.

4.3 Recommendations

Based on the findings, in KKDW, the integration of EA and KM offers significant benefits to organisations by aligning knowledge assets with strategic goals. Together, both EA and KM may improve decision-making by ensuring that relevant, high-quality data is accessible and contextualised for actionable insights. This synergy enhances operational efficiency, as EA streamlines processes and systems while KM promotes the reuse of best practices and reduces duplication of effort. KKDW will also gain agility, with EA providing scalable and adaptable infrastructures that KM leverages to enable swift responses to change. Furthermore, this integration fosters innovation by capturing and disseminating new ideas, supported by flexible architectures that allow experimentation. Ultimately, EA and KM together create a future-ready KKDW, equipped for continuous improvement and sustained competitive advantage.

On top of strengthening KM together with EA in KKDW, the following are other recommendations to be proposed:

1. Enhanced Training Programs: Introduce targeted training sessions to bridge knowledge gaps and improve EA competency levels among staff.
2. Strengthened Governance: Expand the roles and responsibilities of the EA committee to ensure sustained leadership and oversight.
3. Knowledge Management (KM): Develop a comprehensive system for capturing and sharing EA-related information to foster organisation learning.
4. Resource Optimisation: Conduct periodic assessments of financial and human resources to align them with EA objectives.
5. Collaboration and Partnerships: Engage with external experts and agencies to share best practices and enhance EA maturity.

By addressing these areas, KKDW can further strengthen its readiness and achieve long-term success in EA implementation.

5 Conclusion

The study concludes that KKDW has a strong foundation for EA implementation, with a high level of readiness across all assessed factors, particularly KM. By working in synergy, both EA and KM will contribute to KKDW's success. EA designs scalable, interoperable systems that connect data and processes across the enterprise, giving KM

the structure, it needs to grow. Through standardised frameworks and governance policies, EA ensures that KM practices align with organisational goals while maintaining compliance and data quality. On the other hand, KM enriches EA by capturing, organising, and sharing valuable knowledge assets, including lessons learned, best practices, and historical data. This empowers EA teams to make informed decisions and adapt architectures to evolving needs. Concurrently, EA and KM enhance decision-making, foster collaboration, and drive innovation, creating a robust foundation for achieving strategic and operational goals.

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Analyzing the Ways in Which Fake News Makes Firms' Financial Difficulties Worse During Emergencies, Pandemics or Recessions

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Abstract. The proliferation of fake news has become a major problem in today's more connected digital world, especially for companies that are struggling financially during emergencies like pandemics or recessions. This study explores how disinformation erodes consumer trust in times of crisis, distorts market perceptions, and disrupts supply networks, all of which increase a company's financial vulnerability. This study uses a mixed-methods approach, combining quantitative analysis of case studies from a variety of industries, such as retail, healthcare, and finance, during the COVID-19 pandemic, the global financial crisis of 2008, and the financial crisis in Nigeria in 2023, with qualitative insights from interviews with business leaders. The results show that there are three main ways in which bogus news exacerbates financial difficulties for businesses. First of all, it causes abrupt changes in consumer behavior, like boycotts or panic buying, which upsets sources of income. Second, false information concerning product safety or supply chain interruptions raises operating expenses and delays, which exacerbates financial strain. Last but not least, bogus news that attacks a company's reputation lowers investor trust and makes it harder to obtain vital investment. Businesses who were wrongly accused of unethical behavior during the epidemic, for instance, had a sharp decline in stock values, which had long-term effects on the financial recovery. This study emphasizes its real-world economic effects during periods of increased susceptibility and suggests a framework for companies to lessen these impacts, focusing on the open communication and collaborations with reliable media sources to successfully combat false information.

Keywords: Fake news · financial difficulties · pandemics · recessions

1 Introduction

In an increasingly interconnected world, the rapid spread of information plays a critical role in shaping public perception and decision-making. However, the rise of fake news poses significant challenges, particularly during emergencies like pandemics or economic recessions. Fake news, characterized by intentionally misleading or false information, can exacerbate the financial difficulties of firms by influencing consumer

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behavior, investor confidence, and market dynamics. People with unrestricted access to vast amounts of information can express a wide range of values and opinions (Rubin 2019). Over recent years, misinformation commonly referred to as "fake news" has surged in prevalence, particularly through social media platforms. Despite its modern escalation, the creation and spread of misinformation are not new phenomena (Burkhardt 2017). While technological advancements enable people to quickly access information to bridge knowledge gaps, enhance skills, and identify false or incomplete content, relatively few actively seek such accurate resources (Baltezarević & Baltezarevic 2021). Fake news significantly affects politics, democracy, society, and the economy, often driving actions and outcomes, particularly when shared on social media platforms (Pennycook et al. 2018). Its creators often have strategic motives, whether political (e.g., influencing public opinion about politicians) or financial, and these strategies carry tangible consequences (Barclay 2018). In Europe alone, over 70% of individuals encounter fake news regularly, highlighting its pervasive influence on societal opinions, beliefs, and even voting behavior (Watson 2024). According to the World Economic Forum's 2024 Global Risk Report, misinformation ranks among the most significant global threats, demonstrating its widespread implications (Fleck 2024). The economic impact of fake news is profound, with repercussions severe enough to cause business failures and even fatalities unless companies adopt data-driven strategies supported by ethical practices. The COVID-19 pandemic stands out as a prime example, where misinformation led to the coining of the term "infodemic" to describe the rumors, stigma, and misleading information that emerged during the global health crisis (Nasrin 2021). Fake news also negatively influences consumer perceptions of brands. When company advertisements appear on fake news websites, consumer trust in the brand diminishes, affecting attitudes toward the business (Visentin et al. 2019). In today's digital landscape, while the online environment shapes consumer attitudes significantly, a considerable number of internet users are regularly exposed to unreliable information, further compounding the problem (Baltezarević 2022).

1.1 Objectives of the Study

The aim of this study is to analyze the ways in which fake news makes firms' financial difficulties worse during emergencies like pandemics or recessions with the following objectives.

i. To analyze the financial impact of fake news on firms during crises such as pandemics and economic recessions.
ii. To examine how misinformation affects consumer trust, investor sentiment, and operational costs.
iii. To identify patterns in the dissemination of fake news and its implications for different industries.
iv. To propose effective strategies for firms to mitigate the adverse effects of fake news.

2 Research Method

2.1 Data Collection Method

The study focuses on firms operating in diverse industries, including retail, healthcare, and finance, across global crises such as the COVID-19 pandemic, the 2008 financial crisis, and the 2023 Nigerian crisis. The study adopts a mixed-methods approach, Case studies from multiple industries affected by crises, with data on financial performance, stock prices, supply chain delays, and operational costs was used views from interviews with business leaders, exploring the real-world impacts of fake news on decision-making and crisis management.

2.2 Statistical Analysis

To summarize key metrics such as revenue impact, stock price fluctuations, and operational cost increases the study used the Descriptive Statistics and Time Series Analysis To evaluate the longitudinal effects of fake news across different crises and uncover trends in business performance while the Sentiment Analysis was conducted To assess investor sentiment using tools like the VADER classifier and its financial extensions and Comparative Analysis was used to identify differences and similarities in the impacts of various crises on businesses.

3 Result and Discussion

3.1 Descriptive Analysis

The data describes significant impact of fake news on the financial performance and operations of firms during crises. The Impact on Revenue has a mean of −13.4%, indicating an average decline in revenue, with firms experiencing a wide range of losses, from a minimum of −20% to a maximum of −8%. The standard deviation of 3.47% suggests that there is considerable variation in the revenue impact, with some firms suffering more than others. The median value of −13% further aligns with the mean, reinforcing the consistency in the level of revenue loss. This suggests that the majority of firms face notable challenges in maintaining their revenue streams due to the disruption caused by fake news during economic downturns or emergencies. The distribution of revenue impact shows a trend where companies' performance is consistently hindered, particularly in the wake of damaging media coverage (Table 1).

Regarding the Impact on Stock Price, the average decline is more severe, with a mean of −15.3%, signaling substantial losses in market value. The variation is also high, with a standard deviation of 5.39%, which indicates that some firms experience very sharp drops, with stock prices as low as −25% and as high as −5%. The median value of −15% suggests that most firms experience a similar level of stock price decline, which could be attributed to investor panic, uncertainty, and reaction to negative news. This impact on stock prices is particularly alarming because, unlike revenue, stock prices can react more sharply to media coverage, investor sentiment, and public perception, all of which can be significantly influenced by fake news. The severe nature of stock price declines highlights

Table 1. The impact of stock exchange and substantial losses in market value

Variable	Mean	Standard Deviation	Minimum	Maximum	Median
Impact on Revenue (%)	−13.4	3.47	−20	−8	−13
Impact on Stock Price (%)	−15.3	5.39	−25	−5	−15
Supply Chain Delay (Days)	9.3	3.58	0	15	9
Operational Cost Increase (%)	6.15	2.07	3	10	6
Investor Sentiment Change	1.9	1.07	0	3	2
Reputation Damage (Y/N)	0.8	0.41	0	1	1

how vulnerable firms are to public relations crises driven by misinformation. In terms of operational aspects, firms face considerable disruptions in their supply chains and increasing costs. The Supply Chain Delay has an average of 9.3 days, with a standard deviation of 3.58 days, suggesting that while delays are common, their duration can vary greatly depending on the nature of the crisis and the firm's reliance on external suppliers. The minimum of 0 days indicates that some firms manage to avoid significant delays, but the maximum of 15 days reflects the more severe cases. The Operational Cost Increase shows an average rise of 6.15%, with a standard deviation of 2.07%, indicating a moderate but significant increase in costs as firms attempt to adapt to disruptions. These higher operational costs are a natural consequence of navigating supply chain issues, increasing production efforts, or seeking alternatives to maintain operations. The Investor Sentiment Change, with a mean of 1.9 and a median of 2, suggests that while sentiment is generally positive, it can fluctuate depending on how firms handle the crisis. The Reputation Damage metric indicates that 80% of firms experience some form of damage to their reputation during these crises, highlighting the long-term consequences of fake news on a company's public image and the challenges of rebuilding trust after such events. This comprehensive set of variables paints a clear picture of how fake news exacerbates financial distress, operational inefficiencies, and reputational harm during emergencies.

3.2 Time Series Analysis

This section presents a time series analysis of the impact of various crises on business performance, focusing on key indicators such as revenue, stock price, supply chain delays, operational costs, investor sentiment, and reputation damage. The analysis spans historical crises, including the COVID-19 pandemic, the 2008 financial crisis, the 2010 global recession, and the 2023 Nigerian crisis, as well as a projected 2025 crisis. The results offer a comparative perspective, highlighting the distinct and overlapping economic, operational, and reputational effects of each crisis type. By quantifying mean changes across these metrics, the analysis aims to uncover patterns that can inform strategic resilience planning for future disruptions. The findings underline the multi-dimensional

nature of crises, emphasizing the need for holistic approaches to crisis management in a rapidly evolving global economy (Table 2 and Fig. 1).

Table 2. A time series analysis of the impact of various crises on business performance

Crisis Type	Mean Impact on Revenue (%)	Mean Impact on Stock Price (%)	Mean Supply Chain Delay (Days)	Mean Operational Cost Increase (%)	Mean Investor Sentiment Change	Mean Reputation Damage (Y/N)
COVID-19 Pandemic	−14.0	−16.1	8.6	6.5	2.2	0.9
Financial Crisis 2008	−14.5	−19.3	9.7	6.5	2.0	1.0
Nigerian Crisis 2023	−10.2	−12.2	9.2	5.4	1.7	0.6
Global Recession 2010	−12.5	−14.0	12.5	6.5	2.0	1.0
Predicted Crisis 2025	−13.0	−15.5	10.0	6.2	2.0	0.8

3.3 Discussion of the Findings

The time series analysis of various crises indicates that the impact of fake news on firms' financial and operational outcomes differs across each event. During the COVID-19 pandemic, firms experienced a mean revenue decline of −14.0% and a −16.1% drop in stock prices, the most severe among the crises analyzed. This suggests that the pandemic was particularly challenging for firms, with misinformation amplifying the financial difficulties. The supply chain delays averaged 8.6 days, reflecting disruptions that firms faced in procuring materials and delivering products due to the pandemic's widespread effects. The operational cost increase of 6.5% highlights the additional financial burden firms had to bear to adapt to rapidly changing conditions. Despite these challenges, investor sentiment showed a relatively positive shift, with a mean of 2.2, which might indicate optimism about the long-term recovery from the pandemic. The reputation damage was high, with 0.9, meaning that most firms suffered damage to their public image, likely due to the public perception of their responses to the crisis.

In contrast, the 2008 Financial Crisis had a more severe impact on firms' stock prices, with an average decline of −19.3% and revenue down by −14.5%. This indicates that the financial crisis, combined with the global economic collapse, resulted in more significant stock market volatility and overall financial strain compared to the COVID-19 pandemic. Supply chain delays averaged 9.7 days, higher than those seen in the COVID-19 crisis, showing that disruptions in logistics and production were more

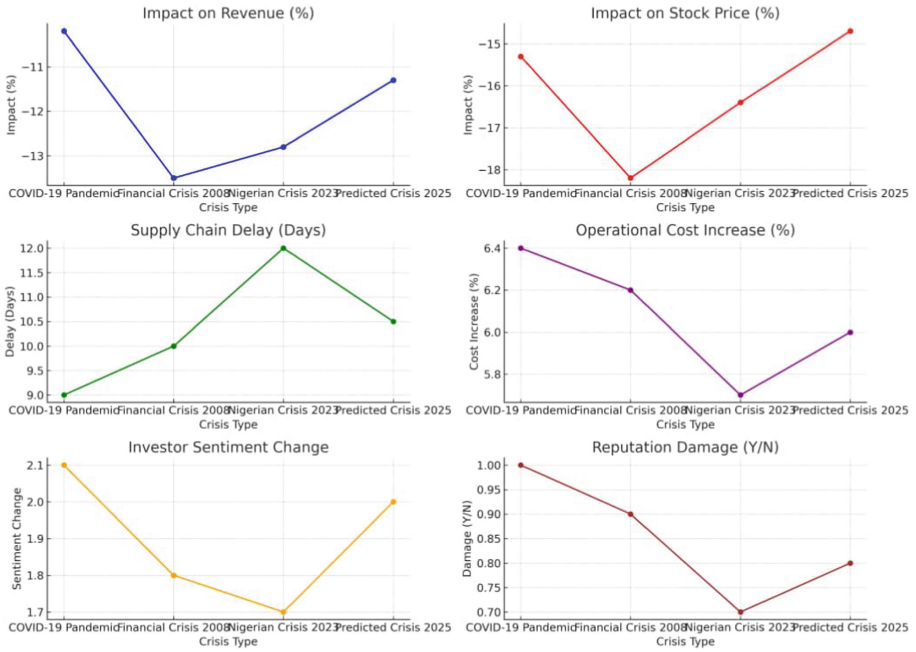

Fig. 1. Time-series analysis graph for the different crises, illustrating the trends for each key variable.

prolonged during the financial downturn. Despite these difficulties, firms faced similar operational cost increases (6.5%) as they struggled to adapt to reduced consumer demand and operational constraints. Investor sentiment remained slightly lower than in the pandemic, with a mean of 2.0, reflecting the more widespread panic and uncertainty among investors at the time. Reputation damage was also significant, with a value of 1.0, showing that most firms experienced significant harm to their public image, likely from their involvement in the crisis or their inability to manage the financial collapse effectively.

The Nigerian Crisis in 2023 presents a slightly different scenario, with a smaller impact on revenue (−10.2%) and stock prices (−12.2%) compared to the global crises. This suggests that while the crisis had a notable effect on firms, it was less severe in terms of financial losses. Supply chain delays of 9.2 days were nearly as severe as those during the 2008 Financial Crisis, indicating significant logistical challenges, though they were not as extensive as in the global recession. Operational costs increased by 5.4%, which is lower than the increases seen in other crises, possibly reflecting the relative containment of the crisis compared to global events. Investor sentiment was somewhat more moderate, with a mean of 1.7, suggesting less drastic shifts in investor perception. Reputation damage was lower, with a mean of 0.6, implying that fewer firms suffered long-lasting harm to their public image compared to the COVID-19 and 2008 crises. Looking ahead to the Predicted 2026 Crisis, the figures suggest that the crisis could be less damaging than previous events. Revenue decline is expected to be −13.0%, stock price

decline −15.5%, and supply chain delays 10.0 days, all indicating moderate disruption but not to the same extent as the earlier crises. The expected operational cost increase is 6.2%, showing that firms will likely face cost pressures, but investor sentiment remains stable at 2.0, and reputation damage is expected to be slightly lower at 0.8, suggesting that the predicted crisis might not be as reputation-damaging as the previous ones. This analysis provides valuable insights into the varying impacts of different crises and helps firms prepare for future disruptions.

4 Conclusion

This study highlights the significant role of fake news in exacerbating firms' financial vulnerabilities during crises such as pandemics and economic recessions. The findings demonstrate that misinformation impacts businesses by disrupting consumer trust, investor sentiment, and operational efficiency. The COVID-19 pandemic, the 2008 financial crisis, and the 2023 Nigerian crisis serve as key case studies showcasing the economic, reputational, and logistical repercussions of fake news. The research underscores the importance of understanding how fake news spreads and its tangible effects on industries, emphasizing the necessity for proactive measures to mitigate these challenges.

5 Recommendations

Base on the result of the study the following recommendations where made to the government of all level and all the stakeholders.

i. Firms should integrate advanced fact-checking tools to monitor and combat misinformation effectively.
ii. Transparent and consistent communication can help build consumer and investor trust during crises.
iii. Strengthening partnerships with credible media outlets can counteract the spread of fake news.
iv. Educating consumers on identifying fake news can reduce its influence on public perception and business outcomes.
v. Firms should establish contingency plans to address operational disruptions caused by misinformation, such as supply chain delays and cost escalations.

6 Research Contribution

This study contributes to the existing body of literature by providing a multidimensional analysis of the impact of fake news on firms' financial and operational performance during crises. It bridges gaps in understanding the mechanisms through which misinformation exacerbates business vulnerabilities and proposes actionable strategies to mitigate its effects. Additionally, the research introduces a framework for integrating fact-checking tools, transparent communication, and collaborative approaches with media to foster organizational resilience against the adverse impacts of fake news.

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The Role of Perceived Value Between Website Service Quality on Consumer Satisfaction: The Case of Asian Creative Website Pinkoi

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Abstract. Pinkoi website is one of most popular e-commerce in Taiwan. The websites sell unique and fashion items so that consumers are favored. The purpose of this research is to explore the website quality service and examine the perceived value relationships with consumer satisfaction base on Pinkoi Online Shopping Website. The sample used in this study was 352 with the questionnaire method. Statistical analysis was using SPSS 19.00. With descriptive statistic, factor analysis, reliability analysis, Pearson correlation and regression analysis. Five factors were found in Pinkoi Website service quality which are aesthetic, security, ease of use, responsiveness and contact. Both Website service quality and perceived value had significant positive impact on consumer satisfaction. In addition, the consumer perceived value has a mediating effect between website service quality and consumer satisfaction. Overall, Pinkoi e-commerce not only the sell a unique, diverse, handmade, and limited-edition merchandise but also their websites service quality influence consumers' perceived value and improve satisfaction.

Keywords: Perceived value · website quality service · consumer satisfaction · Pinkoi

1 Introduction

The world is required to increase technological development in all fields, one of which is the economy. In today's digital era, technology helps people to move quickly, including how to shop. People prefer practical ways to shop. For that currently growing rapidly online shopping websites that are very helpful for people in shopping. According to McKinsey & Company global retail e-commerce sales in the world have continued to increase since 1994, nearly 20 percent of total global sales in 2021 were made from online purchases. By 2025, nearly a quarter of all global sales are expected to be made online [1]. Taiwan's e-commerce penetration rate has remained around 11% over the past three years and is expected to approach 20% by 2030. In the first half of 2024, online retail sales in Taiwan reached NT$313.9 billion, representing a 3% year-on-year growth [2]. One of the most popular e-commerce sites in Taiwan is the Pinkoi website. Pinkoi website provides an attractive shopping experience to customers with an attractive

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website design and a variety of goods offered. The goods offered are unique. Carefully designed and has a very high quality in accordance with international demand. Pinkoi website is supported by designers who can produce unique items, limited edition and international class. This uniqueness and limited edition makes customers comfort to shop at the pinkoi website. Pinkoi is an online shopping website since 2011. Since its establishment until now, Pinkoi has 40 million users and 11.3 million items have sold. Pinkoi users are spread across 93 countries with an average age of 25–44 years. Factors that influence someone to shop online because it saves time [3], there are discounts offered [4], convenience [5], price competition and the openness of access to clear information [6]. But apart from that on the other hand there are some people who still don't want to shop online due to privacy [7], perceived risks [8], education [9], a lack of trust [10], and perceived quality [11].

In particular in terms of e-commerce websites, it is very important to study the relationship between the perceived value of online shopping website customers, customer satisfaction with the quality of service provided by the website. Customers can judge service quality based on their experience when shopping online. Shopping experience is a big influence on customer satisfaction and repurchase intention after transacting online [12]. The pinkoi website also displays excellent service quality resulting in an increase in customer purchasing power. For that it is very important to see the relationship of customer percieved value with service quality on customer satisfaction Pinkoi website.

2 Literature Review

2.1 Perceived Value (PV)

Important factors in a company to assess competitiveness, profit and predict consumer behavior can be seen from the perceived value [13, 14]. One of the consumer behaviors that helps customers to make decisions based on customer perceptions of the value of an item is a perceived value [15]. The definition of perceived value always changes over time. Including qualitative, quantitative, subject and objective factors form a complete consumption experience [16]. Customer perceived value, they assume that the value perceived by the customer is an evaluation of the goods obtained by considering the aspects of the benefits obtained [17].

Based on Zeithaml (1988) [18], it can be said that perceived value has a different level of perception for each customer. There are customers who perceive an item to have a lower value than the price obtained, but on the other hand there are customers who value the value and price as balanced. In essence, for different customers, the perceived value is also different depending on each individual [19].

2.2 Service Quality (SQ)

Customers will be interested in shopping online if the seller provides excellent quality service. For that the quality of service in online shopping is very important and becomes the most important element in terms of the progress of an e-commerce website [20]. Long-lasting online sales are also determined by customer trust. Sellers maintain customer trust by providing the highest quality service, so that customers last a long time

shopping on the website. The best services include updates to items sold, website display, ease of shopping, claims problems, and friendliness of customer service [21].

To see service quality using the SERVQUAL scale, this scale is used to measure the service expected by the customer and the actual service quality obtained and the customer's perception of the quality of the service. The e-SERVQUAL scale was developed to measure the quality of service of the website, and the e-SERVQUAL scale consists of 10 initial components: efficiency, reliability, fulfillment, privacy, responsiveness, compensation, Connection, aesthetics, visibility, personality [22]. Finally, remove the aesthetics, visibility, personality of the three aspects formed into 7 aspects. Yoo and Donthu (2001) [23] explores the quality of web services in online retailing, and develops the SITEQUAL scale, which divides the quality of web services into four components: ease of use, aesthetic design, processing speed, and security, to measure consumer awareness of the quality of service on this online shopping site. In addition, to evaluate the quality of online website services, a SITEQUAL scale was also developed. This scale was suggested by Yoo and Donthu (2001) [23], and there are 4 components in it, namely the aesthetic design of the website, service processing speed, security and ease of accessing the website.

2.3 Customer Satisfaction (CS)

Customer satisfaction (CS) is defined as a condition in which a customer who purchases a product has the intention to repurchase the same product, which aims to increase repeated purchases of a particular product without being influenced by the marketing environment. When customers have positive expectations of the website, they will have the intention to make purchases on the same website again, but if customers have negative expectations of the website, then they will most likely have no intention of making purchases on the same website. On the other hand, the quality of products and services greatly affects customer satisfaction [24].

Online sellers must understand how to improve performance to get customer satisfaction, because the level of customer satisfaction in the online environment is different from the traditional retail environment [25].

Research Hypothesis:

H_1: Pinkoi website service quality has a significant positive impact on customer percevied value.
H_2: Pinkoi website service quality has a significant positive impact on customer satisfaction.
H_3: Customer perceived value has a positive impact on customer satisfaction.
H_4: Customer percevied value is a mediating variable between website service quality and customer satisfaction of Pinkoi.

3 Research Methods

3.1 Research Framework

According to the literature review, this study aims to investigate the relationships among Pinkoi website service quality, customer perceived value and their satisfaction in online shopping website. Based on that, the research hypotheses are depicted in Fig. 1. This

study was designed as experimental research which applies questionnaires as an instrument to collect data from adults age over 18 who visited Pinkoi Creative Shopping Website in Taiwan.

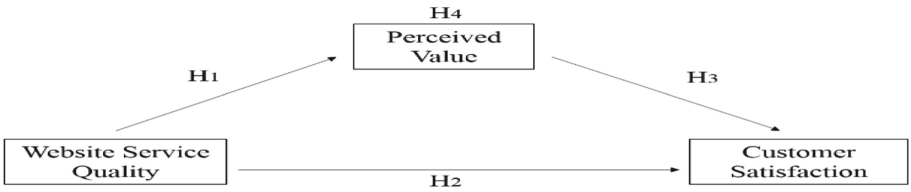

Fig. 1. Research Framework

3.2 Measurement

All the questionnaires were measured by using a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree) with appropriate modifications for this study. The website service quality (WSQ) refers not only to the experience of interacting with the website but also the level of follow-up service activities [26]. Measurement scale adopted by Yoo and Donthu (2001) [23], and Zeithaml et al. (2005) [27] which divided WSQ into 6 factors with 20 questions distributed between six factors which are ease of use, aesthetic design, fulfillment, security, responsiveness and contact. The perceived value (PV) measures the gap between the benefits and the costs customer paid, and the overall perceived value compares quantity, quality, subjectivity, objectivity, etc. [18], the measurement scale adopted from Chen and Hu (2010) [28] which divides PV into "Symbolic Value" and "Functional Value" with 9 questions. Consumer satisfaction (CS) is defined as "a measure of a customer's experience of products and services with a holistic assessment of consumer experience" [29]. The measurement CS employed a measurement developed by Oliver (1980) with 3 items [30].

3.3 Respondents and Sampling Methods

Intentional sampling was used to collect data from 760,000 followers in Pinkoi's Facebook fan page. The subjects were adult users age over 18 who visited Pinkoi Creative Shopping Website. The survey was conducted from October 30 to December 15, 2017. Using network to distribute questionnaire, after the elimination of incomplete questionnaire, the effective questionnaire would code, document, and analysis using SPSS 19.0 statistical software.

4 Results and Analysis Research Methods

4.1 Descriptive Analysis

A total of 352 questionnaires were collected with 328 valid questionnaires from Pinkoi Facebook fans. Invalid questionnaire that was either respondent is age under 18 years old and never purchased on Pinkoi website. Demographic data can be found in Table 1.

Most of the respondents were female (81.4%), aged between 18–24 years old (54.6%), followed by 25–29 years old (32.3%). In terms of education level, the majority hold a college degree (88.1%) with an average monthly income of NT$10,001–30,000 (34.5%) followed by NT$30,001–40,000 (19.8%). Most customers live in Northern (43%) and central Taiwan (33.2%) with few shopping from aboard (2.7%). Most respondents have online shopping habits (96.3%) and know Pinkoi website from social network advertising message (72.9%). They are surfing Pinkoi website monthly (45.4%) because they have purchase intention (35.5%) and like to pay attention to new products (18.9%).

4.2 Validity and Reliability

The exploratory factor analysis with oblique rotation was conducted to determine an appropriate number of factors and the pattern of factor loadings primarily from the data. Website service quality (WSQ) factor analysis shown results of the KMO value is $0.921 > 0.5$, and the $\chi 2$ value of Bartlett's sphere test is 3151.788 significant ($p < .001$) indicating that it is suitable for factor analysis. Item 4 (the Pinkoi website design allows me to complete shopping transactions quickly), item 15 (The Pinkoi website provides a convenient return and exchange mechanism), item 17 (the Pinkoi website can properly handle user-related issues), and item 19 (the Pinkoi website provides a message board function) double loaded on both factors, so it was removed and re-analyze. The results shown in Table 1 indicated that five factors were underlying WSQ, namely "aesthetic" with 19.36% variance explained, "security" with 15.32% variance explain, "ease of use" 14.61% variance explained, "responsiveness" with 14.27% variance explained and "contact" with 12.42% variance explained. The overall cumulative variance explained is 75.98% which indicated the scale has high validity. After factor analysis, Cronbach's α reliability analysis is performed, and the aesthetic, security, ease to use, responsiveness, and contact have α values of respectively 0.88, 0.86, 0.85, 0.84 and 0.81. Additionally, WSQ's α value is 0.87. All α values are all greater than 0.7 indicating that this scale has a high degree of reliability.

Perceived Value -Exploratory factor analysis shown results of the KMO value is $0.924 > 0.5$, and the $\chi 2$ value of Bartlett's sphere test is 2188.99 significant ($p < .001$) indicating that it is suitable for factor analysis. The results showed only one factor was extracted with items loading between .667–.877 and the cumulative variation 65.91%. Additionally, the α value of the PV is 0.93 indicating that this scale has a high degree of reliability. Customer Satisfaction -Exploratory factor analysis shown results of the KMO value are $0.723 > 0.5$, and the $\chi 2$ value of Bartlett's sphere test is 706.604 significant ($p < .001$) indicating that it is suitable for factor analysis. The results showed only one factor was extracted with items loading between .879–.944 and the cumulative variation 84.49%. Additionally, the α value of the CS is 0.91 indicating that this scale has a high degree of reliability.

4.3 Correlations

The means, standard deviations, and bivariate correlations of research variables are presented in Table 3. Research variables' means are between the lowest in security ($M = 4.07$) and the highest in responsiveness ($M = 4.32$) of WSQ. Since all variables'

Table 1. Website service quality factor analysis and reliability

Factor	items	Factor loading	Variance explained %	α value
Aesthetic	7. The design of Pinkoi website is more eye-catching than other websites	0.803	19.36	0.88
	6. Pinkoi website design is creative	0.800		
	5. The layout of Pinkoi website has a sense of design	0.798		
	8. The overall color scheme of the Pinkoi website design is simple and bright, with memory points	0.789		
Security	12. The Pinkoi website will not disclose the personal information of consumers to other entities	0.818	15.32	0.86
	13. The Pinkoi website will protect user credit card information	0.808		
	14. The Pinkoi website has a clear shopping security transaction policy	0.710		
Ease to use	2. The Pinkoi website makes it easy for me to find what I need	0.811	14.61	0.85
	1. Any page of Pinkoi website is clear and easy to use	0.768		
	3. The information on the Pinkoi website is well planned and classified	0.763		
Responsiveness	9. The Pinkoi website will deliver according to the ordered items	0.824	14.27	0.84

(*continued*)

Table 1. (*continued*)

Factor	items	Factor loading	Variance explained %	α value
	10. The Pinkoi website can deliver products to consumers as scheduled	0.782		
	11. The products sold on the Pinkoi website are honest	0.659		
Contact	20. When problems occur, Pinkoi website can immediately answer the inquiry through online customer service or e-mail	0.813	12.42	0.81
	18. The Pinkoi website provides contact information such as customer service hotline and mailbox	0.732		
	16. The Pinkoi website can immediately respond to consumer questions and needs	0.565		
Website SQ cumulative Variance explained (%)			75.98	
Website SQ Cronbach's α value			0.93	

Note: Factor loadings < 0.4 are suppressed.

means are higher than 4 indicated customers believe Pinkoi website service quality is good in all aspects, with high recognize of perceived value and satisfaction of Pinko. The highest mean in responsiveness suggest Pinkoi website deliver merchandise match their order and Pinkoi website can deliver products to consumers on time. An overview of correlations between independent variables is provided in Table 2. As shown in Table 3, at significance level $p < .001$ (2-tailed) CS have positive linear relationships among PV, WSQ and their factors with correlation coefficient r taking values between 0.51 and 0.87. The correlation between WSQ and PV is 0.83 ($p < .001$) means the better the website service quality consumer received, their perceived value would be higher too, such as the service of Pinkoi is excellent value for money, the prices of the products sold on Pinkoi are reasonable, and Pinkoi makes me feel good. Also, a moderate positive correlation was found between WSQ and CS ($r = 0.67$) indicating that the higher value the customer perceived, the higher degree of customer satisfaction. The correlation between PV and CS is 0.80 ($p < .001$), showing that the higher degree in perceived value, their customer satisfaction is relatively higher. Generally, the correlations among variables

are moderately positive (r > 0.6) (Gerber & Kristin 2005). This result indicated that with moderately correlation relationship among the variables, those variables are good to continue for hypotheses analysis.

Table 2. Means, Standard Deviations and Correlations among Variables

Variables	Mean	SD	1	1a	1b	1c	1d	1e	2
1. WSQ	4.14	.52	1						
1a. Aesthetic	4.19	.65	.79***	1					
1b. Security	4.07	.66	.80***	.44***	1				
1c. Ease to use	4.08	.70	.81***	.59***	.51***	1			
1d. Responsiveness	4.32	.59	.77***	.49***	.63***	.52***	1		
1e. Contact	4.13	.61	.83***	.50***	.68***	.57***	.65***	1	
2. PV	4.15	.59	.82***	.63***	.63***	.67***	.69***	.70***	1
3. CS	4.21	.68	.65***	.51***	.50***	.52***	.62***	.54***	.80***

Note: *** $p < .001$. WSQ- Website Service Quality, 2. PV- Perceived Value, 3. CS- Customer Satisfaction.

4.4 Regression Analysis

The results of the effect of website quality services on satisfaction can be analyzed in Table 3, the results obtained have a positive effect with a significant level of high on satisfaction. Strengthening the H1 hypothesis, namely the quality of website services on pinkoi websites have a positive effect on customer satisfaction. The effect of the value of perception of satisfaction results is also discussed in Table 3, R^2 of 0.64 (p = .000). From the data can be seen the results have a significant effect on the value of satisfaction and are very positive for the value of perception. From these results strengthen the H2 hypothesis, the value felt by consumers will affect consumer satisfaction positively.

According to Baron and Kenny (1986) the conditions under which the mediator variable is established include, first the independent variable (WSQ) should be significantly related to the mediator (PV). Second, the independent variable (WSQ) should be significantly related to the dependent variable (CS); third the mediating variable (PV) should be significantly related to the dependent variable (CS). And lastly, the mediating variable (PV) should be significantly related to the dependent variable (CS) with the independent variable (WSQ) included in the equation. If all conditions hold, beta weight drops between independent and dependent variables, partial mediation is deemed present. If the independent variable has non-significant beta weights in the final step, then complete mediation is present.

"Website Service Quality" is an argument and satisfaction is an analysis of intermediary variables: "Website Quality of Service" has a significant impact on satisfaction (βs = 0.654); "Perceived value" is an argument, and satisfaction is an intermediate variable analysis: "perceived value" has a significant effect on satisfaction (βs = 0.800). The

"network service quality" is then set to an argument along with the "perceived value" and the satisfaction is an intermediary variable, and the results, as shown in Table 3, "perceived value" still have a significant effect on satisfaction ($\beta = 0.808$). "Website Quality of Service" no longer has a significant impact on satisfaction ($\beta = -0.010$), β value changes from 0.654 to −0.10. Combined with the above, verify that H3: Consumer perceived value has an intermediary effect on the quality of service and satisfaction of Pinkoi's website network.

Table 3. Regression analysis for mediation effect of Perceived Value

Equation	Ind. V	Dependent V	β	t	R^2
1	Website SQ	Perceived value	.821**	25.991	.675
2	Website SQ	satisfaction	.654**	15.589	.427
3	Perceived value	Satisfaction	.800**	24.04	.64
4	Website quality of service Perceived value	Satisfaction	−.010	−.167	.639
			.808**	13.832	

*Note: ** p<.01.*

5 Research Recommendations Results and Research Restrictions

5.1 Website Service Quality

When consumers shop through e-commerce online, service quality is very important, especially in the field of good service quality. Services will get value and satisfaction from high customers. Therefore, e-commerce owners must improve the quality of website services with active services, making customer service schemes. E-commerce owners must be committed to enhancing the promotion of goods and after-sales services, because consumers will be more interested in shopping on the website if the website provides data accuracy, processing and fast return mechanisms and quick and friendly responses.

5.2 Website Service Quality

Value is the subjective feeling and cogenesis of individuals. Value will also affect customer satisfaction and become an important factor for consumers to make repeated purchases of an item. Value will also change due to internal or external effects. Through this research, it was found that consumers have a role to assess the quality of service of an e-commerce with perceptions of shopping experiences. So that it is not only a company that has a role to provide websites, goods, production control. Consumers can feel the benefits and benefits of accessing the website if the website owner provides the best service so the perceived value of the customer will be high on the website.

5.3 Limitation of the Subject

Samples were obtained from questionnaires distributed to Pinkoi consumers who had conducted shopping at Pinkoi website, because members of the member on the Pinkoi website were protected by laws including consumer personal data, so that the data cannot be shown to the public. Because of this, this includes one of the restrictions in this study, so the questionnaires are distributed to Facebook social media users as questionnaire objects. Most samples are consumers living in Taiwan. Comprehensive survey will help Pinkoi website managers companies to develop different marketing strategies for consumers in various countries.

5.4 Online Store Restriction

Pinkoi website platform is not just a business, but there are a variety of design halls, even if the Pinkoi website itself has a mechanism to audit the qualification of sellers, but how many different design hall products, attitudes, and customer satisfaction will vary. In the follow-up study, the researchers were able to use single network e-commerce as research, perhaps more understanding of the network service quality, consumer perceived value, and satisfaction of the exact reasons to provide more practical feedback to the relevant enterprises.

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Economic Development Mechanisms: Community Resources

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Abstract. Over the past decade, Thailand's economic growth rate has averaged only 3% per year, insufficient to overcome the "middle-income trap." To address this, the country must transform its economic and social development model by leveraging its biodiversity and cultural diversity. This research explores the relationship between community resources and economic development mechanisms, with a focus on resource management's role in shaping local economies. Both natural and human resources are vital for sustainable growth, with effective management fostering local economic development. The study emphasizes integrating human resources into economic frameworks to enhance community potential while using modern technology and innovation to break limitations. It highlights sustainable practices like infrastructure development, equitable income distribution, and resource preservation. The research also examines eco-tourism management through a case study of Ban Koh Klang, Krabi Province, employing qualitative methods such as non-participant observation and semi-structured interviews. Data from primary and secondary sources were analyzed to provide a comprehensive understanding. Thailand's transformation is guided by the BCG Economy Model, which integrates Bioeconomy, Circular Economy, and Green Economy to drive balanced and sustainable development. The model aligns with Sustainable Development Goals (SDGs) and the Sufficiency Economy Philosophy (SEP). By utilizing scientific knowledge, technology, and innovation, the BCG Model creates added value from biodiversity and cultural resources. Collaboration through the Quadruple Helix mechanism—government, private sector, academia, and local communities—is crucial for fostering inclusive and sustainable growth.

Keywords: Community Resources · Economic Development · Management · Mechanisms · Resources

1 Introduction

Thailand's natural and environmental resources have been extensively utilized for development, leading to significant degradation, and posing continuous threats to biodiversity. This degradation negatively impacts the quality of life and imposes substantial economic costs [1]. Despite numerous conservation efforts, conflicts persist between conservationists advocating sustainable resource management and businesses seeking unsustainable

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exploitation for economic gains, thus limiting integrated and effective solutions [2]. To achieve sustainable economic and social growth, it is imperative to balance resource conservation with utilization across various sectors, including industries, agriculture, and tourism [3]. This approach requires the adoption of sustainable and eco-friendly production practices, alongside equitable benefit-sharing mechanisms for stakeholders engaged in conservation initiatives [4]. Furthermore, fostering consumer awareness of sustainable consumption patterns is critical for long-term environmental stewardship. Supporting organizations that implement economic, social, and legal measures for sustainable resource utilization aligns with Thailand's National Strategy Master Plan for Sustainable Growth, which emphasizes environmentally conscious development strategies [5]. This strategy underscores the importance of preservation, restoration, and sustainable use of natural resources without exceeding the ecological carrying capacity. A prime example of international collaboration in this domain is the East Asian–Australasian Flyway Partnership (EAAFP), which aims to conserve migratory waterbirds and their habitats. This initiative spans 22 countries and supports over 50 million migratory birds annually, including 36 globally threatened and 19 endangered species [6]. Migratory birds play an essential role in maintaining ecological balance by controlling pest populations, pollinating plants, and dispersing seeds, which directly contribute to agricultural productivity and food security [7]. In 2023, Thailand registered three critical sites—Krabi Estuary, Pak Thale–Laem Phak Bia, and Khok Kham—as part of the EAAFP network [8]. The Krabi Estuary, the nation's first recognized migratory bird site, has become a focal point for developing economic mechanisms and incentives for sustainable conservation and habitat utilization. Research in this area includes assessing the status of natural resources, biodiversity, and local socioeconomic conditions to establish market-driven frameworks, such as geographical indication (GI) products, for sustainable development [9]. This also aims to enhance equitable benefit-sharing and drive bioeconomic growth through the integration of scientific knowledge, technology, and innovation, fostering sustainable resource management and increased economic returns [10]. Therefore, the objectives are:

1. To support the Royal Initiative on the Plant Genetic Conservation Project (RSPG) under the auspices of His Majesty the King, which aims to conserve and promote the sustainable use of genetic resources.
2. To develop economic mechanisms and incentive measures to encourage conservation efforts, ensuring the sustainable utilization of biodiversity and natural resources while fostering collaboration among stakeholders.

2 Literature Review

2.1 The Economics of Ecosystems and Biodiversity (TEEB)

The Economics of Ecosystems and Biodiversity (TEEB) integrates knowledge from economics and ecology to provide conceptual frameworks and tools for analyzing and managing ecosystems and biodiversity for the sustainable benefit of humanity. TEEB originated from the growing awareness of the degradation of natural capital and the loss of biodiversity, which stem from insufficient understanding of their value and benefits to society [11]. TEEB was developed in 2008, beginning with the identification of issues

related to natural resource degradation and biodiversity loss during the BCD COP9 meeting in Germany. Recognizing TEEB as a vital discipline, stakeholders agreed on its role in addressing environmental challenges. The primary goal of TEEB is to make the value of natural capital and ecosystem services visible to society ("Making Nature's Values Visible"). The process consists of three key steps: Recognizing Values: This step aims to raise awareness about the comprehensive value of natural capital, beyond direct production and consumption benefits. It involves assessing ecosystem services and identifying stakeholders to understand who benefits and how. Demonstrating Values: This step quantifies and evaluates the economic value of ecosystem services for all societal sectors. For instance, assessing the economic benefits of community-based marine conservation or the social impact of forest resource loss highlights the importance of preserving natural resources. Capturing Values: The final step involves using these valuations in policymaking by developing mechanisms and measures to ensure sustainable economic activities. This includes reducing environmental impacts, fostering conservation, and enhancing ecosystem integrity for long-term societal well-being. In Thailand, TEEB was advanced through the ECOBEST project (2011–2015), which aimed to apply TEEB principles to reduce biodiversity loss and benefit local communities. While the project has ended, it fostered awareness and shifted paradigms for conservation and development across sectors in Thai society.

2.2 Ecosystem Services (ES): Benefits from Nature

Ecosystem Services (ES) refer to the range of benefits that humans derive from ecosystems, contributing both directly and indirectly to human well-being. These benefits can be categorized as tangible, such as food, water, and materials, or intangible, including climate regulation and cultural inspiration [12]. For instance, pollinators like bees play a vital role in food production, while wetlands provide crucial protection against flooding for human settlements [12]. The MA, supported by the United Nations in 2005, classified ecosystem services into four categories:

1. **Provisioning Services** – These are products directly obtained from ecosystems, including food and fibers, freshwater, genetic resources, and medicinal compounds.
2. **Regulating Services** – These services provide benefits derived from natural ecosystem processes, such as climate regulation, water flow regulation, erosion control, pollination, and wastewater treatment.
3. **Cultural Services** – Non-material benefits that enhance human experiences, including spiritual and religious values, aesthetic appreciation, recreation, ecotourism, and educational and cultural heritage.
4. **Supporting Services** – These services are essential for ecosystem functioning and the production of other services, such as nutrient cycling, soil formation, primary production, and habitat provision [12].

2.3 Ecosystem Services in Thailand

In Thailand, ecosystems such as mangroves, forests, and wetlands provide a variety of services that sustain local livelihoods and help mitigate the effects of climate change. Forests, for example, offer timber, prevent soil erosion, and function as significant carbon

sinks [13]. Mangroves play a crucial role in acting as storm buffers and serving as nurseries for fisheries [14]. Additionally, wetlands contribute to water filtration, carbon storage, and the support of biodiversity [15].

2.4 Valuing Ecosystem Services

To inform policy, ecosystem services can be evaluated using both qualitative and quantitative methods. Qualitative assessments typically involve straightforward reporting or visual representations, often utilizing color codes to denote impacts (e.g., green for positive impacts and red for negative ones) [16]. In contrast, quantitative or semi-quantitative assessments involve the use of numerical scoring or indices, such as the Ecosystem Service Index (ESI), to provide a more detailed measure of ecosystem service values [17].

Ecosystem Service Index (ESI): Calculation Method
The ESI scores ecosystem services on a scale from −1 (significant negative impact) to +1 (significant positive impact):

++ = +1.0
+ = +0.5
0 = 0 (neutral)
- = −0.5
-- = −1.0

The formula for ESI is:

$$\begin{aligned} \text{ESI} &= \text{Total Number of Services Evaluated} \\ &= \sum(\text{Positive Scores}) - \sum(\text{Negative Scores}) \end{aligned}$$

The Ecosystem Service Index (ESI) offers an overview of ecosystem service benefits at various spatial scales, which is essential for understanding and quantifying these services in the context of sustainable development [18]. By evaluating ecosystem services, the index supports key areas such as conservation planning, climate adaptation strategies, and public awareness and education [19]. Incorporating ecosystem service valuation into policy frameworks ensures the long-term preservation of biodiversity while simultaneously promoting economic and social well-being [20].

3 Methodology

This research aims to study ecotourism management in the Ban Koh Klang area of Krabi Province, using qualitative research methods to analyze and summarize appropriate management strategies for the area.

3.1 Data Collection Methods

The study utilized primary data and secondary data, detailed as follows:

3.1.1 Primary Data

Primary data were collected by the researcher using two main methods:

3.1.1.1 Non-participation Observation

The researcher conducted field observations to examine:

a) **Physical characteristics:** Such as the conditions of the tourist area, infrastructure, and facilities.
b) **Biological characteristics:** Such as biodiversity and the use of natural resources in the area.
c) **Community and area context:** The relationship between the community and the tourist sites, as well as activities conducted in the area.

3.1.1.2 Semi-structured Interviews

The researcher conducted interviews with key informants involved in ecotourism management, including Community leaders, Tourism operators, Tourists, Relevant agencies.

3.1.2 Secondary Data

Supplementary data that supported the analysis included: Related concepts and studies: Such as theories on ecotourism management and case studies from other areas. Tourism plans and policies: Such as provincial or national tourism development plans. Statistical data: Including tourist numbers, tourism revenue, and popular activities among tourists. Online media: Local websites, articles, and reports from various organizations.

3.2 Data Analysis

The collected data were analyzed using content analysis to summarize findings on:

1. The current state of tourism management
2. Potential and challenges of the Ban Koh Klang area
3. Sustainable ecotourism management strategies

The combination of primary and secondary data provided a comprehensive perspective on key issues related to ecotourism management in the study area.

3.3 Population and Sampling in the Research

This research selected its population and sample group by focusing specifically on individuals involved in ecotourism activities in the Ban Koh Klang community of Krabi Province. The sample group consisted of key informants, and data were collected through interviews with six groups as follows:

1) Government Officials (4 people)

Selection Criteria: Two administrators: the Head and Deputy Head. Two operational staff members directly involved in ecotourism management.

2) Experts from the Ecotourism Division, Department of Tourism and Sports (1 person)

One ecotourism specialist was selected based on their expertise and experience in ecotourism.

3) Local Administrative Organization Leaders (2 people)

Selection Criteria: Two leaders from the local administrative area under the jurisdiction of the Subdistrict Administrative Organization (SAO), which plays a key role in development and collaboration with the Ban Koh Klang community. The sample consisted of the President or Vice President of the SAO.

4) Community Leaders (3 people)

Selection Criteria: Leaders residing within a 5-kilometer radius of Ban Koh Klang.

Key figures such as the Village Head, Sub-Village Head, or Village Head Assistant who actively contribute to the area's ecotourism initiatives.

5) Local Residents (10 people)

Selection Criteria: Residents of the Ban Koh Klang community actively engaged in or impacted by ecotourism activities.

6) Tourists (10 people)

Tourists who had visited Ban Koh Klang and participated in ecotourism activities during the study period.

The diverse composition of these groups provided a comprehensive perspective on ecotourism management from various stakeholders, ensuring a well-rounded understanding of the situation in Ban Koh Klang.

3.4 Data Collection Methods and Tools

The data collection method for this study was semi-structured interviews conducted with key informant groups, divided into three main groups: 1) Central Government Officials: Government officials, including staff from the Department of Tourism and Sports. 2) Local Government Officials: Representatives from local administrative organizations, specifically the Subdistrict Administrative Organization (SAO). 3) General Public and Tourists: Local residents and visiting tourists.

3.5 Interview Development and Validation Process

For the creation of the interview guide used in this research, the researcher undertook the following steps to ensure the reliability and validity of the data collection tool:

1. Expert Review (OIC): The interview guide was reviewed by experts to assess the Objective-Item Congruence (OIC), ensuring that each question aligned with the research objectives.
2. Pilot Study: The interview guide was tested for question appropriateness through a pilot study conducted with undergraduate students from the Faculty of Economics, Srinakharinwirot University. This process helped refine the questions for clarity and relevance.
3. Triangulation Method for Tool Validation: The quality of the data collection tool was verified using the Triangulation Method by examining:
   3.1) Data Sources: Cross-checking information from different times, locations, and informants to ensure consistency.
   3.2) The researcher assessed whether the data remained consistent when collected at different times, from different places, or by different informants.
4. Pre-Test with Key Informants: The semi-structured interview guide was tested with key informants from relevant local government agencies and local residents in Bangkok to further validate its reliability.
5. Final Data Collection: After adjustments, the validated tool was utilized for data collection with the primary informants in Ban Koh Klang, Krabi Province.

This rigorous development and validation process ensured that the interview guide was both reliable and capable of producing accurate, meaningful data for the research objectives.

3.6 Data Collection Tools

The tools used for data collection in this study included:

1. **Interviews**, divided into four categories:
   (1) Interview for government officers
   (2) Interview for community leaders
   (3) Interview for local residents
   (4) Interview for tourists
2. Each interview guide consisted of four sections:

   Section 1: Personal information of the interviewee
   Section 2: Opinions and experiences regarding the management of eco-tourism in Ban Koh Klang, Krabi
   Section 3: Problems and obstacles in eco-tourism management
   Section 4: Suggestions and recommendations

3.7 Data Analysis

The researcher analyzed the collected data based on theoretical concepts reviewed for the study, and the analysis followed the research objectives. The findings were used

to propose guidelines for managing eco-tourism in line with eco-tourism principles, as follows:

1. **Context and Current Situation of Eco-Tourism in Ban Koh Klang, Krabi:**

Studied the development, management, outcomes, problems, and obstacles related to eco-tourism in the area.

2. **Analysis and Recommendations for Eco-Tourism Management in Ban Koh Klang:**

Suggestions for appropriate eco-tourism management in line with eco-tourism principles were analyzed in the following areas:

Area Composition: Defining the size and boundaries of eco-tourism areas and Local identity, including cultural and historical sites linked to the ecosystem
Activity Composition: Offering eco-tourism education and nature conservation for tourists, providing proper and high-quality interpretative programs in eco-tourism areas and Raising awareness and fostering eco-tourism consciousness among tourists, locals, and related operators
Participation: Involving local communities in analyzing and prioritizing eco-tourism management problems, Engaging the community in planning and problem-solving with government agencies, involving locals in assessing and improving eco-tourism projects and supporting the creation of local tour guide networks and promoting knowledge on eco-tourism-related occupations
Tourism Service Management: Developing facilities in eco-tourism areas, providing eco-tourism services, managing waste generated by tourists and Managing souvenir services and food sales

3.8 Content Analysis

Content analysis was employed to evaluate the current situation of the studied area, integrating both primary and secondary data collected through surveys and interviews [21]. The data were systematically categorized and analyzed in accordance with theoretical frameworks, assessing whether the identified issues and operational strategies aligned with existing theories [22]. Subsequently, appropriate models were applied to propose improvements [23].

Traditional Livelihood and Eco-Tourism
Traditional Fishing and Agriculture Practices: The study also examined traditional occupations in the Ko Klang Community, including rice farming, fishing, and fish product processing, such as the production of dried fish and shrimp paste [24]. The eco-tourism model aims to provide tourists with immersive, hands-on experiences that offer insights into the community's traditional ways of life. These activities include sugar palm climbing, sugar syrup boiling, rice planting, harvesting, rice milling, and fishing [25]. By participating in these practices, tourists can engage with local traditions passed down through generations, fostering a deeper understanding of self-sufficiency and sustainable living [26].

Guidelines for Eco-Tourism Development: Private Sector

1. **Area Management**

The government should develop strategies to manage and protect public areas, prevent encroachment, and organize shops and restaurants to ensure that tourism growth does not negatively impact the environment. Areas for shops should be well-defined to prevent encroachment on public land, and these businesses should maintain an organized, aesthetically pleasing appearance.

2. **Education and Communication**

Educating tourists about eco-tourism principles is essential, along with conducting briefings for all visitors to ensure they understand eco-tourism practices and the proper conduct in eco-tourism destinations. Communicate the positive and negative impacts of eco-tourism to the local community, along with guidelines on how to manage eco-tourism effectively. Guides and staff who interact with tourists should be well-versed in eco-tourism principles, conservation, and the environmental significance of the area to help tourists understand and value local ecosystems.

3. **Eco-Tourism Activities**

Promote cultural tourism activities to preserve local traditions, especially in coastal areas. Activities should be diverse to attract various tourist segments. Emphasize the importance of preserving valuable local customs, such as traditional performances (e.g., *Nora* dance and *Nang Talung* shadow puppet shows).

4. **Tourism Service Management**

Maintain excellent customer service by ensuring the staff is friendly, welcoming, and has good interpersonal skills. The government should continue to provide essential infrastructure (e.g., roads, water, electricity) to make tourism more convenient, while local businesses like shops and restaurants should offer warm, welcoming service without taking advantage of tourists.

5. **Environmental Management**

Environmental conservation should focus on reducing plastic waste, separating waste materials and using reusable paper products. Local businesses are aware of the deteriorating marine environment, and many see the decline in wildlife, especially migratory birds, due to agricultural encroachment, unsustainable fishing practices, and community wastewater. Local businesses, including restaurants and accommodations, should focus on cleanliness and waste management. Some have begun initiatives such as reducing plastic waste and using eco-friendly products, though more work is needed. Encourage community involvement in environmental conservation projects, such as mangrove planting, to enhance coastal ecosystems. Develop measures to prevent encroachment on protected areas, such as the construction of restaurants extending into the sea and establish stronger enforcement and legal action against such violations. Promote the use

of renewable energy, such as biodiesel from agricultural waste, by resort operators to help reduce environmental impacts.

Marketing Promotion Strategies

1. **Establish a Coordinating Organization**

A dedicated organization should be responsible for managing eco-tourism, collaborating with the Tourism Authority of Thailand (TAT) to market eco-tourism destinations effectively. Currently, marketing efforts are localized and limited, often done through community-based promotions, leaving many eco-tourism destinations unknown to a wider audience. Marketing is usually done via websites by local businesses without much support from government authorities.

2. **Develop Unique Selling Points (USPs)**

To highlight the value and uniqueness of eco-tourism sites, local areas should create selling points such as events, festivals, and cultural traditions. These initiatives can be incorporated into tourism programs and promoted through tour operators. The community should also emphasize green tourism practices, such as using natural materials for packaging (e.g., banana leaves, bamboo), and encouraging the elimination of non-biodegradable products like Styrofoam. By setting clear guidelines and penalties for businesses, a standard for eco-friendly tourism practices can be established and maintained.

These guidelines suggest the importance of collaboration between the government, local businesses, and the community to ensure the long-term success of eco-tourism, balancing economic growth with environmental conservation and cultural preservation.

Community Participation Guidelines in Eco-Tourism

Role of Community Leaders

Community leaders should play a pivotal role in promoting eco-tourism activities, acting as facilitators and organizers for local initiatives. Establishing clubs or groups focused on eco-tourism can help foster community involvement and engagement. The involvement of community leaders will ensure that more people are actively participating in eco-tourism-related activities, contributing to both its success and sustainability.

Community-based Eco-Tourism Development Guidelines

Area Management

The priority should be to preserve natural areas as much as possible. Sustainable tourism development should aim to protect and enhance the environment, ensuring that local ecosystems remain intact while still accommodating tourism growth. The development of tourism should be done in harmony with environmental conservation efforts to ensure long-term ecological balance.

Education and Communication

Many community members lack knowledge of eco-tourism principles. Therefore, it

is essential that community leaders and stakeholders provide basic education on eco-tourism. This will help raise awareness and foster an understanding of the value of natural resources. Community leaders and involved parties should focus on educating the local population about eco-tourism, emphasizing the importance of preserving natural resources, biodiversity, and the local environment. This can include workshops, talks, or educational materials that explain how eco-tourism can benefit both the community and the environment. By promoting strong community leadership and providing education on eco-tourism, the community can better engage in sustainable practices while enjoying the benefits of tourism. This approach fosters an environment where local people feel empowered and responsible for both the growth of tourism and the conservation of their natural resources.

4 Results and Analysis

The study on the development of community-based ecotourism in Ko Klang, Krabi Province, aims to promote ecotourism development through qualitative research methods. The research was conducted to achieve the objectives of the study, which involved collecting data from three main groups: government officials, local residents, and private sector operators. Below is an overview of the research process and key issues studied:

Key Informants

Government Officials
The study included 10 government officials working in tourism-related agencies, with at least 2 years of experience in tourism development in the community.

Local Residents
The study selected 10 individuals living in the area around Songkhla Lake, focusing on people with expertise or experience related to natural resource usage in the region.

Private Sector
The study selected 10 participants from businesses operating accommodations, restaurants, and tour companies in the area.
Research Issues

Strengths, Weaknesses, Obstacles, and Opportunities
The study examined factors affecting the development of ecotourism, such as enhancing the potential of the area, managing the challenges, and identifying opportunities for sustainable development.

Development Strategies
Ecotourism development requires cooperation from the government, private sector, and the community to create sustainable and environmentally friendly solutions.
Research Tools

Structured Interviews: The researcher used in-depth interviews and observational methods to collect data from the key informants.

Data Collection

Documentary Research: Relevant documents, articles, academic papers, and other materials related to tourism were reviewed.

In-depth Interviews: Data was gathered through in-depth interviews, transcription, and content analysis to draw out meaningful insights from the responses.

Data Analysis

The researcher analyzed the data using Content Analysis, categorizing the information based on the research issues, synthesizing it, and forming hypotheses based on the collected data. Transcriptions from interviews were analyzed, compared, and related to the existing literature to identify key trends and conclusions.

Study Findings

The development of ecotourism in Ko Klang involved cooperation from various sectors, focusing on aspects such as maintaining cleanliness, waste management, promoting sustainable tourism practices, and raising awareness about environmental conservation. Both government and private sector stakeholders played a key role in the development of the region's ecotourism industry.

Tourism Activity Management Guidelines

Tourism activities in the Ko Klang Community, Krabi Province, should prioritize fostering an appreciation of the surrounding marine environment. For example, boat tours that allow tourists to observe the natural surroundings, as well as visits to Keo Thulu Island, where visitors can learn about the life cycles of local plants and animals, should be organized [27]. Additionally, tourists could observe the local practice of collecting swallow nests, offering insights into traditional ecological practices [28]. When organizing such tourism activities, it is essential to minimize environmental impacts. This includes providing environmental conservation training for tour guides and boat drivers to ensure that tourists are served in a responsible and sustainable manner [29]. Most tourists have demonstrated cooperation in adhering to these guidelines, particularly in wildlife sanctuary areas where hunting is prohibited [28]. The main tourism activities include boat tours to observe the natural surroundings and walking tours along nature trails. These activities allow tourists to experience the beauty of nature and raise awareness about the value of Songkhla Lake. Cultural tourism activities should also be organized to preserve and promote the unique local traditions, such as the Boat Procession (Chak Phra) or the Buddha Relic Procession, the merit-making ceremony during the tenth lunar month, the procession of raising cloths up to the monastery, and the floating raft festival. We have unique local traditions that have been passed down through generations and hold deep cultural significance. These traditions should be preserved and can serve as a charming attraction to entice tourists to visit and experience them.

Tourism Service Guidelines

1) Tourist Information Center

The tourist information center should have 2 staff members available to assist visitors. Their responsibilities include answering inquiries and providing information about

Songkhla Lake, as well as offering details about local tourist attractions. In addition to giving advice and explanations, the center should also provide tourists with pamphlets containing relevant information about the lake and its attractions.

2) Tourist Information Center
The tourist information center should always have staff on duty to assist visitors. It should also feature a clearly visible sign indicating that it is a tourist information center to ensure convenience for tourists.

3) General Amenities
Essential facilities such as resting areas, toilets, parking spaces, and trash bins should be adequately provided to accommodate the number of tourists. These amenities should harmonize with the natural environment to maintain its aesthetic appeal. For instance, providing sufficient toilets, rest pavilions, parking spaces, and trash bins would ensure a comfortable experience for visitors.

4) Signage
Direction signs, visitor guidelines, and prohibition signs should be appropriately designed, adequate in number, and environmentally integrated. Signboards with clear and engaging messages should be placed at all key points of the tourist site. Existing signage that has become outdated should be refurbished or replaced to enhance their effectiveness and maintain a consistent aesthetic with the surroundings.

Development of Government Personnel
A training program should be implemented for personnel involved in tourism at various tourist spots. The training should focus on fostering a love for service and a willingness to welcome visitors warmly, creating a positive and lasting impression on tourists.

"...There should be a training program to instill a passion for service among staff to enhance tourists' experiences and impressions."

Community Development for Local Tour Guides
Efforts should be made to encourage and support community members in developing skills to become local tour guides. Additionally, training programs in English should be promoted to better accommodate international tourists.

"...Other tourist destinations have successfully trained students and community members as local guides. The sub-district could adopt this idea to train locals, not only to generate income but also to increase their awareness and understanding of local tourism resources and their value."

Safety Development
There should be an adequate number of security personnel to ensure the safety of tourists. "…There is a need for sufficient security staff to look after tourists, as the current number of personnel is inadequate."

Budget Allocation
The government should allocate sufficient funding to support the development of ecotourism. This includes financial support for improving tourist facilities and for the sustainable management of ecotourism resources.

"...There must be an appropriate budget allocation to develop facilities in tourist areas effectively."

Environmental Management Guidelines

1) Collaboration in Environmental Conservation
All relevant agencies must cooperate to protect the community's environment. Although Thailand has adequate environmental protection laws and marine wildlife conservation regulations, enforcement is challenging due to the insufficient number of government officers in charge. "*…There are many regulations for environmental and marine wildlife conservation, but enforcement is limited due to a lack of personnel. Cooperation among multiple agencies is needed, with clearly defined roles and responsibilities."*

2) Planning for Environmental Problem Prevention and Mitigation
Environmental planning should align with the development plan for the watershed areas surrounding Koh Klang community. Different agencies need to work together effectively. In the past, multiple agencies were involved in development and conservation efforts, but their operations were fragmented, hindering progress.

"...Small group meetings on watershed development have been organized for different areas within the community. Regular brainstorming sessions should continue, focusing on environmental problem-solving and progress tracking for each agency."

3) Monitoring and Reporting on Aquatic Life and Plant Species
A dedicated agency should study the population of aquatic animals and plant species, presenting data to government, private sectors, and the public. This transparency will raise awareness of declining populations and encourage collaborative problem-solving.

"...Natural habitat alterations for other purposes directly damage the watershed ecosystem. Transforming land for agriculture renders it unsuitable for aquatic animals and other wildlife, causing some species to decline or nearly disappear from the community, with adverse impacts on the community itself."

4) Tourist Capacity and Environmental Impact Assessment
It is essential to evaluate the area's capacity to accommodate tourists and limit their numbers. Controlled tourism prevents excessive environmental impact.

"...In the future, there must be assessments of the area's capacity to host tourists to avoid disrupting the natural balance."

5) Waste and Wastewater Management
Proper waste and wastewater management systems should be established for the community. Meetings with community leaders, residents, and private sectors should be held to address these issues and provide appropriate solutions. Regulations should require restaurants and resorts to treat wastewater before releasing it into the sea. Government agencies must conduct regular inspections and impose strict penalties for violations.

"…If improper waste and wastewater disposal continues, the situation will worsen. Community leaders need to be informed of the problems and educated on proper management to prevent escalating issues." To enhance environmental management in the community and tourist areas: 1) Employ daily cleaning staff for tourist spots. 2) Increase the number of trash bins and enforce penalties for littering. 3) Build proper drainage systems and sanitary wastewater disposal facilities. 4) Educate the community on effective waste and wastewater management practices.

Marketing Promotion Guidelines

1) Establishing a Tourist Data Collection System

A system for collecting tourist data should be developed to guide marketing efforts. Currently, there is no statistical or demographic data on tourists. This lack of information hinders the ability to design effective marketing strategies. Furthermore, there is no mechanism for gathering tourists' feedback, such as attitudes, complaints, suggestions, or opinions, which could help improve tourism services and staff performance. "…*The tourism site should discuss this matter with policymakers to assign clear responsibilities for data collection to specific agencies or departments."*

2) Continuous Marketing Promotion

Marketing initiatives should be promoted consistently. Collaboration with the Tourism Authority of Thailand (TAT) should be pursued to include the community's attractions and activities in the official tourism calendar. This would help increase awareness and visibility of the area and its tourism offerings. "…*Community traditions and events are not well-publicized, and tourists are unaware of them. Increased publicity efforts are needed. Coordinated efforts among relevant organizations, such as district offices, local administrative organizations, TAT, and national parks, could effectively promote community traditions and events, making them more widely recognized among tourists."*

Guidelines for Local Community Participation

1) Work Planning to Promote Local Participation

Strategic planning is necessary to encourage local residents to actively participate in ecotourism development. This can be achieved through public relations campaigns and educational initiatives about ecotourism in the area. Community meetings should be organized to explain the benefits of resource conservation and the potential income generated from ecotourism. These efforts aim to foster good collaboration between local government agencies and the community in advancing ecotourism.

"...Government agencies must develop concrete plans to empower communities to become a central force in driving ecotourism themselves."

2) Collaborating with the Community to Develop Ecotourism Groups

Communities should be actively involved in developing ecotourism initiatives. This includes establishing a fully equipped ecotourism information center with trained staff, detailed information about attractions, and guidelines for responsible tourism before visiting various sites. "…*Currently, community participation in ecotourism promotion is still not well-structured. Most residents lack a clear understanding of ecotourism and its*

importance. Only certain groups involved in community tourism projects are aware of the concept. Expanding community networks is essential to enhance local involvement in ecotourism, which not only preserves the environment but also helps distribute income within the community."

Examples of Existing Ecotourism Initiatives

"Toddy Palm Way of Life": Activities related to toddy palm include climbing toddy palm trees, processing toddy palm fruits, making palm syrup, and crafting products from toddy palm materials.

"Rice Farming Way of Life": Demonstrations of traditional rice farming, the primary livelihood of local residents, often alternated with toddy palm-related activities depending on the season.

These initiatives provide opportunities for visitors to engage with local traditions and lifestyles while encouraging community participation in tourism. Broadening these efforts can further strengthen ecotourism and environmental conservation while supporting sustainable income generation.

Economic Value from the Use of Natural Resources, Environment, and Biodiversity in Krabi Province

The economy of Krabi Province is primarily driven by agricultural production, forestry, and fisheries, contributing a total value of 24,677 million baht, or 27.51% of the provincial economy [30]. Key economic crops in the region include rubber, the most widely cultivated crop, covering approximately 925,930 rai, followed by oil palm, which is the second-largest crop. Krabi is the largest oil palm-growing area in Thailand, with around 891,243 rai of cultivated land [31]. A significant challenge facing the province is the growing demand for agricultural land; however, further expansion is limited by the need to preserve forested areas in order to maintain ecological balance [32]. In terms of economic well-being, the average annual income per person in Krabi was 239,309 baht in 2017, ranking second among the Andaman coastal provinces, with Phuket having the highest average income of 209,011 baht. Krabi ranked 15th in the country for average income per capita [33].

Analysis and Economic Mechanisms for Conservation

To develop an economic valuation of the region's natural resources, environment, and biodiversity, the consultant should:

Assess the Economic Contribution of Resources

To assess the economic contributions of natural resources, agriculture, and biodiversity to Krabi's economy, it is important to consider both direct and indirect benefits. Direct contributions include tangible goods such as harvested crops (e.g., rubber, oil palm), fisheries products (e.g., fish, shrimp), and forest products (e.g., timber), which are integral to the local economy [31]. Agriculture, particularly rubber and oil palm production, plays a pivotal role in sustaining livelihoods and contributing to the province's economic output [30]. Additionally, the fisheries sector generates significant income through both domestic and international trade [32]. Indirect contributions, on the other hand, encompass intangible benefits derived from ecosystem services such as carbon sequestration,

water regulation, soil fertility, and biodiversity preservation [34]. These ecosystem services, while not immediately quantifiable in monetary terms, are crucial for maintaining the ecological balance that supports agricultural production and other industries. The mangrove forests in Krabi, for example, play a key role in carbon sequestration, mitigating climate change impacts, and protecting coastal areas from erosion [35]. Furthermore, the preservation of biodiversity in the region ensures the continued health of local ecosystems, which in turn sustains agricultural productivity and promotes tourism [29].

Economic Mechanisms for Conservation

To enhance the economic sustainability of Krabi Province and support biodiversity conservation, several models can be implemented. Payments for Ecosystem Services (PES) is one such model, where local stakeholders are incentivized to protect and sustainably manage natural resources. This approach compensates individuals or communities for the ecosystem services they provide, such as carbon sequestration, water filtration, and biodiversity preservation [37]. Implementing PES schemes in Krabi could encourage local farmers, fishers, and communities to adopt practices that reduce environmental degradation while supporting their livelihoods. Additionally, the establishment of a biodiversity fund is proposed, where revenues generated from sustainable tourism or eco-friendly agricultural practices are reinvested into conservation initiatives. This fund could support habitat restoration projects, wildlife protection, and biodiversity monitoring programs [37]. For instance, eco-tourism activities, such as nature tours or responsible fishing, could contribute to the fund, ensuring that the profits from tourism directly benefit conservation efforts. Furthermore, green finance options such as grants, and loans could be developed to support businesses that actively contribute to maintaining biodiversity. These financial mechanisms would encourage businesses to adopt sustainable practices, such as using eco-friendly technologies or supporting local conservation projects. By providing financial incentives, green finance options can play a critical role in fostering a more sustainable and environmentally conscious economy [38]. These initiatives could be tailored to meet the specific needs of Krabi's agricultural and tourism sectors, ensuring that economic growth does not come at the expense of environmental health.

Incentive Measures for Conservation

To further promote sustainable practices in Krabi Province, several strategic incentives and programs can be introduced. Incentives such as tax breaks, subsidies, or certifications can be provided to farmers and businesses that adopt sustainable practices aimed at protecting local biodiversity. These financial and recognition-based incentives encourage the adoption of environmentally friendly practices, such as organic farming, reduced pesticide use, and sustainable resource management [39]. By offering these incentives, the province can motivate stakeholders to engage in practices that benefit both their economic well-being and the environment. In addition, promoting eco-certification programs for tourism operators is essential to encourage environmentally responsible practices. These certification schemes, such as Green Globe or EarthCheck, can offer tourism businesses recognition for adopting sustainable practices, such as reducing carbon footprints, minimizing waste, and protecting natural habitats. Encouraging tourism operators to participate in such programs not only enhances the ecological integrity of the region but also

attracts eco-conscious tourists, thus benefiting the local economy [40]. Finally, strengthening collaborations between the government, private sector, and local communities is crucial for fostering a shared responsibility for conservation. Multi-stakeholder partnerships can lead to more effective conservation policies, promote knowledge exchange, and ensure that conservation efforts are aligned with both environmental goals and economic interests [42]. For instance, joint efforts between local communities and businesses to manage natural resources, as well as government-led initiatives to support these partnerships, can create a more cohesive and impactful approach to biodiversity conservation. These measures aim to ensure that Krabi's natural resources continue to support its economy while maintaining ecological sustainability.

Biodiversity in Krabi Province

Krabi Province is home to a significant international wetland area, designated as a Ramsar Site (Site No. 1,100). This region encompasses numerous rivers and streams that flow into the sea, covering an area of approximately 102.12 km^2 of mangrove forest (Ramsar Convention Secretariat, 2020). Additionally, the mudflats span roughly 12 km, including an area between the Krabi River mouth and the Yuan Canal, which covers about 5,812.5 rai [42]. The mangrove forest at the mouth of the Krabi River is notably dense, covering 31% of the total mangrove area in Krabi Province, or 5% of Thailand's entire mangrove forest area. This area is rich in marine life, with at least 50 species of fish, mostly of economic importance. Additionally, the mudflats of the Krabi River mouth are a significant migratory bird habitat. Among the 107 species of migratory birds found here, some are near extinction. The area also hosts 139 species of shorebirds and 137 species of resident birds. Around Si Boya Island, the area serves as a habitat for endangered species such as dugongs, dolphins, and sea turtles. This region also has 90% of the seagrass species found in Thailand. These features contribute significantly to Krabi's biodiversity, making it a crucial area for conservation efforts, particularly concerning endangered species and marine ecosystems. When considering the economic value derived from the use of natural resources, it can be analyzed using Kuznets' theory [43], which was first presented in the journal The American Economic Review under the title "Economic Growth and Income Inequality." This study explores the relationship between per capita income and income inequality within a population, using data from developed countries such as the United States, the United Kingdom, and Germany. The findings showed that as an economy expands and per capita income increases in the early stages, income distribution (measured by the Gini Coefficient) becomes more unequal. However, when economic growth continues and reaches a certain point, income inequality begins to decrease. This relationship forms a turning point, with the graph displaying a U-shaped curve, known as the Kuznets Curve. This curve suggests that economic growth initially leads to increased inequality, but as development progresses, inequality eventually declines. The curve is depicted in Figure below called the Kuznet Graph.

Guidelines for Evaluating the Economic Value of Natural Resources and the Environment

In national development, natural resources must be utilized in the forms of production and consumption. The use of natural resources and the environment can take the form of direct consumption or using them as part of other production factors to produce goods and services. The environment serves as a waste sink for production processes, processing, or direct human consumption. If natural resources were abundant enough to meet human needs, these issues would not arise. However, problems occur when natural resources are overused, or when waste is released beyond a sustainable level, making it impossible for nature to restore balance. The link between natural resource bases and the economic system can be observed in the fact that the demand for natural resources exists in both direct consumption and as a production factor. For example, natural resources from forests may be consumed directly, such as when people travel for eco-tourism, or used as production factors, such as extracting wood for furniture, building houses, or harvesting herbs for medicinal purposes. The economic valuation of natural resources and the environment is the process of measuring the value of changes in natural resources and the environment that affect human well-being. These changes may affect the income of producers, the prices of goods and services, or may impact goods and services for which the market system cannot reflect their true value. Economic valuation of natural resources and the environment is a crucial tool for understanding the impact of environmental changes and supporting informed decisions regarding resource management and conservation for the future.

5 Conclusion

Ecosystem Services refer to the benefits humans receive from ecosystems, contributing to human well-being both directly and indirectly. These benefits include tangible (physical) and intangible (non-physical) values. Examples include pollination of plants by bees and other animals, which supports food production, or riparian buffers and

wetlands that act as barriers to prevent flooding in residential areas. The Millennium Ecosystem Assessment (MA), a major project supported by the United Nations in 2005, assessed and analyzed the impacts of human activities on ecosystems and human well-being. It categorized ecosystem services into four main types within the framework of ecosystem service assessment: **1. Provisioning Services**: These are services that ecosystems provide as essential resources for human survival. Examples include Food (plants, fruits, vegetables, meat, fish), Freshwater, Raw materials for construction, such as wood and stone, Medicinal resources derived from plants and animals. **2. Supporting Services:** These services maintain the structure and functionality of ecosystems, ensuring their sustainability. Examples include Pollination, Nutrient cycling, Soil formation and fertility maintenance, Carbon cycling within ecosystems. **3. Cultural Services:** These are non-material benefits that provide social, psychological, and cultural value. Examples include Natural beauty that promotes tourism, Inspiration for art, literature, and music, Educational and research opportunities from nature, Spiritual and religious significance. **4. Regulating Services:** These services help regulate environmental processes and mitigate potentially harmful impacts. Examples include Climate regulation, Flood regulation, Water purification, Pest, and disease control. The Ecosystem Services Assessment Framework enables researchers and relevant organizations to analyze the impacts of human actions on ecosystems. It also provides guidance for protecting or restoring ecosystems effectively to ensure the continuity of these ecosystem services in the long term.

To assess the ecosystem services of the study area, the evaluation will be conducted using key baseline data and input from primary stakeholders in the area. The importance of various ecosystem services will be determined by assigning significance levels as follows:

- **++:** Significant positive benefits
- **+:** Positive benefits
- **0:** Minor or no benefits
- **-:** Negative benefits
- **--:** Significant negative benefits
- **?:** Lack of evidence

Subsequently, statistical analysis will be performed using the **Ecosystem Services Index (ESI)** equation as follows:

$$\mathrm{ESI} = \frac{\sum(n_{+1.0}+n_{+0.5}) + \sum(n_{-1.0}+n_{-0.5})}{\sum n_{TOTAL}}$$

$$\mathrm{ESI} = \frac{\sum(15+13) + \sum(0+1)}{\sum 34}$$

$$\mathrm{ESI} = \frac{280+10}{320} = 0.90625$$

The findings will be presented using graphs to analyze the prioritization of ecosystem services. Once the consultant has studied and gathered relevant data from the area, including but not limited to the status of migratory birds, habitats, land-use maps, ecosystem services, the value and utilization of natural resources, the environment, biodiversity,

management, and threats to biodiversity, this information will be used for further analysis. The consultant will then draft economic mechanisms and incentive measures for the conservation of migratory birds and the sustainable use of their habitats in the area. At least two key steps or methodologies will be developed, including: 1) Drafting regulations or rules for the area. 2) Identifying biodiversity-derived products with potential for commercial promotion. Therefore, data from primary and secondary sources were analyzed to provide a comprehensive understanding. Thailand's transformation is guided by the BCG Economy Model, which integrates Bioeconomy, Circular Economy, and Green Economy to drive balanced and sustainable development. The model aligns with Sustainable Development Goals (SDGs) and the Sufficiency Economy Philosophy (SEP). By utilizing scientific knowledge, technology, and innovation, the BCG Model creates added value from biodiversity and cultural resources. Collaboration through the Quadruple Helix mechanism—government, private sector, academia, and local communities—is crucial for fostering inclusive and sustainable growth.

Suggestions

The consultant must organize meetings or operations to inform target groups about the operational plan. This is to gather feedback and suggestions for improving the methods to enhance efficiency and ensure alignment with the local context. At least one meeting or activity must be held, with a total of no fewer than 50 participants. The consulting firm will conduct the meeting online with stakeholders in Krabi Province. The meeting will be held via electronic communication using an online conferencing system that can accommodate 500–1,000 participants effectively. The Webex platform will be used, with the meeting number: 142 205 0906, which offers high-definition signal quality and records data throughout the meeting. The consultant will prepare an operational meeting plan that includes Principles and Rationale, Objectives, Guidelines and Methods, Presentation Topics, Event Schedule, Date, Time, and Venue. The plan will be submitted to the Office of Natural Resources and Environmental Policy and Planning for approval before implementation.

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Innovation and Knowledge Creation

Design of Human-Machine Collaboration for Industry 5.0

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Abstract. Industry 5.0, also referred to as the Fifth Industrial Revolution, is much more than technological evolution. It is an emerging concept that builds upon the advancements of Industry 4.0 and recognizes the crucial importance of human interaction in the industrial landscape. Human-machine collaboration is the cornerstone of Industry 5.0, emphasizing a synergistic relationship between human creativity and machine efficiency. This collaboration is essential for achieving personalized production, fostering innovation, and addressing sustainability and ethical concerns. The design of human-machine collaboration in Industry 5.0 requires a theoretical foundation to ensure systems are not only functional but also aligned with human-centric principles. Several theories and frameworks from research can guide the design of human-machine collaboration systems. This paper discusses the various theories that can be used to design human machine collaboration will be discussed with its underpinning theory, uses, advantages and limitations. The paper concludes with discussion about challenges that industry 5.0 face such as ethical AI use, workforce training, Inclusion and Accessibility, sustainability, and cybersecurity that must be addressed to make sure that we enrich human roles rather than diminished by technology.

Keywords: Industry 5.0 · Human-machine collaboration · Theoretical foundation · Innovation

1 Introduction

Industry 4.0 and Industry 5.0 represent distinct stages in industrial development, each with unique goals, technologies, and impacts. While Industry 4.0 emphasizes automation, digitization, and the use of cyber-physical systems, Industry 5.0 shifts the focus to

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a human-centric approach that integrates advanced technologies with human creativity, sustainability, and well-being. Industry 5.0 builds upon the foundations of Industry 4.0 by integrating advanced technologies like artificial intelligence (AI), robotics, and the Internet of Things (IoT) with a human-centric focus. This paradigm emphasizes synergy between humans and machines to achieve higher levels of efficiency, personalization, and innovation, while also addressing societal and environmental sustainability.

Industry 5.0 represents a shift toward integrating human creativity and intelligence with advanced technologies, particularly artificial intelligence (AI), to foster sustainable, human-centric, and efficient industrial systems. The design of AI-driven smart industrial technologies emphasizes seamless collaboration between humans and machines, highlighting key principles and innovations. Human-Machine Collaboration (HMC) is the cornerstone of industry 5.0. It refers to the cooperative interaction between humans and machines, where each leverages its strengths to achieve tasks efficiently and effectively. In the context of AI-driven smart industrial technologies, HMC blends human creativity, decision-making, and adaptability with machine precision, computational power, and automation capabilities [1].

As Industry 5.0 continues to redefine industrial processes, the question arises: do we need robust theories for designing human-machine collaboration? It is our belief that theories provide structured frameworks to guide the development, implementation, and evaluation of human-machine systems, ensuring that such collaborations are effective, ethical, and sustainable. Theories not only guide design but also drive innovation by identifying new dimensions of human-machine collaboration.

The design of human-machine collaboration in Industry 5.0 requires a theoretical foundation to ensure systems are not only functional but also aligned with human-centric principles. Theories are indispensable for the design of human-machine collaboration in Industry 5.0. They provide the necessary frameworks to address the complexities of human-machine interactions, ensuring systems are efficient, ethical, and sustainable. Theories provide structured frameworks to guide the development, implementation, and evaluation of human-machine systems, ensuring that such collaborations are effective, ethical, and sustainable. There are many theories that can be used for Human-Machine Collaboration Design, especially in AI-Driven Smart Industrial Technologies.

Several theories and frameworks from research can guide the design of human-machine collaboration systems. These include activity theory [2]; Human-Centred AI (HCAI) Framework [3–5]; Ethical Theories in AI [6]; Trust in Automation Theory [7]; Distributed Cognition Theory [8]; Complex Adaptive Systems (CAS) Theory [9]; Control Theory [10]. Each theory has advantages and limitations. This chapter explores each of these theories and briefly review the theory, discuss its advantages and limitations giving the readers what are available to them to use depending on the context of their needs.

The chapter begins with the emerging importance of Industry 5.0, the differences between Industry 4.0 and Industry 5.0, industry 5.0 applications, and key principles. It then discusses the central rennet of industry 5.0, human machine collaboration, its importance, principles, applications, and design. Designing effective Human-Machine Collaboration (HMC) in AI-driven industrial technologies requires a theoretical foundation that balances technological efficiency with human-centric principles. Research

provides several theories and frameworks that guide the development of collaborative systems, ensuring they are functional, intuitive, and effective. The various theories that can be used to design human machine collaboration will be discussed with its underpinning theory, uses, advantages and limitations will be discussed in the subsequent section. While these theories provide robust frameworks, their practical application requires interdisciplinary collaboration, iterative design, and user-cantered testing. The paper concludes with discussion about challenges that industry 5.0 face such as ethical AI use, workforce training, Inclusion and Accessibility, sustainability, and cybersecurity that must be addressed to make sure that we enrich human roles rather than diminished by technology.

2 Industry 5.0

2.1 The Importance of Industry 5.0

Industry 5.0 prioritizes human-centric approaches in manufacturing systems, leveraging synergies between human expertise and artificial intelligence. This paradigm shift enables AI to manage repetitive tasks while empowering workers to concentrate on innovation and strategic roles, thereby boosting production adaptability and creativity [11]. Furthermore, it integrates sustainability goals by enhancing resource efficiency, reducing waste, and curbing emissions, ensuring ecological balance while addressing current and future developmental needs [12].

The framework also emphasizes ethical workplace practices through customizable production methods, catering to consumer diversity while improving employee engagement. By incorporating intelligent systems, Industry 5.0 establishes agile manufacturing networks capable of mitigating market volatility and supply chain instability, thereby strengthening operational resilience [11]. These advancements underscore its role in redefining production paradigms and advancing manufacturing through human-machine synergy.

2.2 The Differences Between Industry 5.0 and Industry 4.0

Industry 5.0 diverges from its predecessor by emphasizing human-technology integration, sustainability, and systemic adaptability. While Industry 4.0 is primarily driven by technological automation to maximize efficiency, Industry 5.0 repositions humans as central actors, utilizing their problem-solving and creative capacities alongside collaborative tools [11, 12].

In objectives, Industry 4.0 prioritizes operational optimization via data-driven automation, whereas Industry 5.0 balances economic goals with societal well-being and environmental stewardship [11]. Technologically, Industry 4.0 relies on automation and IoT systems, while Industry 5.0 adopts collaborative robotics and augmented reality to deepen human-machine interaction [12]. Additionally, Industry 5.0 advances sustainability by prioritizing circular economy principles, contrasting with Industry 4.0's narrower focus on productivity [11].

This evolution reflects a transition from efficiency-centric automation to holistic, value-driven manufacturing systems.

2.3 The Importance of Human Machine Collaboration

Central to Industry 5.0 is human-machine collaboration, a paradigm shift emphasizing synergy between automation and human expertise to transition industries from technology-centric operations to human-augmented systems [13]. This approach enhances operational flexibility and productivity by integrating human ingenuity with advanced technologies like AI, IoT, and augmented reality, fostering personalized manufacturing and sustainable practices.

Yahia et al. (2024) argued that Industry 5.0 prioritizes human-centricity, advocating technological advancements that amplify human skills rather than displace labor. Machines handle repetitive tasks, freeing workers to focus on strategic innovation, thereby optimizing resource efficiency [14].

Regarding sustainability, Nikiforidis et al. (2024) highlighted intelligent systems' capacity to minimize waste and improve resource utilization, aligning with green economy goals [13]. Concurrently, Yahia et al. (2024) noted that explainable AI reduces cognitive demands through intuitive interfaces, enhancing decision-making clarity and workplace well-being [14].

In summary, human-machine collaboration not only elevates productivity, transparency, and safety but also advances sustainable development and human-centered industrial design, underscoring the alignment of technological progress with societal needs.

2.4 The Principles of Human Machine Collaboration

Human-robot collaboration merges human cognitive and creative strengths with machines' computational and operational capacities. This framework centers on harnessing mutual strengths to enhance task efficiency and problem resolution [15, 16]. In Industry 5.0, successful implementation relies on core principles that optimize human-machine interaction while ensuring societal and ethical alignment.

1) Human-Centric Design

Industry 5.0 prioritizes human-centric systems, positioning humans as central to collaborative workflows. Technologies must align with human needs, capabilities, and experiential contexts, fostering trust and operational efficacy through user-oriented adaptations.

2) Sustainability Focus

Emphasizing ecological and social accountability, Industry 5.0 mandates that collaborative systems balance productivity with environmental stewardship. Sustainable practices prioritize resource efficiency and long-term viability, mitigating ecological harm while advancing economic goals.

3) Strategic Synergy

Effective collaboration requires leveraging distinct competencies through task allocation. For instance, collaborative robots excel in precision tasks, while humans oversee strategic adjustments, enhancing production adaptability.

4) Operational Transparency

Trust in human-robot systems depends on clear communication of machine decision-making. Transparent operational rationales—such as in autonomous systems—enable human oversight and collaborative refinement.

5) Adaptive Responsiveness

Dynamic adaptability ensures systems adjust to environmental shifts. As Yahia et al. (2024) noted: real-time data integration allows intelligent manufacturing to optimize outputs amid market volatility, maintaining competitiveness in evolving industrial landscapes.

2.5 The Application of Human Machine Collaboration

Industry 5.0 leverages human-robot collaboration (HRC) across various domains, with notable applications including:

Intelligent Manufacturing: Strategic task allocation between robots and humans enhances production outcomes. Robots execute precision tasks like assembly via AI-driven algorithms, while humans manage optimization and address anomalies [13].

AI-Enhanced Decision Support: Integrated AI in HRC systems assists workers in complex decision-making, improving operational safety and situational awareness [17, 18].

Predictive Maintenance: Combining data-driven failure prediction with real-time equipment monitoring, recent studies bridge Industry 4.0 technologies with Industry 5.0 principles. A hierarchical framework tested in power plants demonstrates enhanced maintenance efficiency through technological synergy [12].

Quality Control: Machine vision and deep learning enable automated defect detection, with interpretable visual outputs (e.g., saliency maps) clarifying AI decision-making processes [13].

Explainable AI (XAI): Transparent interfaces and feedback mechanisms in XAI reduce cognitive load during human-machine interactions, boosting operational efficiency and user satisfaction by simplifying information complexity [14].

2.6 The Design of Human Machine Collaboration

Implementation of following design principles enhances industrial human-machine interaction, advancing secure, productive, and adaptive operational frameworks.

Safety Assurance Design: Safety forms the foundation of human-machine collaboration system design. Within industrial settings, addressing emerging risks necessitates multi-level safeguards to ensure system stability. For instance, logistics centers employ advanced sensors to enhance close-range detection accuracy while integrating AI-driven safety technologies for risk mitigation [19].

Human-Machine Interface Optimization: Effective collaboration hinges on intuitive interfaces. Augmented reality (AR) offers real-time visualization of production metrics and AI-generated recommendations, boosting operational decision-making precision [13].

Efficient Collaboration Design: Streamlining information exchange is vital for productivity. Implementing standardized protocols minimizes transmission errors, while real-time equipment feedback enables operators to optimize workflows. Transparent decision-support mechanisms further foster user trust and coordination efficacy [19].

Customization and Adaptability: Flexible systems must accommodate diverse user skills and task requirements. For example, adaptable systems enable robotic path recalibration during obstructions, while modular architectures allow rapid functional adjustments to meet evolving demands [20].

3 Theories for Designing Industry 5.0

Theories are indispensable for the design of human-machine collaboration in Industry 5.0. They provide the necessary frameworks to address the complexities of human-machine interactions, ensuring systems are efficient, ethical, and sustainable. By grounding design efforts in robust theoretical principles, researchers and practitioners can navigate the multifaceted challenges of this new industrial era. There are many theories and frameworks that can be used to design industry 5.0 applications. This section discusses some of them that can be used to design industry 5.0 applications.

3.1 Activity Theory

Activity Theory, proposed by Engeström (2000) [2], is a sociocultural framework that focuses on how humans interact with tools, including machines, within their environment. This theory emphasizes understanding the broader context of tasks, considering motivations, goals, and tools as part of an activity system. In Industry 5.0, Activity Theory helps in designing systems that integrate seamlessly into human workflows while supporting collaboration between humans and machines.

Activity Theory (AT) is a theoretical framework that examines human practices as complex, socially situated activities, emphasizing the interactions between individuals and their socio-cultural context. It provides a lens to understand how tools, community, and rules mediate human actions [21]. According to Kaptelinin & Nardi, (2006), the principles are:

1) Object-Orientedness: Activities are directed towards an object, which gives meaning and purpose to the actions performed.
2) Mediation: Human actions are mediated by tools and signs, which can be physical artifacts or symbolic systems like language.
3) Hierarchical Structure of Activity: Activities are organized into a hierarchy: activities (motivated by objects), actions (goal-directed processes), and operations (routine processes).
4) Internalization and Externalization: Internal mental processes are influenced by external activities and vice versa, highlighting the dynamic interaction between thought and action.
5) Development: Activities evolve over time, reflecting the historical and cultural development of the individual and society.

Activity theory has been used in many disciplines including education, human computer interaction**,** organisation development, software engineering, knowledge management, mobile computing, and others [22].

There are many benefits of Using Activity Theory for Designing Applications. Firstly, activity theory takes a holistic approach by offering a comprehensive view of human activities, considering the complex interplay between individuals, tools, and their socio-cultural context [23]. Secondly, by focusing on the specific contexts in which activities occur, AT ensures that designs are relevant and effective for the intended users [21]. Thirdly, AT helps in identifying systemic contradictions within activity systems, providing opportunities for innovation and improvement in design. [24].

According to Agote-Garrido et al. (2023) [25], since Industry 5.0 emphasizes human-centricity, sustainability, and resilience in manufacturing system, integrating AT into the design of Industry 5.0 systems can provide several benefits:

- Comprehensive Analysis: AT provides a holistic view of human activities, considering the interplay between individuals, tools, and the community.
- Tool for Design**:** AT offers a framework to design and evaluate systems that align with human practices and cultural contexts.
- Human-Centric Design**:** By focusing on the interactions between workers and technological tools, AT helps in designing systems that enhance human capabilities and well-being.
- Sustainability: Understanding the socio-cultural context of activities can lead to the development of practices that are environmentally sustainable and socially responsible.
- Resilience: Analyzing the hierarchical structure of activities allows for the identification of potential disruptions and the design of systems that can adapt to changes effectively.

Although AT Offers many advantages for the design of industry.50 applications, there are limitations. Because of the complex and abstract nature of AT, it makes it challenging to apply. It requires detailed analysis of various components of activity systems.

In summary, Activity Theory offers valuable insights for the design of Industry 5.0 systems by emphasizing the importance of human-centric, sustainable, and resilient practices. However, its application requires careful consideration of the specific socio-cultural contexts involved.

3.2 Human-Centred AI (HCAI) Framework

Shneiderman (2020) proposed Human-Centered Artificial Intelligence (HCAI) design framework for Industry 5.0 [3–5]. HCAI work introduces a transformative framework for designing AI systems centered on human empowerment and responsibility. This approach aims to develop AI systems that are reliable, safe, and trustworthy, thereby supporting human self-efficacy, creativity, and responsibility. HCAI framework is built upon several key principles. Firstly, the framework advocates for designing systems that combine substantial human oversight with robust automation, ensuring that AI serves as a tool to augment human capabilities rather than replace them). Secondly, by aligning AI functionalities with human needs and contexts, the framework seeks to enhance human

performance, fostering greater creativity and responsibility. Thirdly, to create AI systems that are safe, reliable, and trustworthy.

There are several benefits of using the HCAI framework for designing industry 5.0 applications [3–5]. These include:

- Improved Safety: Systems designed with HCAI principles are more likely to anticipate and prevent errors, leading to safer operational environments.
- Enhanced User Trust: AI systems that are transparent and align with human values, are more likely to be trusted by users to effectively engage with the technology.
- Greater Adoption of AI Technologies: When users feel that AI systems enhance their capabilities without undermining their autonomy, there is a higher likelihood of acceptance and widespread use.

Despite its advantages, the HCAI framework has limitations. Designing systems that balance high human control with advanced automation requires sophisticated approaches and can be resource intensive. Psychosocial dimensions like trust and motivation are often overlooked in industrial applications, there is a need comprehensive integration of human factors. Because of Rapid advancements in AI technology, it is necessary to continue to update the framework to address new ethical and practical challenges.

In summary, Shneiderman's HCAI framework offers a valuable approach for integrating AI into human-centric applications, particularly within the context of Industry 5.0. By adhering to its principles, industries can develop AI systems that not only enhance human performance but also maintain safety, reliability, and trustworthiness.

3.3 Ethical Theories in AI

As organizations integrate Artificial Intelligence (AI) into industrial processes, ethical considerations become a cornerstone for successful implementation. The "AI4People Ethical Framework" offers valuable insights into designing a "Good AI Society," which is highly relevant to Industry 5.0 [6]. The transition to Industry 5.0 emphasizes collaborative interactions between humans and intelligent systems, necessitating robust ethical frameworks. Floridi et al. (2018) propose the AI4People framework, outlining five principles—beneficence, non-maleficence, autonomy, justice, and explicability—which provide valuable insights for ethical AI integration [6].

Beneficence ensures AI promotes human well-being and sustainability. Industry 5.0's human-centric approach aligns with this principle by enhancing worker productivity and safety. Non-maleficence focuses on minimizing harm, such as bias and privacy risks, which are critical for maintaining trust in industrial AI systems. Autonomy underscores retaining human decision-making power. Floridi et al. (2018) advocate a "decide-to-delegate" model, allowing humans to oversee AI systems, essential for collaboration [6]. Justice demands fairness, ensuring AI benefits are distributed equitably. Lastly, explicability ensures transparency and accountability, fostering trust in AI decisions.

While comprehensive, the framework faces challenges in operationalization. Industry-specific standards are needed to implement these principles effectively. Additionally, the European-centric perspective of the framework limits global applicability, especially in diverse regulatory environments. Floridi et al. (2018) also offer limited

strategies for balancing innovation with ethical safeguards, a critical tension in Industry 5.0 [6].

Despite challenges, the AI4People framework offers actionable guidance for fostering ethical human-machine collaboration. Practical measures, such as ethical audits and AI literacy programs, can enhance explicability and worker empowerment. Cross-disciplinary collaboration among ethicists, engineers, and policymakers is vital for bridging gaps between ethical theory and technological practice.

In summary, Floridi et al.'s (2018) framework provides a solid foundation for ethical AI integration in Industry 5.0, emphasizing human-centricity, justice, and transparency. However, its operationalization requires contextual adaptation and innovative tools to address emerging challenges and ensure a sustainable future.

3.4 Trust in Automation Theory

Trust theory examines how human confidence in automated systems influences collaborative efficiency and safety. Hoff and Bashir (2015) identify analytical cognition—rational assessment of system reliability—as foundational to trust formation, alongside analogical reasoning (contrasting human and machine reliability) and affective reactions (intuitive technological perceptions) [7]. Contextual variables, including operational environments and task demands, directly shape trust development and functional outcomes. System attributes such as transparency, responsiveness, and dependability further modulate user evaluations and trust calibration, as individuals adjust confidence levels based on performance observations.

Hoff and Bashir conceptualize trust as a three-tiered construct: dispositional, situational, and learning-based. Dispositional trust reflects inherent user tendencies shaped by personality and prior interactions. Situational trust fluctuates with task complexity and environmental uncertainty, while learning-based trust evolves through sustained system engagement. This hierarchical model offers a systematic lens for analyzing context-dependent trust dynamics and informs automation design principles.

Effective system design prioritizes intuitive interfaces, real-time feedback, and user autonomy to foster appropriate reliance. Environmental stressors (e.g., time constraints, high-risk scenarios) critically mediate trust-dependency relationships, necessitating robust fault tolerance to mitigate trust erosion during system failures. Future research should examine temporal trust dynamics, cultural variability in trust formation, and real-world trust measurement methodologies. By integrating these insights, designers can enhance human-machine synergy and technological adoption, advancing the framework proposed by Lee and See (2004) [26].

3.5 Complex Adaptive Systems (CAS) Theory

Introduced by Holland (1992), Complex Adaptive System (CAS) theory posits that system components dynamically adjust to environmental shifts through interactive and self-organizing processes, offering a framework for analyzing interconnected and evolving systems like contemporary industrial and societal structures [9]. CAS theory integrates principles including diversity, localized interactions, feedback loops, self-organization,

and adaptive capacity. Complex system behaviors emerge not from individual component properties but through ongoing modifications in local interactions and feedback processes.

Key contributions include: (1) prioritizing diversity and localized interactions, where heterogeneous agents evolve via proximate exchanges, enhancing comprehension of macro-scale system dynamics; (2) emphasizing self-organization as a fundamental mechanism through which systems spontaneously develop structured patterns, elucidating emergent order in biological and engineered systems while maintaining stability amidst environmental fluctuations; and (3) enabling cross-disciplinary research through versatile analytical frameworks.

Notable limitations involve restricted predictive capacity stemming from systemic nonlinearity and complexity, constraining practical applications in domains requiring precise forecasting like policy formulation. Foundational concepts such as self-organization and adaptability remain theoretically abstract without standardized metrics, challenging their operationalization in empirical models. Additionally, the theory's oversimplification of agent behaviors neglects underlying multidimensional influences.

Implementation challenges include interpretational difficulties arising from nonlinear dynamics and hierarchical system structures, computational constraints when scaling analyses, and disciplinary fragmentation hindering unified modeling approaches across fields with divergent methodological paradigms.

Despite these constraints, CAS theory advances innovative perspectives for analyzing complex system dynamics, transcending conventional analytical approaches while enhancing interpretation of socio-natural phenomena. It establishes robust conceptual frameworks for addressing intricate problems, with potential for refinement and broader application through technological advancements.

3.6 Control Theory

Sheridan's (1992) control theory examines interactions between humans and automated systems to accomplish operational goals [10]. Central to this framework is "optimal control allocation," enhancing operational efficiency and safety through strategic human-machine authority distribution while establishing a hierarchical control structure.

Key contributions include: (1) A multi-tiered human-machine control model stratifying tasks into basic operational controls and advanced cognitive functions, offering a foundation for multi-tiered automation design; (2) A collaborative emphasis enabling machines to manage repetitive or hazardous tasks, freeing humans for strategic decision-making—a principle guiding collaborative system architectures; (3) The widely adopted "progressive automation" concept advocating incremental machine autonomy; and (4) A task-characteristic matrix to allocate control roles, serving as a practical design tool.

Criticisms of the theory highlight its limitations: Task stratification oversimplifies real-world complexity, as dynamic environments feature ambiguous task boundaries, complicating human-machine coordination. Cognitive strain under high workload conditions—leading to human judgmental inaccuracies—remains unaddressed. Static frameworks falter in dynamic contexts, and early theoretical assumptions lack compatibility with advancements in AI and related fields.

Contemporary challenges include: dynamic task distribution in complex environments requiring enhanced adaptive capabilities; mitigating cognitive strain and decision-support deficits to reduce human error; cross-disciplinary applicability hurdles in emerging domains; and unresolved ethical and safety considerations in extreme operational contexts.

In summary, while Sheridan's theory laid critical groundwork for human-machine system design, technological evolution exposes its constraints. Future frameworks must revise and expand the theoretical foundation to align with technological progress and evolving application demands.

4 Discussions and Conclusion

Each pf these theories has the potential to be used to design effective Human-Machine Collaboration Design, especially in AI-Driven Smart Industrial Technologies. However, it is important to study the use of them to identify the benefits and limitations. Further research is required to verify each of the use of the theories.

While these theories provide robust frameworks, their practical application requires interdisciplinary collaboration, iterative design, and user-cantered testing. Industry 5.0 offers immense potential, challenges such as ethical AI use, workforce training, and cybersecurity must be addressed. Ensuring that human roles are enriched rather than diminished by technology is a critical consideration.

Future advancements in technologies like quantum computing and brain-machine interfaces promise to deepen human-machine collaboration, paving the way for even more integrated and innovative solutions.

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Advancing Sustainability Through Innovation: Best Practices for Food Industry Companies

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Abstract. The food processing industry plays a critical role in global sustainability challenges due to its environmental, economic, and social impacts. As food companies expand to meet increasing demand, integrating sustainable innovation becomes essential. This study investigates best practices in innovation for sustainable development within the food industry, providing insights and recommendations to enhance sustainability efforts. Using a comprehensive research approach, including literature reviews and multiple case studies, the study explores methods that reduce carbon footprints, improve resource efficiency, and promote ethical business practices. Key areas examined include eco-friendly product development, corporate strategies, supply chain sustainability, stakeholder engagement, and regulatory impacts. Findings highlight challenges in adopting sustainable innovation and the need for a holistic approach that balances environmental, social, and economic factors in the food industry's sustainability efforts.

Keywords: Sustainability · Sustainable development · Food industry · Innovation

1 Introduction

The food processing industry plays a fundamental role in addressing global sustainability challenges due to its extensive environmental, economic, and social impact. As the global population continues to grow, food production and processing industries must innovate to meet rising demand while ensuring that their operations do not contribute to long-term ecological degradation. Sustainable development in the food sector requires a balance between environmental preservation, economic viability, and social equity to secure a viable future for generations to come. However, many companies struggle to integrate sustainability into their core business strategies, particularly within their innovation frameworks [1].

Innovation, as a driver of economic growth and technological advancement, has long been recognized as crucial for enhancing productivity and competitiveness. Within the food industry, innovation extends beyond product development to encompass supply chain optimization, sustainable sourcing, energy efficiency, and waste reduction. Traditional innovation models, often characterized by closed, linear processes, may not adequately address the complex sustainability challenges faced by the food industry.

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Consequently, a shift towards a more holistic and interconnected approach to innovation is necessary [2, 3].

This study aims to identify and critically evaluate key components of existing innovation models to promote sustainable development within the food industry. By integrating sustainability principles into innovation frameworks, this research seeks to provide insights into best practices that food processing companies can adopt to enhance environmental responsibility while maintaining economic competitiveness. The study employs a comprehensive research methodology, including literature reviews, case studies, and qualitative analysis, to examine how different innovation strategies contribute to reducing carbon footprints, improving resource efficiency, and fostering ethical business practices [4].

The research contributes to the field in several ways. First, it provides an in-depth analysis of sustainable innovation in the food industry, exploring cutting-edge approaches that align with environmental and social goals. Second, it highlights challenges faced by companies in adopting sustainable innovation practices and offers recommendations to overcome these barriers. Third, it examines the role of stakeholder engagement, regulatory policies, and corporate strategies in driving sustainability efforts. By doing so, this study aims to bridge the gap between theoretical frameworks and practical implementation, offering actionable insights for businesses, policymakers, and researchers interested in fostering sustainable development in the food sector.

2 Literature and Background

Innovation, derived from the Latin term *innovare* (meaning "to make new"), is a cornerstone of economic growth and industrial advancement. The Organisation for Economic Co-operation and Development [5] defines innovation as the introduction of a significantly improved product, process, or service that contributes to productivity and market competitiveness. Within the context of sustainability, innovation plays a crucial role in developing new methods, technologies, and business models that minimize negative environmental impacts while maximizing social and economic benefits [6].

Innovation is often categorized into different types, including product innovation, process innovation, business model innovation, and marketing innovation [7]. In the food industry, these innovations can manifest through eco-friendly packaging, energy-efficient processing methods, sustainable ingredient sourcing, and circular economy initiatives. Companies that successfully integrate sustainability into their innovation strategies can achieve long-term resilience while contributing to broader environmental and societal goals [8].

Sustainable innovation in the food industry refers to the development and implementation of practices that reduce environmental impact, enhance resource efficiency, and promote ethical business operations. Adams et al. define sustainable innovation as a process that integrates environmental, social, and economic considerations from the early stages of idea generation through to commercialization [8]. This approach aligns with the "triple bottom line" framework, which emphasizes the interconnectedness of people, profit, and planet [6].

Key areas of sustainable innovation in the food industry include:

- Eco-friendly product development – Reformulating products with sustainable ingredients, reducing additives, and creating biodegradable packaging [4].
- Supply chain sustainability – Implementing sustainable sourcing practices, reducing food waste, and optimizing logistics to lower carbon emissions [9].
- Energy efficiency and waste management – Investing in renewable energy sources, water conservation techniques, and waste-to-energy conversion technologies [10].
- Stakeholder engagement and corporate responsibility – Collaborating with suppliers, governments, and consumers to promote sustainability initiatives.

Although the food industry is leaning towards sustainable production and sustainability in general due to increasing internal and external pressure to solve environmental, economic, and social sustainability challenges, it still encompasses a great percentage of greenhouse gas (GHG) emissions, waste production, inadequately supervised social sustainability performance, and questionable CSR in some companies. Added to this is a critical knowledge gap regarding the precise innovation practices and strategies that can successfully integrate the principles of sustainability into the fundamental operations of food industry companies.

Numerous studies have shown that the food supply chain is jeopardizing the functioning of clean air, water, healthy soils, and the presence of a diverse range of other living species, which collectively constitute our life support system. There is a need for more detailed studies on how such effects can be minimized and how those already in place can either be improved or managed. According to [11], assessments of individual food products indicate that dairy products carry a disproportionately high environmental burden, contributing 12–18% of GHG emissions from livestock production (dairy cattle) and about half of the food system's total impacts. Other diet-related GHG emissions stem from beverages, which account for 15% of GHG emissions, while snacks, including biscuits and confectionery, account for about 8% of emissions. Additionally, the European Commission in 2019 observed that many of today's food production systems compromise the Earth's capacity to produce food in the future. The beverage industry (including brewery companies) remains one of the largest users of water, producers of solid waste, wastewater, and emissions, and is highly energy-intensive, which poses major environmental challenges [12]. The paradoxes and dilemmas of waste management, carbon emissions, and policy issues related to innovation applications present fertile grounds for scholarly inquiries into sustainable development.

Despite the potential benefits, food industry companies face several challenges in implementing sustainable innovation. One of the primary barriers is the high cost associated with adopting new technologies and processes. Many companies, particularly small and medium-sized enterprises (SMEs), lack the financial resources required to invest in sustainable solutions [13]. Additionally, the long payback period for sustainability investments can deter businesses from prioritizing these initiatives [14].

Another significant challenge is regulatory complexity. Governments and international organizations have introduced various sustainability regulations, including carbon emission limits, waste management policies, and eco-labeling standards. However, compliance with these regulations can be burdensome, particularly for companies operating in multiple jurisdictions with varying legal requirements [5].

Consumer perceptions and market demand also influence the adoption of sustainable innovations. While there is growing awareness of sustainability issues, many consumers continue to prioritize price, convenience, and taste over environmental impact. Companies must navigate this challenge by effectively communicating the benefits of sustainable products and educating consumers on the long-term advantages of environmentally responsible choices [15].

Stakeholder engagement is a critical component of sustainable innovation. Stakeholders include customers, employees, suppliers, investors, governments, academic institutions, and non-governmental organizations (NGOs). Each stakeholder group plays a unique role in driving sustainability efforts:

- Consumers – Demand sustainable products and influence market trends.
- Employees – Contribute to innovation through idea generation and process improvements [16].
- Suppliers and partners – Provide sustainable raw materials and collaborate on eco-friendly supply chain solutions [17].
- Investors – Fund sustainability initiatives and support long-term environmental goals [18].
- Governments and regulatory agencies – Set policies, provide incentives, and enforce sustainability standards [5].
- Academic institutions – Conduct research on sustainable technologies and best practices [19].

The food industry stands at the intersection of innovation and sustainability, requiring a transformative approach to ensure long-term environmental and economic viability. Sustainable innovation offers a pathway to achieving these goals by integrating eco-friendly practices into product development, supply chain management, and corporate strategies. However, challenges such as financial constraints, regulatory complexities, and consumer perceptions must be addressed to maximize the impact of sustainability initiatives. Stakeholder engagement and supportive policies play a crucial role in fostering sustainable innovation, enabling companies to contribute positively to both the environment and society. This literature review provides a foundation for understanding the complexities of sustainable innovation in the food industry and highlights the key areas for further research and practical implementation.

3 Materials and Methods

This study employs a multiple case study approach to examine key innovation practices for sustainable development in the food industry. It integrates triangulation by utilizing multiple data sources, including reports, information available online, questionnaires and in-depth interviews, to enhance the validity and reliability of findings. The interviewees included executives, sustainability officers, innovation managers, and operations personnel. The interview questions closely mirrored those in the questionnaire but provided an opportunity for deeper insights into challenges and barriers to adopting sustainable innovation practices, successes and lessons learned in implementing sustainability initiatives, the role of consumer preferences, market dynamics, and regulatory frameworks in shaping sustainability strategies, and the influence of stakeholder engagement

in aligning innovation efforts with broader sustainability goals. The qualitative data from interviews was used to complement and contextualize other findings, ensuring a robust analysis through methodological triangulation.

A purposive sampling technique was employed to select food industry companies that significantly contribute to sustainability challenges, such as greenhouse gas emissions and waste generation. The study focuses on key food industry sectors: dairy, beverage, and fruit and vegetable processing. Companies were selected from Zimbabwe and South Africa, considering their impact on sustainability and their regional economic significance.

The dairy industry has been identified as a major contributor to greenhouse gas emissions, particularly due to methane released by livestock and energy-intensive processing operations. The Zimbabwean dairy company selected for this study is one of the largest producers of dairy products in the country, manufacturing cultured milks, flavored milk, dairy fruit mixes, yogurts, ice creams, cheeses, condiments, and spreads. With over 50 brands, it operates factories in Harare, six other cities within Zimbabwe, and an additional facility in Malawi. The company is listed on the Zimbabwe Stock Exchange (ZSE) and aims to dominate the domestic market while expanding its regional presence.

Similarly, the South African dairy company, established in 1916, specializes in a variety of dairy and non-dairy food products, including yogurts, milk powders, infant formulas, and cheese. It has positioned itself as a key player in the global market for high-value-added foods and operates five factories and two distribution centers across South Africa.

The beverage and brewery sector is another key focus due to its significant environmental footprint, especially in terms of water usage and emissions. The Zimbabwean brewery company included in this study was founded in 1898 as the country's first brewery and has grown into an integrated beverage company with a diverse portfolio of local and international brands. It manufactures beer as its primary product but also produces sparkling soft drinks, juices, teas, sports drinks, and other non-alcoholic beverages. The company operates fourteen sorghum breweries across Zimbabwe and is committed to growing its business sustainably while supporting local communities.

In the fruit and vegetable processing sector, the South African company chosen is an internationally recognized producer of convenience meal solutions, including fresh, frozen, and canned fruit and vegetable products. Founded in 1896 and headquartered in the Western Cape, the company has a well-capitalized production base comprising fourteen manufacturing facilities across South Africa and a fruit processing facility in Eswatini (formerly Swaziland). It supplies its products to twelve other sub-Saharan African countries and aims to be the preferred supplier of fresh, frozen, and long-life meal solutions in its selected markets.

For all companies, the main processes analyzed were supply and procurement, manufacturing operations (defined as converting raw materials into finished or edible products), and employee training programs. These areas were chosen as they represent critical points where sustainability-driven innovation can have the most significant impact.

Despite the strengths of this methodological approach, several limitations were acknowledged. One limitation is the potential for self-reported bias, as the reliance on company-provided data may lead respondents to portray their sustainability efforts

more favorably. Additionally, the findings are based on a specific group of food industry companies, which may limit their broader applicability across the global food sector. The study was conducted within a fixed timeframe, making it difficult to capture emerging trends in sustainability innovation. Furthermore, the research primarily focused on large food processing companies, excluding small and medium-sized enterprises (SMEs) that may exhibit different innovation dynamics. Lastly, sustainability practices in the food industry involve multiple complex factors, including supply chain management, transportation, and sustainable business model innovation, some of which were beyond the scope of this study. Future research is encouraged to build on these findings by incorporating a broader range of companies, including SMEs, and considering a more extended timeline to capture evolving trends.

4 Research Results

The study reveals that a beverage company based in Zimbabwe, acknowledges sustainable development as part of its goals but does not prioritize it as a primary objective. Despite this, the company has implemented several sustainability practices, particularly in waste management. It has a policy for segregating waste at the source, with biodegradable waste being used for composting. Compliance audits have led to the engagement of a waste management contractor, though the associated disposal costs present challenges for smaller food processing companies.

Water quality issues significantly impact operations of food companies in Africa, causing occasional food waste due to substandard raw materials and equipment malfunctions. Energy waste is minimal due to the use of efficient machinery, but operational inefficiencies, such as miscommunication between departments, contribute to unnecessary steam wastage. Plastic packaging remains predominant, despite prior attempts to introduce more sustainable alternatives like aseptic cartons, which were discontinued due to high costs and low consumer acceptance.

Analyzed companied track energy usage daily and partially integrates renewable energy. However, issues with past solar installations have dampened enthusiasm for further investments in solar power. For example, one company complies with regulations from Zimbabwe's Safety, Health, and Environment (SHE) body and the Environmental Management Agency (EMA) but does not formalize sustainability agreements with suppliers. Nevertheless, ethical supplier screening is conducted informally. While companies do not consider themselves "green companies", they engage in sustainability initiatives such as carbon emissions tracking, supplier engagement, and employee training.

The findings indicate that while sustainability is increasingly recognized, economic and logistical challenges prevent it from being the primary focus for some companies. Their approach to sustainability is largely compliance-driven, influenced by regulatory requirements rather than proactive innovation. This aligns with Jayathilakan et al., who highlight food waste as a persistent challenge in the food processing sector [20].

Plastic packaging remains a significant sustainability issue. The failure of aseptic cartons due to cost and consumer acceptance aligns with Poovazhahi & Thakur, who stress the importance of balancing cost, efficiency, and environmental impact [21]. The

company also faces operational inefficiencies that contribute to resource waste, reinforcing the findings of Sun et al., which emphasize the role of technological innovation in minimizing waste [22].

Open innovation and supplier engagement remain underdeveloped areas. The lack of formal sustainability agreements with suppliers suggests missed opportunities for leveraging partnerships to improve sustainability performance [23]. However, informal supplier screening helps maintain ethical sourcing standards.

5 Discussion

5.1 Theoretical Implications

The study supports existing theories on sustainable innovation and its impact on business performance. León-Bravo et al. posit that sustainability positively affects financial, social, and environmental outcomes, but Company A's experience suggests that short-term costs can outweigh perceived benefits [1]. The study also highlights the influence of regulatory frameworks on corporate sustainability, as suggested by Secundo et al., with compliance playing a key role in shaping business strategies [17].

The research underscores the importance of incremental innovation [24], where companies make gradual improvements rather than adopting radical changes. This aligns with Company A's adoption of efficient machinery and hybrid energy solutions. The findings also suggest that open innovation, as discussed by Gassman & Enkel, could be more effectively leveraged to accelerate sustainable development [25].

5.2 Practical Implications

Companies should invest in technology that minimizes water and energy waste, with real-time monitoring and automation optimizing resource use and reducing inefficiencies. More research and investment in alternative packaging solutions could help transition away from plastics, and collaboration with material science firms could lead to cost-effective, consumer-friendly options. Establishing formal sustainability agreements with suppliers would enhance ethical sourcing and promote industry-wide sustainability practices. Educating employees on sustainability best practices can drive internal innovation and reduce waste. Additionally, companies should carefully plan renewable energy projects, ensuring accurate capacity assessments to avoid failures like those experienced in previous solar installations.

6 Conclusions and Future Research Directions

The study highlights the complexity of integrating sustainability into the food and beverage industry, particularly in Africa, where cost constraints and regulatory compliance shape business strategies. While companies are making progress in sustainability, major challenges remain, particularly in packaging, waste management, and supplier engagement. Future research should explore several key areas, including the long-term

financial impacts of sustainability investments to determine whether sustainable practices yield financial benefits over extended periods. Additionally, understanding African consumers' willingness to pay for sustainable products would help inform packaging and product innovation. Investigating best practices for supplier engagement, particularly in developing economies, could provide valuable insights into how sustainability agreements can be successfully implemented. Analyzing the role of government incentives in encouraging businesses to adopt sustainable practices is another crucial research avenue. Furthermore, identifying emerging technological innovations that could be feasibly implemented in resource-constrained environments would help drive sustainable progress. Sustainability in Africa's food processing industry is evolving, with gradual improvements being made. However, businesses must balance economic viability with environmental and social responsibilities to achieve long-term success.

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Research and Development Dynamics in Functional Materials: A Comparison Case Study of Compound Semiconductor Technology Through Network Analysis

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Abstract. This study aims to qualitatively and quantitatively explore the R&D and business development activities of functional chemical manufacturers specializing in semiconductor materials, with a focus on gallium nitride (GaN) power devices. By employing time-dependent patent network analysis, the research investigates the correlation between business growth, continuous innovation, and temporal changes in network structures. Data analysis of patent records from 1970 to 2022 identified two power-law distributions in centrality measures, revealing significant insights into the evolution of research networks and their implications for market dynamics. These findings provide a foundation for understanding the strategic development of GaN power devices and their role in achieving carbon neutrality.

Keywords: Network analysis · R&D strategy · GaN Power Device · SiC Power device

1 Introduction

In the chemical industry, unlike commodity chemicals, functional chemicals such as electronic materials generate the highest added value and royalty income in manufacturing, and their position has become increasingly important in recent years. Chemicals are broadly classified into general-purpose (bulk) and functional (specialty) chemicals. The applications of functional chemicals can be categorized into medical, pharmaceutical, personal care, electronic materials, and others, but this paper will focus on electronic materials. In particular, the semiconductor industry has recently been positioned as an important industry from the perspective of economic security, and we believe that qualitatively and quantitatively clarifying the R&D and business development activities of functional chemical manufacturers that develop and produce semiconductor materials to support this industry is essential to deepening and developing the semiconductor industry. From the standpoint of semiconductor material manufacturers, sustainable growth will be achieved when the same compounds are used in more and more applications. The

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gallium nitride technology has created a large market for LED applications, and the next growth market is expected to be gallium nitride power semiconductors. Gallium nitride (GaN) power devices significantly improve energy efficiency and operating performance compared to conventional silicon-based semiconductors. Silicon-based semiconductors, known for their significant power consumption and losses, have reached their material limits in these respects. Gallium nitride (GaN) technology has emerged as a transformative force, initially dominating the LED market and now poised to revolutionize power semiconductor applications. GaN power devices offer unparalleled energy efficiency compared to silicon-based semiconductors, making them critical to achieving carbon neutrality by 2050. While GaN has gained prominence, silicon carbide (SiC) also represents a significant advancement in power semiconductor technology. SiC devices are known for their superior thermal conductivity and ability to operate at higher voltages and temperatures, making them ideal for high-power applications. Both GaN and SiC are seen as complementary rather than competing technologies, each with distinct advantages suited to specific applications.

2 Literature Review

2.1 Power Device Development Review

R&D networks are complex and dynamic, evolving through collaboration and competition. Studies by Kuwashima and Tomita highlight the strategic importance of early customer engagement and process innovation in functional chemicals. [1–4] Additionally, complex network theories, such as small-world and scale-free networks, provide frameworks for understanding R&D dynamics. Recent advancements in patent and network analyses offer tools for mapping innovation and identifying influential nodes within research ecosystems. However, empirical research on time-series changes in network structures specific to functional materials remains limited. Inoue et al. [5] provide an in-depth analysis of joint patent networks to understand the dynamics of cooperative research and development. Their study identifies power-law distributions in network degree and node density, revealing structural characteristics consistent with preferential attachment models. By considering the geographical and institutional proximities influencing R&D collaborations, the study underscores the importance of spatial and organizational factors in fostering innovation ecosystems. This framework is particularly relevant when analyzing the interplay between global innovation hubs and emerging technology clusters in functional materials like GaN and SiC. Comparatively, studies on SiC have emphasized its suitability for applications requiring high efficiency and durability. Research on SiC-based systems often highlights their advantages in electric vehicles (EVs), renewable energy systems, and industrial equipment due to their ability to handle higher voltages and temperatures than GaN. These studies underline the importance of considering application-specific requirements when evaluating material choices. The imperative for enhanced efficiency, reduced size, and heightened performance across diverse sectors such as electronics, power electronics, and renewable energy has spurred a vigorous surge in research and development towards next-generation power devices. Notably, significant attention has been directed towards silicon carbide (SiC) power

devices. SiC presents numerous advantages over traditional silicon counterparts, including elevated breakdown voltage, enhanced temperature tolerance, and diminished switching losses. A pivotal milestone occurred in 1993 when a particular research group published a comprehensive theoretical analysis [6], marking the commencement of focused efforts toward optimizing SiC material quality, device architecture, and manufacturing methodologies. Consequently, the fruition of these endeavors culminated in the development of SiC Schottky diodes and SiC metal-oxide-semiconductor field-effect transistors (MOSFETs).

2.2 Network Analysis Review

In the realm of network analysis, seminal contributions have been made by Watts and Strogatz [7–9], who expound upon the concept of small-world networks, delineating the correlation between clustering coefficients and average path lengths. Barabási [10–12] proposes a random network model that exhibits the properties of scale-free networks, which describes in detail the statistical dynamic properties of complex networks. Dorogovtsev and Mendes [13] provide a comprehensive review encompassing research on network evolution, delving into pivotal phenomena such as the "small-world phenomenon" and "scale-free networks". Newman [14] further elucidates the intricate nature of complex networks, elucidating their constituent elements (nodes) and interactions between them (edges), along with characteristic features like degree distribution, clustering coefficient, and average path length. Scott et al. [15–17] offer a comprehensive exposition on social network analysis, encapsulating fundamental concepts and applications about network structure, dynamics, and influence metrics.

Moreover, Ortiz-Arroyo [18] introduces methodologies for identifying key players within social networks leveraging entropy measures, while Burt [19] underscores the significance of structural holes in fostering innovation and information diffusion. Uzzi and Spiro [20] accentuate the optimal balance between interaction among specialized experts and interdisciplinary collaboration for fostering creative outcomes. Borgatti et al. [21] advocate for applying network analysis in social sciences, propounding methodologies for analyzing networks across diverse scales and layers, validated through empirical investigations. Mucha et al. [22]. Have proposed and validated on a real data set a method for analyzing networks with temporal variation, different scales, and even multiple layers to understand the structure and dynamics of the network. Baum A.C. Joel [23] et al. argue that firms, through deliberate partner selection strategies, suggest that firms can actively form innovation networks.

Although various studies have been conducted on the analysis using complex networks as described above, there have not been enough further studies on business growth/continuous innovation creation beyond R&D and time-series changes in network structure for functional chemicals, especially for electronic materials represented by semiconductor materials. Patent analysis could help promote research and development (R&D) by providing insights into innovative activities combined with network analysis. Lee et al. [24] studied to identify promising detailed IPC technology areas, the technology mapping analysis, the time series analysis, and the social network analysis are conducted based on the patent-IPC matrix. Combination analysis with text mining and patent network analysis, which helps to refine a reasonable search strategy has mentioned

by Zhou et al. [25] Block [26] studied the significance of battery material information in patent documents for advancing battery technologies. The study, to broaden the perspective of materials research in the battery field by using materials information on the patent situation in the battery field, states that it will assist R&D managers and research scientists in designing better materials discovery strategies and selecting appropriate collaboration partners in their respective processes.

In recent years, social network analysis has been applied to business and economic fields, such as online networking and recent coronary infections due to the spread of social networking services. Against this background, however, there has not yet been enough empirical research on how to construct a forum for creating "knowledge" that is useful in practical terms in the research and development field.

3 Research Questions

What are the temporal dynamics of R&D networks in functional materials, and how do they influence market trends?

4 Methodology

This study used the Database of Chinese Granted, Chinese Granted Patents for Utility Models, Chinese patent Applications, Chinese Utility Model Applications, European Granted Patens, European Patent Applications, French Granted Patents, French Patent Applications, German Gebauchsmusters (Utility Model), German Granted Patents, German Patent Applications, Great Britain Granted patents, Japanese Granted Patents, Japanese Granted Patents for Utility Model, Japanese Patent Abstracts, Japanese Patent Application, US Granted Patents, US Patent Applications, and WIPO PCT Publications to analyze jointly applied patents related to GaN (Gallium Nitride)/SiC (Silicon Carbide) power device. Of the patent information using the word "GaN" in the full text of the patents, 244,693 patents that were made known after 1971, when the GaN device was started to be studied. Also Extracted as SiC was 79,983.

4.1 Network Analysis

In this work, we derived three different concepts of centrality to estimate network properties. The first one is eigenvector centrality. The simplest form of centrality is the degree at a node. However, the degree is an extremely crude measure of centrality. In effect, it gives one "centrality point" for each neighborhood a node has. However, not all neighbors are necessarily equal. Often a node's importance in a network is increased by having connections to other nodes that are themselves important. We can the eigenvector centrality using node's several points proportional to the centrality score of its neighbors rather than one point for each neighbor in the network it has. The graded equation is given as

$$u(t+1) = Au(t) \tag{1}$$

Where A and $u(t) \equiv (u_1, u_2, \ldots, u_n)^T$ are the neighbor matrix and the vector aligned centrality u_i of the node v_i respectively.

Interpreting the above equation as the influence u_i of a node is the sum of u_j over adjacent points, we can regard variable t as the index of updates for the iteration. Since the above equation is an incremental equation with t as the index, we consider repeating it to find the centrality at each vertex. In general, however, it is not possible to find the number of updates for $u_1, u_2, \ldots, u_N$ diverges. Therefore, we impose a bound condition each time such that the sum of $u_1, u_2, \ldots, u_N$ is equal to 1, and iterate. The linear algebra show us that these iterations are shown to be maximal eigenvectors of A if there is at least one closed odd angle in the network. Therefore, if the largest eigenvalue of A is λ_N, eigenvector centrality is given as

$$Au = \lambda_N u \tag{2}$$

With eigenvector centrality defined in this way, a node can achieve high centrality by having many neighbors with modest centrality or a few neighbors with high centrality (or both). This situation is natural. The node can influence by knowing many nodes or the node can influence by knowing a few nodes.

Second, we evaluated the closeness centrality. The closeness centrality is defined that how close on average, the node is from itself to others. Mathematically, the closeness centrality is defined as

$$\frac{N-1}{\prod_{j=1,\, j\neq i}^{N} d(v_i, v_j)} = \frac{1}{L_i} \tag{3}$$

Where $d(v_i, v_j)$ is the distance between nodes v_i and v_j. L_i is the average distance from node v_i to other nodes.

The betweenness centrality is the degree to bridge and control the flow of information in a network for the nodes. Mathematically, betweenness centrality is defined as

$$b_i = \frac{\sum_{i_s=1, i_s\neq i}^{N} \sum_{i_t=1, i_t\neq i}^{i_s-1} \frac{g_i^{(i_s, i_t)}}{N_{i_s, i_t}}}{(N-1)(N-2)/2} \tag{4}$$

Where $g_i^{(i_s, i_t)}$ is the number of vertices in the shortest path going from the start point v_{i_s} to the endpoint v_{i_t}. N_{i_s, i_t} is the number of shortest paths from the start point to the endpoint [27].

5 Results and Discussion

5.1 Network Analysis

Table 1 listed in the 1980s, the results indicate robust information propagation and interaction among network nodes, characterized by a short average path length of 2.5 and a limited number of researchers involved in Gallium Nitride R&D. This suggests effective information sharing and collaborative behavior within the network. The 1990s saw significant changes with approximately triple the number of nodes and fivefold the

edges. Notably, the 2000s to 2010s comparison reveals almost saturated edge numbers and a slight decrease in the clustering coefficient, reflecting increased barriers to entry and the continued patent activities of established companies to strengthen their market positions.

Table 1. Result of Network analysis of GaN

	1980s	1990s	2000s	2010s	2020s
Number of nodes	574	1,403	11,289	11,779	4,118
Number of edges	1,270	5,127	78,434	67,625	17,025
Number of records	766	7,770	62,672	129,571	40,726
Cluster Coefficient (CC)	0.71277	0.69086	0.74329	0.67927	0.58816
Avarage Degree	4.42509	7.30862	13.89565	11.48230	8.26858
Avarege shortest path length (PL)	2.54337	2.97732	3.62414	3.37345	4.68687

Table 2. Result of Network Analysis of SiC

	1975-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	2020-2023
Number of Nodes	43	116	274	401	1072	2457	5,080	4,863	2,215	1,307
Number of edges	88	320	1155	1096	4308	9049	36,848	32,575	7,184	2,514
Cluster Coefficient(CC)	0.545	0.695	0.731	0.732	0.756	0.749	0.796	0.772	0.626	0.517
Average Degree	4.093	5.517	8.431	5.466	8.037	7.366	14.507	13.397	6.487	3.847

Table 2 lists the results of the SiC network analysis. The number of nodes and edges has increased with time, and the order has increased accordingly. As for the network structure, the maximum cluster coefficient is around 0.7, suggesting that the nodes in the network have relatively high local ties and form strong clusters.

The results of time-series changes in the graphs of closeness centrality and betweenness centrality, and closeness centrality and eigenvector centrality, especially the relationship between closeness centrality and eigenvector centrality, show that in the 1990s, the graph shows a clear gradient of rightward movement (power-law), close to that of a scale-free network. By mapping eigenvector centrality against closeness centrality, the graph shows the degree to which nodes in the network influence closeness. Node nodes with high closeness centrality and high eigenvector centrality have an important role and influence in the network. Because of their high closeness centrality, they are strongly connected to other nodes in the network, and information propagation occurs quickly. They are also recognized as essential nodes or clusters in the network because of their high eigenvector centrality. For example, from 1995 through 2023, gradual right-shouldered linearity is depicted (power-law). In most cases, the network diagram is similar to a scale-free network. Information propagation occurs quickly, and because of their high mediating centrality, they are located on the paths between different nodes

and serve as intermediaries in the flow of information. For example, in the graph of mediating centrality versus closeness centrality on the left side in the 2005–2009 figure, the closeness centrality values are concentrated around 3 × 10^(−1), and the values of mediating centrality are dense around 10^(−4). This indicates that R&D information comes and frequently goes, as many nodes with high closeness centrality also have high mediational centrality. The 2010–2014 graph plots eigenvector centrality against closeness centrality on the right side of the figure. By mapping eigenvector centrality against closeness centrality, the graph shows the degree to which nodes in the network influence closeness. Node nodes with high closeness centrality and high eigenvector centrality have an essential role and influence in the network. Because of their high closeness centrality, they are strongly connected to other nodes in the network, and information propagation occurs quickly. They are also recognized as essential nodes or clusters in the network because of their high eigenvector centrality (Fig. 1).

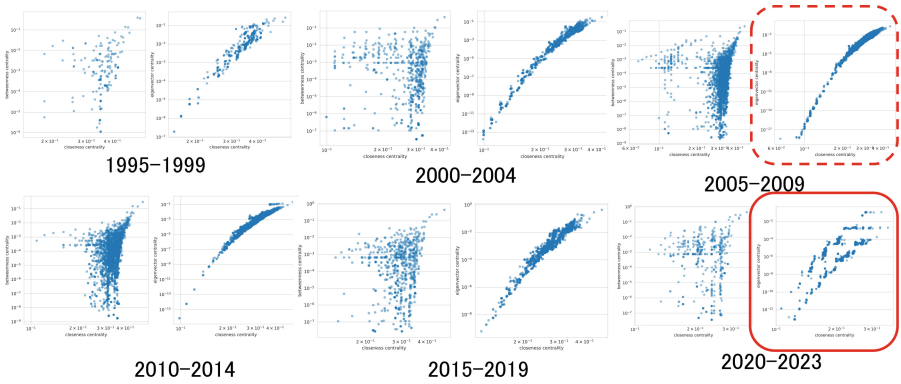

Fig. 1. GaN Network Analysis result of centrality (1995–2023) - Closeness Centrality vs Eigenvector Centrality (Right) - Closeness Centrality vs Betweenness Centrality (Left)

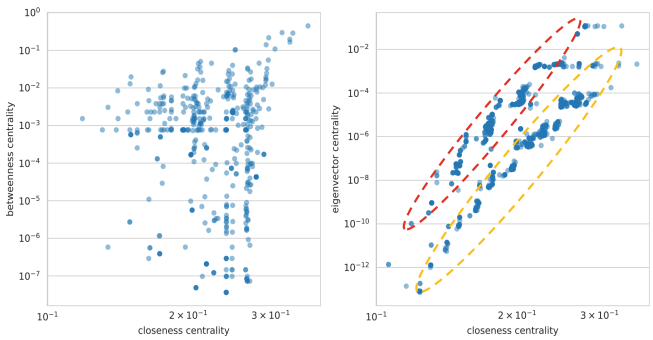

Fig. 2. GaN Network Analysis results of centrality (2020–2023) - Closeness Centrality and Betweenness Centrality (left) - Closeness Centrality and Eigenvector Centrality (right)

Figure 2, focusing on 2020–2023, clearly indicates the two power-law curves. It indicates that there are two different clusters. The 2020–2023 graph shows a slightly existing second power-law curve similar to the GaN network analysis in Fig. 3.

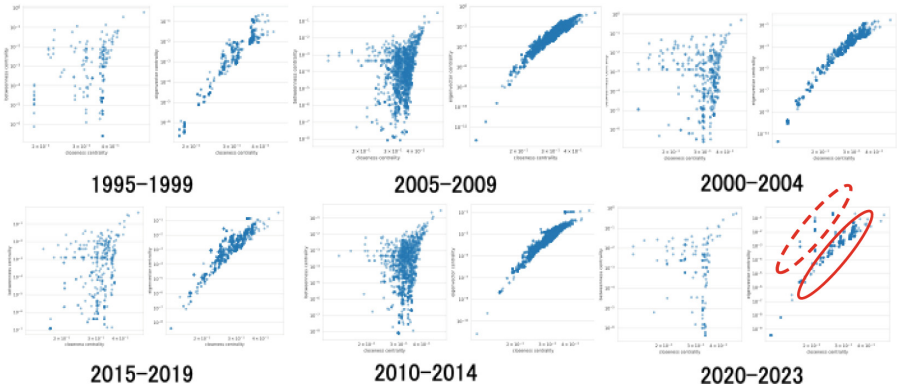

Fig. 3. SiC Network Analysis result of centrality (1995–2023) - Closeness Centrality vs Eigenvector Centrality (Right) - Closeness Centrality vs Betweenness Centrality (Left)

The time series variation of the entire network is shown in Fig. 4. The evolution of R&D is clear. It can be seen that the 1970s to 1980s was the initial stage of research; in the 1990s, it entered the mass production sample evaluation stage; in the early 2000s, development toward commercialization began, and from the late 2000s to the early 2010s, development progressed at a rapid pace. In the latter half of the 2010s, however, R&D activities reached a plateau, and the focus shifted from R&D to production technology development.

The decrease in the number of nodes indicates this. In the 1970s, 1980s, and 1990s, nodes with structural holes can be seen between large clusters. Strategically, contact with these nodes is advantageous for obtaining R & D information. Next, in Fig. 2, the analysis results for betweenness centrality and eigenvector centrality concerning proximity centrality are presented. The left side of the figure displays a graph depicting eigenvector centrality in relation to proximity centrality, while the right side illustrates a graph representing betweenness centrality in relation to proximity centrality. Upon examining the time series changes in the graphs for proximity centrality, betweenness centrality, proximity centrality, and eigenvector centrality, a clear right-hand-upward trend is observed in the late 1990s. Moreover, during the 2000s, the graphs unmistakably depict characteristics resembling those of a scale-free network. The time-series change in the numbers of joint applications, number of nodes, and the number of edges are shown in Table 2 (Fig. 5).

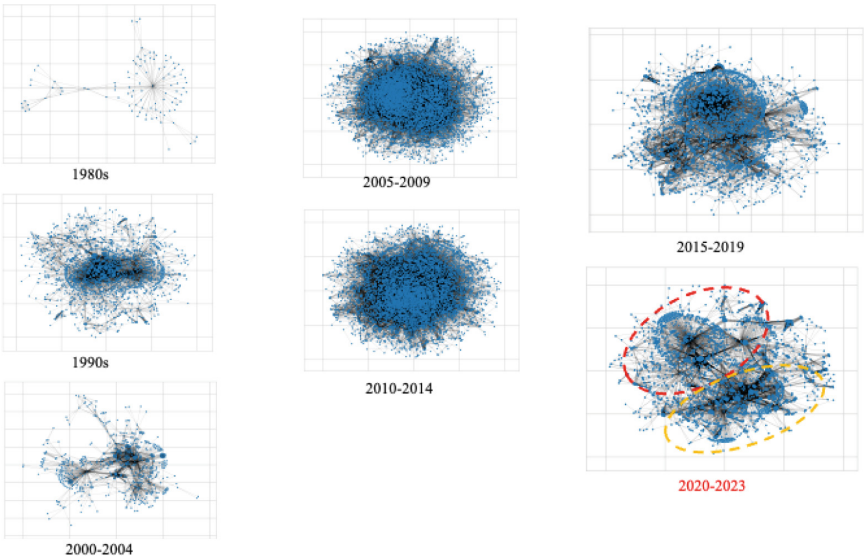

Fig. 4. Time-dependent changes in GaN power device network

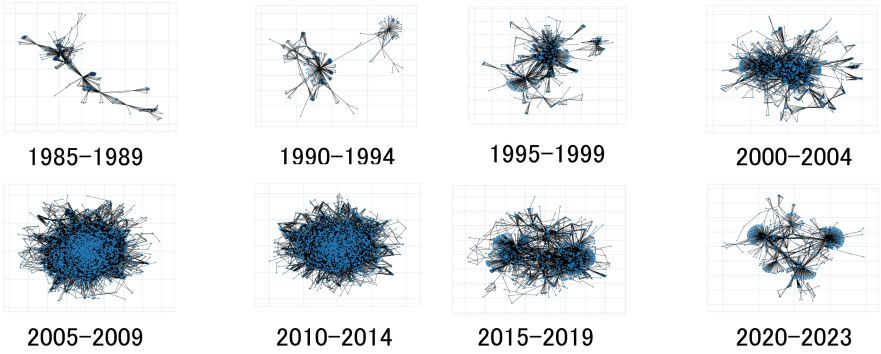

Fig. 5. Time-dependent changes in SiC power device networks

5.2 Division of Applications (2020–2023)

Recent analyses indicate that the GaN power device market is bifurcating into two major segments: information and communication technology (ICT) and industrial/automotive applications. The structure of the research network has similarly diverged, with clusters specializing in either ICT or high-power industrial uses. This division reflects strategic efforts to align R&D focus with market demand, as GaN technology increasingly caters to distinct application needs.

5.3 Comparison with SiC

While GaN excels in high-frequency and low-power-loss applications, SiC's strengths lie in high-voltage and high-temperature environments. Patent analysis indicates that SiC is often prioritized in EV powertrains and renewable energy systems, where durability and efficiency under extreme conditions are paramount. The networks associated with SiC research demonstrate a similar trend of increasing complexity, with strong clustering around industrial applications and EV technologies.

5.4 Market Implications

Projections indicate that GaN power devices will expand into automotive and industrial sectors, leveraging insights from evolving R&D networks in the Fig. 6. SiC, on the other hand, is expected to maintain a dominant role in high-power and high-temperature applications, with significant overlap in market segments such as EVs and energy storage. Based on the GaN power device market forecast, the market can be divided into two major segments in 2030: the Information and Communication equipment market and other areas such as industrial applications and electric vehicles. The structure of the entire network in Fig. 2 2020–2023 will be divided into two major segments, suggesting that research and development are already divided into these two application areas in the research phase.

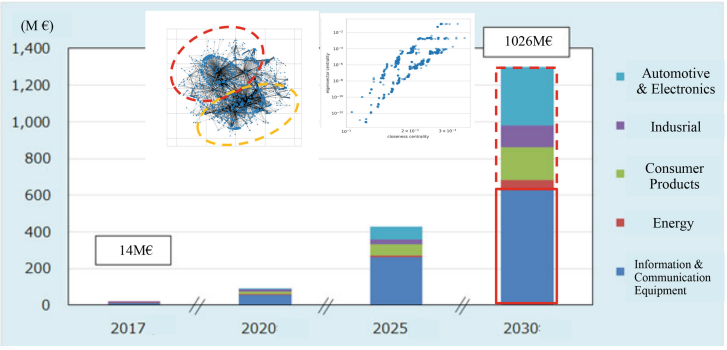

Fig. 6. Division application of GaN device market [28]

Figure 7 presents a juxtaposition of the time-series data illustrating changes in the number of nodes and the number of joint patent applications with the market size data for SiC power devices. The figure clearly demonstrates that the growth in the number of joint patent applications has been proportional to the expansion of the market size. However, an evident decline in the number of nodes indicates that, beginning in the late 2010s, some companies either scaled back or withdrew their R&D efforts despite the expanding market size. This divergence can be interpreted as a discernible distinction between successful and less successful players. The market is anticipated to experience steady growth after 2023. In this context, several strategic options can be considered:

1) For those contemplating entry into the SiC power device market, viable choices include forming alliances with industry leaders, adopting technology transfer initiatives, or pursuing mergers and acquisitions (M&A). This is particularly relevant as the number of nodes and edges in networks has been steadily declining since the late 2000s.
2) For companies already engaged in their own R&D efforts, a thorough analysis of the competitive landscape is essential. Decisions can then be made on whether to maintain the current R&D strategy, collaborate through joint ventures with competitors, or embark on an M&A strategy. It's imperative to note that a standalone, in-house R&D approach may not be the most suitable course of action.

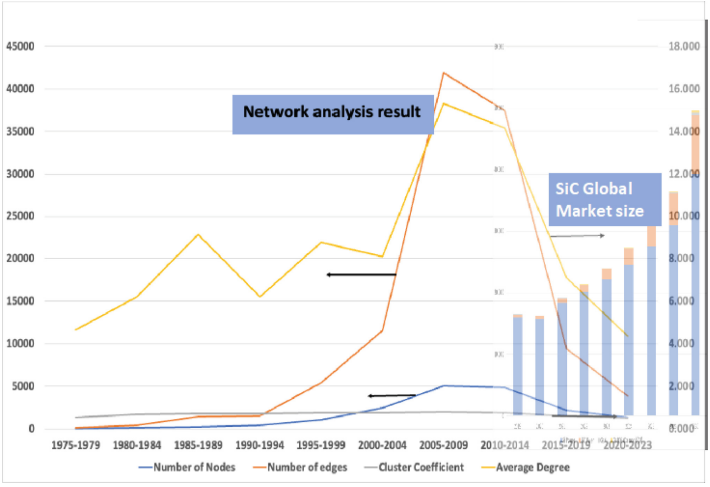

Fig. 7. Superimpose of Network analysis result, jointly applied patents, and Market size [21].

The temporal evolution of R&D networks underscores the critical role of collaboration and strategic positioning in driving innovation. The transition from small-world to scale-free networks reflects increasing complexity and specialization. Companies leveraging structural holes and fostering diverse networks are better equipped to navigate dynamic market conditions. Integrating patent analysis with network metrics provides actionable insights for policymakers and industry stakeholders to foster innovation ecosystems. The recent bifurcation of GaN applications into ICT and industrial/automotive sectors has important implications for R&D strategies. This division aligns with global market demands, suggesting a strategic response by researchers and firms to capitalize on specific technological strengths. Such segmentation may facilitate more targeted innovation but also poses challenges in maintaining cross-sectoral collaboration. Comparatively, GaN and SiC technologies highlight the importance of material-specific advantages in shaping their respective market trajectories. GaN's high efficiency in low-power applications complements SiC's dominance in high-power domains, suggesting a synergistic relationship rather than direct competition. Both materials are pivotal in achieving energy efficiency and supporting the transition to carbon neutrality.

6 Conclusion

This study demonstrates the transformative potential of GaN and SiC power devices within functional materials. By combining network analysis with patent data, the research highlights the interplay between innovation, collaboration, and market dynamics. The division of GaN applications into ICT and industrial/automotive sectors reflects strategic R&D alignment with market demands. Future studies should explore the applicability of these findings across other functional materials to inform strategic decision-making in R&D management.

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KM and Education

Competence and Satisfaction in Delivery Room Simulation-Based Learning Among Nursing Students: A State University Experience

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Abstract. Simulation-based clinical education plays a pivotal role in assessing and enhancing clinical competence, particularly during the COVID-19 pandemic. This study, in support of the CHED-LAKAS program of the Commission on Higher Education (CHED), evaluated the perceived competence and satisfaction of Level IV nursing students in intrapartal and immediate newborn care during delivery room simulation-based learning (DR-SBL) at a state university. Using a quantitative descriptive correlational design, 143 respondents from the West Visayas State University College of Nursing, La Paz, Iloilo City, were surveyed through researcher-made questionnaires adapted from standardized tools. Results showed that students rated themselves as highly competent in intrapartal and immediate newborn care, with the highest competence observed in managing resources, environment, and equipment. Satisfaction levels were similarly high, with no significant differences based on gender. A positive correlation was found between perceived competence and satisfaction ($p < .05$), highlighting the interconnectedness of these factors in DR-SBL. The findings affirm the effectiveness of DR-SBL in fostering competence and satisfaction among nursing students, ensuring meaningful learning experiences and readiness for clinical practice.

Keywords: Perceived Competence · Satisfaction · Delivery Room · Simulation-Based Learning · Nursing Students · Nursing Education

1 Introduction

The unprecedented emergence of COVID-19 significantly impacted the education and training of future nurses, necessitating the adaptation of teaching strategies to ensure competence in patient-centered care, collaboration, evidence-based practices, safety, and informatics [1, 2]. Simulation-based clinical education has emerged as a valuable approach for teaching, learning, and assessing clinical competence in health professions education [3]. It allows students to apply theoretical knowledge in realistic contexts without compromising patient safety, making it particularly crucial during the pandemic when access to clinical settings was limited [4].

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In the Caring Arts Laboratory at West Visayas State University - College of Nursing (WVSU-CON), Levels III and IV student nurses undergo simulation-based learning (SBL) to develop skills in intrapartal and immediate newborn care. These simulations utilize low-fidelity models and follow a structured sequence of pre-briefing, simulation, and debriefing phases. SBL enables students to bridge the gap between theoretical knowledge and practical application, addressing a longstanding challenge in nursing education where clinical realities often differ from theoretical ideals. Furthermore, simulation is acknowledged as the gold standard in nursing education, promoting the mastery of fundamental skills, critical thinking, and reflective abilities [2, 5].

Simulation in the delivery room context involves education, hands-on practice, and the development of proficiencies needed for both routine and emergency obstetric-gynecological scenarios [6]. While SBL has proven effective in preparing students for real-world clinical roles, challenges persist, including the absence of well-equipped skills laboratories and limited opportunities for practical application in some regions [7]. Moreover, the COVID-19 pandemic exacerbated these challenges, disrupting nursing education and restricting access to clinical settings.

Given these factors, assessing perceived competence and satisfaction among nursing students engaged in SBL is crucial. These measures not only highlight the effectiveness of instructional strategies, but also guide enhancements to better prepare students for clinical practice [8]. With these having said, the current study aims to evaluate the perceived competency and satisfaction levels of Level IV student nurses in a State University regarding their simulation-based learning experiences in the delivery room.

2 Theoretical Background

2.1 Advancing Nursing Competence Through Delivery Room Simulation-Based Learning

SBL has emerged as a pivotal educational strategy in nursing, effectively addressing the challenges faced by novice nurses in clinical environments characterized by elevated patient acuity, shorter hospital stays, and increased acute care admissions [7]. By bridging the gap between theoretical knowledge and clinical practice, SBL facilitates enhanced learning outcomes such as improved knowledge, self-assurance, satisfaction, critical thinking, and psychomotor skills [9]. High-fidelity simulation (HFS) and standardized patients (SP) are commonly employed methods that replicate real clinical scenarios, enabling student nurses to refine their competencies in a controlled and risk-free setting [10, 11]. Despite its broad acceptance, discrepancies remain in SBL's impact on confidence and learning satisfaction [5, 12].

In the Philippines, many prominent nursing institutions, including the University of the Philippines, Manila - College of Nursing and Central Philippine University - College of Nursing, have integrated SBL into their curricula to meet flexible learning requirements set by the Commission on Higher Education (CHED) [13, 14]. Advanced technologies, such as high-fidelity birthing mannequins like Lucina, have been used during the COVID-19 pandemic to develop delivery room competencies in lieu of real hospital exposure [15]. These simulations provided near-realistic training in tasks such as normal delivery, breech birth, and eclampsia management, allowing students to actively

engage in safe labor and delivery scenarios under the supervision of clinical instructors [16].

SBL has shown significant benefits for nursing students at varying levels of education. For instance, a study found that simulation scenarios tailored to academic levels helped students develop distinct competencies, from basic assessments and communication skills at earlier levels to leadership and advanced skills at later stages [17]. Specific to delivery room SBL, Level III and IV student nurses demonstrated proficiency in critical intrapartal and newborn care tasks, including sterile perineal care, safe delivery of the baby and placenta, cord management, and administration of neonatal injections. These competencies highlight the importance of incorporating both theoretical knowledge and hands-on practice to prepare students for real-world clinical challenges.

SBL is particularly beneficial in maternity nursing education, where opportunities for direct clinical practice are often limited due to factors such as declining birth rates and patient privacy concerns. Studies revealed that SBL significantly enhances clinical competence, communication skills, and confidence in maternity nursing practice [18, 19]. In scenarios involving normal and high-risk deliveries, SBL improved students' ability to interpret fetal monitoring outcomes, evaluate uterine contractions, and provide patient-centered care [20]. These findings highlight the necessity of continuous curriculum improvements and exposure to diverse simulation techniques to equip student nurses with the essential knowledge and core skills required for maternity nursing practice.

In essence, as SBL is a form of learning technology that has been employed in nursing education for many years, which serves as a bridge between theoretical concepts and clinical practice. Its enduring relevance stems from its ability to provide realistic, risk-free environments where students can develop and refine critical competencies. However, as education and healthcare technologies evolve, new challenges and opportunities emerge. The integration of artificial intelligence (AI) into SBL presents possibilities for more advanced and adaptive simulations, enabling personalized learning experiences and enhanced assessment of clinical decision-making skills [21]. Despite these advancements, issues such as accessibility, cost, and the ethical implications of AI-driven technologies continue to pose challenges [22]. These evolving dynamics further strengthen the need for ongoing research and curriculum development to ensure that SBL remains an effective and equitable tool for preparing student nurses for the complexities of modern healthcare.

2.2 Student Satisfaction with Delivery Room Simulation-Based Learning

As noted earlier, SBL provides authentic and clinically relevant opportunities for experiential learning, enabling student nurses to practice procedures in environments that replicate real clinical settings. By observing clinical instructors' demonstrations and applying learned techniques using human patient simulators, students have report higher levels of learning satisfaction [23]. SBL employs varying levels of fidelity, from low-fidelity simulations for teaching basic physical assessment and psychomotor skills to high-fidelity simulations that replicate human patients in complex clinical scenarios [24]. These simulations help bridge the gap between theoretical instruction and practical application, particularly in delivery room scenarios.

Delivery room simulation-based learning or DR-SBL immerses student nurses in time-sensitive and critical scenarios related to intrapartum and immediate newborn care, offering hands-on opportunities that are often unavailable in real clinical settings [25]. Competencies developed during DR-SBL include performing various maneuvers, monitoring labor progress, executing sterile perineal care, safely delivering babies and placentas, and providing immediate newborn care, such as administering Vitamin K and Hepatitis B injections. These scenarios promote safety and quality nursing care, fostering essential skills that contribute to reducing preventable maternal and neonatal deaths [26]. Tools like the CAE Lucina childbirth simulator, widely used in Philippine nursing schools, further enhance the quality of training by simulating a range of delivery situations, including rare emergencies, leading to improved student satisfaction and self-confidence [16].

Research has consistently demonstrated the positive impact of SBL on student preparedness and satisfaction. In a study, results found that simulation groups scored significantly higher in preparation for delivery, supportive care, and maternal-fetal monitoring compared to control groups [24]. Importantly, students were able to appreciate the alignment of SBL scenarios with their learning objectives, the provision of realistic and challenging simulations, and the inclusion of guided debriefing sessions. Furthermore, the effectiveness of SBL lies not in the complexity or cost of the simulators but in carefully designed scenarios, appropriate cues, and skillful debriefing [27]. Hence, facilitated debriefings are critical, as much of the learning occurs during these reflective sessions rather than the simulations themselves.

The implementation of well-structured simulation designs that incorporate clear objectives, realism, problem-solving elements, student support, and guided reflection has been positively correlated with students' perceived satisfaction and competency development. In the Philippines, DR-SBL has been validated as an effective strategy for enhancing the skills, knowledge, and attitudes of nursing students, ensuring their readiness for globally relevant quality patient care [16]. Despite the absence of real patients, the controlled yet realistic training environment of DR-SBL allows students to practice and refine their clinical skills, ultimately boosting their confidence and preparedness for real-world delivery room scenarios.

2.3 Challenges and Inclusivity in Delivery Room Simulation-Based Learning

As DR-SBL gained its popularity in nursing education for its ability to provide students with hands-on, immersive training in intrapartal and immediate newborn care. However, several challenges limit its effectiveness. One significant limitation is the inherent inability of simulations to fully replicate the holistic biopsychosocial needs of real patients, as they focus primarily on technical competencies [28]. However, while simulations allow instructors to control scenarios and provide a safe learning environment, they fail to capture the unpredictability of real-life clinical situations [29]. Even with advances in high-fidelity simulators, technological constraints prevent them from mimicking the intricate complexities of human systems, leaving gaps in students' preparation for authentic clinical encounters.

Another notable challenge is the financial burden associated with simulation-based learning. Establishing and maintaining simulation laboratories requires substantial

investments in high-fidelity equipment, maintenance, and faculty training [30]. Additionally, many nursing programs lack adequately trained educators to deliver effective simulation experiences, as teaching in simulation settings requires distinct skills beyond traditional pedagogy [31]. Poorly designed or rushed simulation scenarios exacerbate these limitations, potentially leading to the omission of critical competencies and communication principles essential for patient care [32]. Lastly, time constraints often restrict comprehensive assessments, leaving students inadequately prepared for certain real-world responsibilities, such as seeking patient consent or fostering therapeutic communication [7].

Despite these challenges, DR-SBL has demonstrated its capacity to foster inclusivity and equitable learning opportunities for nursing students across different demographics. Studies have noted that DR-SBL benefits both male and female students alike, with no significant gender-based differences in perceived competence or satisfaction [24]. These findings underscore the universal applicability of simulation-based learning as a pedagogical approach, ensuring equitable skill development and confidence-building for all learners. The active, hands-on nature of simulation helps students overcome theoretical limitations, promoting readiness for real-world clinical practice regardless of gender or prior experience.

Lastly, DR-SBL's inclusivity extends to diverse educational settings, even in low-resource environments where students often encounter simulation-based education for the first time. Some emphasizes that the importance of implementing evidence-based simulation grounded in established learning theories to maximize its benefits [33]. Therefore, by fostering equitable and accessible training opportunities, DR-SBL prepares nursing students to meet the demands of professional practice, equipping them with the skills, confidence, and adaptability necessary for delivering high-quality patient care in diverse clinical settings.

2.4 Kolb's Experiential Learning Cycle in Delivery Room Simulation-Based Learning

This study is grounded in David A. Kolb's Experiential Learning Theory, which serves as the theoretical framework to understand the factors influencing student nurses' perceived competence and satisfaction with DR-SBL in Maternal and Child Health Nursing. Kolb's learning cycle comprises four interconnected stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation [34]. These stages illustrate how learning occurs through experience, reflection, and application, forming a continuous cycle of knowledge acquisition and skill development [35].

The first stage, **Concrete Experience**, involves *direct engagement* or *doing*. In DR-SBL, this refers to student nurses actively participating in delivery room simulations, where they are immersed in realistic clinical scenarios. This phase emphasizes hands-on involvement, allowing participants to encounter situations without initial reflection but with the intent to analyze them later [36]. The second stage, **Reflective Observation**, focuses on analyzing the experience. Participants revisit the tasks performed during the simulation, reviewing their actions and outcomes. This phase encourages active discussions with peers and instructors, fostering insights through comparison and critical questioning. Reflection allows students to identify strengths and areas for improvement,

contributing to a comprehensive understanding of the experience [35, 36]. The third stage, **Abstract Conceptualization**, involves interpreting the experience and integrating it with theoretical knowledge. Participants evaluate their actions, draw connections between outcomes and principles, and develop generalizations or solutions. This phase emphasizes logic and systematic planning to build concepts that can address challenges encountered during simulations. Through this process, students refine their understanding and prepare for future applications [35]. Lastly, the final stage, **Active Experimentation**, focuses on applying acquired knowledge, skills, and attitudes in real-world clinical practice. In this phase, participants use their new understanding to predict outcomes, make improvements, and refine their approaches to patient care. Kolb emphasizes the practical and experimental nature of this phase, where learners actively influence or change situations based on their learning [36].

Kolb's Experiential Learning Cycle aligns seamlessly with the objectives of DR-SBL, emphasizing the importance of hands-on experience, critical reflection, and application in fostering student competence and satisfaction. Its cyclical design allows learners to enter and progress through the stages at any point, ensuring flexibility and adaptability in learning [37]. This framework has been shown to enhance perceived competence and satisfaction in simulation-based learning, as evidenced by studies highlighting its effectiveness in developing critical nursing skills [36].

SBL has emerged as a vital pedagogical approach in nursing education, particularly in DR-SBL, wherein it bridges the gap between theoretical knowledge and clinical practice. Research highlights its effectiveness in fostering student competence, confidence, and satisfaction by providing immersive, hands-on experiences in realistic scenarios. While DR-SBL offers significant advantages, such as enhancing practical skills and promoting inclusivity across diverse student populations, it faces challenges, including financial constraints, technological limitations, and the need for well-trained educators. Moreover, the inability to fully replicate the complexity of real-life patient care and the risk of poorly designed scenarios underscore the need for continuous improvements. Despite these limitations, DR-SBL has been shown to be a universally effective method for preparing nursing students to excel in clinical practice, providing equitable opportunities to build critical competencies and address complex healthcare demands.

3 Method

This study employs a quantitative correlational design to analyze and evaluate the relationships among the variables of interest [38]. Using a volunteer sampling approach, the survey questionnaire was distributed to all the more than 200 Level IV student nurses enrolled in West Visayas State University - College of Nursing. In total, around 143 students completed the survey. Among the 143 participants, 71.30% (or 102) are female students, and 28.70% (or 41) are male students. The study protocol followed the principles of the Helsinki Declaration to ensure the safety, well-being, and protection of all participants. Informed consent was obtained from participants, who were also given the freedom to withdraw from the study at any point during the data collection process. No personally identifiable information was collected to maintain confidentiality and privacy. Ethical approval for the study was granted by the West Visayas State University Unified Research Ethics Committee.

The data for this study was gathered using a researcher-made questionnaire, adapted and modified from standardized tools, including the *Performance Rating Scale of West Visayas State University - College of Nursing* and the *Student Satisfaction and Self-Confidence in Learning* (SCL) Scale [39]. These tools were selected for their open-access availability, and proper citations were provided for the original authors. The questionnaire was divided into three main parts:

- **Part I**: *Personal Demographic Data Sheet* - This section collected participants' demographic information, including age, gender, and academic year level.
- **Part II-A** and **II-B**: *Perceived Competence*
- Part II-A focused on intrapartal care competencies using a modified version of the *Intrapartal Care Performance Rating Scale*. It contained 61 items divided into eight domains: safety and quality nursing care, functions during labor, management of resources, health education, legal and ethical responsibilities, personal and professional development, quality improvement, and communication/teamwork. A 5-point Likert [40] type rating scale ranging from 1 ("strongly disagree") to 5 ("strongly agree") was used, with scores interpreted as "highly competent" (3.68–5.00), "moderately competent" (2.34–3.67), and "poorly competent" (1.00–2.33).
- Part II-B evaluated competencies in immediate newborn care, featuring 58 items across six domains with the same scoring system. These items assessed the students' perceived ability in newborn care-related tasks, ensuring a comprehensive evaluation of their competence in simulation-based scenarios.
- **Part III**: *Level of Satisfaction* - This section included 15 items adapted from the SCL Scale to measure satisfaction with DR-SBL. Using the same Likert scale as Parts II-A and II-B, satisfaction levels were categorized as "highly satisfied" (3.68–5.00), "moderately satisfied" (2.34–3.67), and "poorly satisfied" (1.00–2.33). The questions assessed aspects like teaching methods, content mastery, and motivation.

The questionnaire was validated for face and content validity by experts in nursing research and education. Reliability testing was conducted through a pilot study with 30 Level III nursing students, yielding strong internal consistency with Cronbach [41] Alpha reliability values ranging from .73 to .95 across all domains. These results confirmed the questionnaire's reliability for evaluating competence and satisfaction [38]. Typical values of above .60 is considered adequate and acceptable [42].

Additionally, the instrument aligned with ***Kolb's Experiential Learning Theory*** by linking its phases to specific questionnaire items:

- **Concrete Experience**: Questions focused on skills and knowledge acquisition in simulation scenarios.
- **Reflective Observation**: Questions evaluated the effectiveness of teaching methods and materials.
- **Abstract Conceptualization**: Questions addressed critical reflection and mastery of content.
- **Active Experimentation**: Items from Parts II-A and II-B measured the application of learned competencies.

The final questionnaire was administered via Google Forms to ensure convenience and accessibility for participants.

4 Results and Discussion

4.1 Perceived Competence with the Intrapartal Care of DR-SBL

Table 1 showcases the perceived competence levels of Level IV student nurses in intrapartal care using DR-SBL. Overall, the students rated themselves as "*highly competent*," with an average score of 4.43 ($SD = 0.44$), consistently high across various domains. The highest mean score was observed in *Management of Resources, Environment, and Equipment* ($M = 4.58$, $SD = 0.48$), reflecting strong confidence in tasks such as preparing the delivery room, handling instruments, maintaining a sterile environment, adhering to safety protocols, and efficiently managing post-care procedures. This heightened competence is attributed to the immersive and hands-on nature of DR-SBL, which provides students with comprehensive training in resource management and safe healthcare practices. Other domains such as *Legal and Ethico-Moral Responsibilities* ($M = 4.52$), *Personal and Professional Development* ($M = 4.49$), and *Health Education* ($M = 4.45$) also received high ratings, further demonstrating the consistent effectiveness of DR-SBL in cultivating critical nursing skills.

Table 1. Perceived competence with the intrapartal care of DR-SBL.

Factors (α reliability)	Mean	SD	Description
Management of Resources, Environment and Equipment (.92)	4.58	0.478	Highly Competent
Legal and Ethico-moral Responsibility (.73)	4.52	0.520	Highly Competent
Personal and Professional Development (.89)	4.49	0.497	Highly Competent
Health Education (.83)	4.45	0.573	Highly Competent
Communication, Collaboration, and Teamwork (.88)	4.43	0.602	Highly Competent
Functions during Actual Labor (.91)	4.38	0.497	Highly Competent
Quality Improvement, Research, and Records Management (.95)	4.37	0.531	Highly Competent
Safety and Quality Nursing Care (.86)	4.26	0.597	Highly Competent
Overall	4.43	0.442	Highly Competent

Note. $N = 143$, SD = standard deviation. The description was based on the indicated scale. Highly competent (3.68–5.00), moderately competent (2.34–3.67), poorly competent (1.00–2.33).

While all domains were rated highly, *Safety and Quality Nursing Care* scored comparatively lower ($M = 4.26$). This highlights a potential limitation in DR-SBL's ability to fully replicate the complexities of ensuring patient safety and delivering top-quality care in real-world scenarios. Students' self-assessed competence in this domain may reflect the inherent challenges of simulating such nuanced aspects of nursing care. These findings align with prior research [5, 43, 44], which all noted the broader benefits of using

SBL, including improved self-confidence, cognitive processing, and practical engagement. While these self-assessments provide valuable insights into students' perceptions, objective measures and external evaluations are crucial to validate and complement their self-reported competencies, ensuring a holistic understanding of their preparedness for clinical practice.

4.2 Perceived Competence with the Immediate Newborn Care of DR-SBL

Table 2 showcases the perceived competence of Level IV student nurses in immediate newborn care through DR-SBL. The students rated themselves as "*highly competent*," with an overall mean score of 4.53 ($SD = 0.45$), indicating a consistently high level of self-assessed competence across various domains. Key competencies included *Safety and Quality Nursing Care* ($M = 4.56$, $SD = 0.51$), *Management of Resources, Environment, and Equipment* ($M = 4.64$, $SD = 0.47$), *Health Education* ($M = 4.51$, $SD = 0.50$), *Legal and Ethico-Moral Responsibilities* ($M = 4.57$, $SD = 0.48$), *Quality Improvement, Research, and Records Management* ($M = 4.37$, $SD = 0.58$), and *Communication, Collaboration, and Teamwork* ($M = 4.53$, $SD = 0.56$). The low standard deviation values across domains signify consistent confidence among students in their abilities.

Table 2. Perceived competence with the immediate newborn care of DR-SBL.

Factors (α reliability)	Mean	SD	Description
Management of Resources, Environment and Equipment (.93)	4.64	0.467	Highly Competent
Legal and Ethico-moral Responsibility (.84)	4.57	0.476	Highly Competent
Communication, Collaboration, and Teamwork (.82)	4.53	0.505	Highly Competent
Health Education (.91)	4.51	0.495	Highly Competent
Quality Improvement, Research, and Records Management (.86)	4.37	0.579	Highly Competent
Safety and Quality Nursing Care (.93)	4.56	0.505	Highly Competent
Overall	4.53	0.454	Highly Competent

Note. $N = 143$, SD = standard deviation. The description was based on the indicated scale. Highly Competent (3.68–5.00), Moderately Competent (2.34–3.67), and Poorly Competent (1.00–2.33).

Among the assessed competencies, the highest mean score was observed in the *Management of Resources, Environment, and Equipment* ($M = 4.64$, $SD = 0.47$), reflecting students' confidence in maintaining a well-organized and resource-efficient environment for newborn care. However, the relatively lower score for *Quality Improvement, Research, and Records Management* ($M = 4.37$, $SD = 0.58$) suggests potential areas for enhancement, underscoring the need for targeted interventions to strengthen competence in these aspects. These findings emphasize the importance of continuous evaluation and

adaptation of DR-SBL programs to ensure holistic development across all competencies. The results align with previous studies wherein findings consistently demonstrate that DR-SBL enhances critical skills, including problem-solving, communication, leadership, and delegation. These skills are essential for providing effective and safe newborn care. The alignment between this study's findings and existing literature reaffirms the effectiveness of DR-SBL in preparing nursing students for the complexities of real-world clinical environments, fostering both their confidence and competence in immediate newborn care.

4.3 Competence, Satisfaction, and Gender Inclusivity in DR-SBL

Level IV student nurses expressed a high level of satisfaction with their experiences in DR-SBL, categorizing their engagement as "*highly satisfied*." This satisfaction can be attributed to DR-SBL's unique ability to bridge the gap between theoretical knowledge and practical application. By providing a controlled and iterative environment, DR-SBL enables students to refine their skills, boosting their confidence and competence. Furthermore, its holistic approach addresses clinical skills, critical thinking, communication, and teamwork, aligning seamlessly with the multifaceted requirements of nursing education. This comprehensive framework enhances students' learning experiences and fosters a positive perception of DR-SBL as an effective educational tool.

Analysis of gender differences revealed **no significant** disparities in perceived competence or satisfaction levels among male and female students. This suggests that DR-SBL offers an equitable learning environment, supporting all participants regardless of gender. Both male and female students reported similar levels of competence and satisfaction, highlighting DR-SBL's inclusivity and ability to provide consistent learning experiences across diverse student groups. The absence of significant gender-based differences underscores the program's success in fostering a supportive environment that promotes diversity and equity within nursing education.

Strong positive correlations were identified between *perceived competence* and *satisfaction*, emphasizing the role of self-assurance in enhancing the learning experience. Specifically, Spearman's rho revealed a significant correlation between competence in intrapartal care and satisfaction ($\rho = .672, p < .001$), as well as between competence in immediate newborn care and satisfaction ($\rho = .641, p < .001$). These values underscore that students who feel more competent are also more satisfied with DR-SBL, creating a positive feedback loop that reinforces learning and professional growth. This alignment with previous research highlights the value of DR-SBL in fostering critical nursing skills, confidence, and readiness for real-world clinical practice.

5 Conclusions, Implications, and Recommendations

5.1 Conclusion

The current study highlighted that DR-SBL plays a crucial role in enhancing the perceived competence and satisfaction of Level IV student nurses. Findings revealed a strong positive relationship between perceived competence and satisfaction, demonstrating that as students develop greater self-assessed competence in intrapartal and

immediate newborn care, their satisfaction with the learning process increases. This underscores the importance of simulation-based learning in bridging the gap between theoretical knowledge and practical application, enabling students to refine their clinical skills in a structured, controlled, and immersive environment. DR-SBL not only enhances students' technical abilities but also fosters critical thinking, decision-making, teamwork, and communication skills, which are vital for real-world nursing practice.

Moreover, this study reinforced Kolb's Experiential Learning Cycle as an effective framework for guiding simulation-based education. Kolb's model emphasizes the interplay of experience, reflection, conceptualization, and experimentation, making it an ideal fit for DR-SBL, where students actively engage in hands-on learning, critically reflect on their experiences, and apply newly acquired knowledge to clinical situations. While this study focused on nursing education, its implications extend beyond this field. The alignment between Kolb's framework and DR-SBL suggests that similar experiential learning models can be applied in other healthcare disciplines and professional education settings that require skill mastery through practical engagement. This strengthens the argument that experiential learning, when effectively implemented, can enhance learner engagement, competence, and overall satisfaction across a variety of fields.

5.2 Limitations and Future Directions

Despite the promising results, this study has several limitations. First, the research was conducted within a single institution, which may limit the generalizability of findings to other nursing programs and healthcare settings. Expanding future research to multiple institutions with diverse student populations and educational environments could provide a broader understanding of DR-SBL's effectiveness. Second, the study relied solely on quantitative data, capturing only numerical self-assessments of competence and satisfaction. Incorporating qualitative feedback from students through focus groups or interviews would provide deeper insights into their learning experiences, challenges, and recommendations for improvement. Third, technological limitations within the simulation environment may have affected the depth of students' learning experiences. Since high-fidelity simulation models cannot fully replicate the complexity and unpredictability of real-life clinical scenarios, future research could explore the integration of advanced technologies, such as artificial intelligence (AI) and virtual reality (VR), to enhance simulation realism.

Additionally, it is essential to consider country-specific factors when implementing DR-SBL, as variations in healthcare policies, resource availability, and cultural perspectives may influence how simulation-based learning is adopted and optimized. Comparative studies examining DR-SBL across different educational, economic, and cultural contexts could provide valuable insights into best practices and adaptation strategies. Addressing these limitations in future research would contribute to the continuous improvement of simulation-based learning methodologies, ensuring that nursing students worldwide receive high-quality, technologically advanced, and competency-based training that prepares them for the demands of modern healthcare practice.

5.3 Implications

For Theory: This study reinforces David A. Kolb's Experiential Learning Theory, which emphasizes learning through active participation and reflection. DR-SBL exemplifies Kolb's principles by immersing students in realistic, hands-on experiences that enhance competence in intrapartal and immediate newborn care. The observed positive correlation between perceived competence and satisfaction aligns with Kolb's cycle of experiential learning, fostering active engagement, reflection, and practical application. Furthermore, the inclusivity of DR-SBL, with no significant differences in outcomes based on gender, supports Kolb's assertion of holistic and equitable learning.

For Practice: The findings suggest that incorporating DR-SBL into healthcare education can create an immersive and effective learning environment, fostering higher satisfaction and better preparation for clinical practice. By offering realistic and inclusive simulation scenarios, nursing programs can bridge the gap between theory and practice while ensuring equitable learning opportunities. This approach equips students with the necessary skills to excel in real-world scenarios, ultimately contributing to improved patient care.

5.4 Recommendations

To further enhance the effectiveness of DR-SBL, it is recommended that nursing education institutions integrate additional simulation activities into their curricula, particularly those focused on intrapartal care and immediate newborn care. These activities should aim to provide students with valuable hands-on experiences, bridging the gap between theoretical knowledge and clinical application. Clinical instructors should be offered training and professional development opportunities to refine their skills in delivering effective DR-SBL, ensuring consistent quality and alignment with the positive learning outcomes highlighted in this study.

The Commission on Higher Education and other academic institutions are also encouraged to promote the inclusion of SBL methodologies within nursing education guidelines. Resources should be allocated to support the acquisition of simulation equipment, establishment of training programs, and facilitation of continuous evaluation efforts to ensure the sustainability of DR-SBL initiatives. Given the observed high levels of competence and satisfaction, institutions are urged to prioritize investments in simulation-based technologies and methodologies to enhance the overall quality of nursing education.

Future researchers should also consider conducting studies across diverse demographics, educational settings, and cultural contexts to validate the universality of the findings. Longitudinal studies could also provide insights into the sustainability of the positive correlation between perceived competence and satisfaction over time, offering a clearer understanding of their impact on students' long-term career trajectories. Mixed-method approaches combining quantitative data with qualitative insights may yield a more comprehensive understanding of the factors contributing to competence and satisfaction. Additionally, comparative analyses of DR-SBL and other teaching methodologies could further elucidate its unique contributions to nursing education.

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Enhancing Sustainability Practices in Higher Education Through Knowledge Management Methodologies

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Abstract. Universities over the years have address the need to incorporate and adapt their practices for the current society needs, one of the lates common global issues is related with sustainability, then how to incorporate these practices on a practical bases in university campuses. Challenges for smaller universities are higher, also the influence of sustainability is emerging as an important factor in student decision-making for their studies, according to the QS Student Pulse survey 79% of students felt that it was very important that universities reduce their environmental impact and should be concerned with sustainability (QS Student Survey 2022).

This paper is related to the exploration of the use of a SECI model approach for enhancing best sustainability practices specially in smaller size universities comparing students' sentiments and perspectives regarding general sustainability aspects in two European universities. The study compares different practices and use a Knowledge Management approach to suggest implementation steps to enhance the sustainability practices at universities. Most common practices are identified, and some practical recommendations and experiences are discussed. In general, the perception of students was not has positive has anticipated and improving opportunities were identified. This paper is intended has a first discussion.

Keywords: Sustainability practices · SDGs · University Rankings · Knowledge transfer

1 Introduction

1.1 About Sustainability in Higher Education

Sustainability has gradually become a core component of higher education, driven many trends like global awareness of environmental, social, and economic challenges and impact, governments and society have been more aware and more demanding this has

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resonated in higher education. Sustainability has been a matter of thoughts and work since late 16 hundreds, in 1856 Eunice Newton Foote wrote a paper about greenhouse gasses that was read during the AAAS conference by Joseph Henry of the Smithsonian. Foote demonstrated that carbon dioxide is a greenhouse gas and suggested that it would lead to a warmer earth if the atmosphere continued to accumulate CO2 (Jeosse 2023). During the 70s there was early environmental awareness in the world such has the first global conference on environment in (un.org 1972), during the 80s the foundations of sustainability in education were implemented such as the Tallories declaration leaded by Jean Mayer president of Tuff university where 20 president universities committed to sustainability in higher education (ULSF.org 2024) now more than 500 higher education presidents have signed, by the 90s universities participated in a stage of global frameworks and collaboration, with the earth summit in Rio de Janeiro Brazil in 1992.

In the current century some universities started to institutionalized sustainability and more collaboration was done (OECD 2001), but only by 2015 with the UN sustainable development goals (OECD 2016) and 2016 the Paris agreement, and the rise of sustainable campuses and sustainable rankings greenmetrics university rankings in 2011 (Greenmetrics 2024) and the Times Higher Education impact ranking in 2019 (THE 2024). During this decade, the 2020s we had the enormous impact of Covid 19, and many sustainability advances in Higher Education such as Focus on SDGs in curricula, with the increasingly incorporation offer of interdisciplinary programs and courses explicitly tied to sustainability, circular economy and SDGs (Van Kruchten S. and Van Eijk F. 2020), there has been a more sustainable Campus Operations in many aspects, CO2 emission controls, sustainable plans, use of sustainable energy, saving water, recycling programs, net-zero energy buildings, sustainable food systems, and waste reduction initiatives became benchmarks of institutional commitment, also partnerships and global university rankings participation such as Times Higher Education Impact Rankings that evaluates universities based on their contributions to the SDGs (THE 2024) and by the end of 2022 QS University ranking has launched a new version of a Sustainable University rankings (TOP Universities 2025).

Almost 70 years later a lot has been done and we can with confidence declare that 2020s will be the years of Sustainable, circular economy and innovation in universities (Fig. 1).

Fig. 1. Sustainability model. (OECD 2001; Dalay Cleyton 1994)

1.2 About Sustainability Practices in Higher Education

Sustainability and Education

Education plays a pivotal role in increasing public awareness and understanding of the Circular Economy, demanding the acquisition of new skills and knowledge (European Environment Agency 2016). So, through education, individuals gain awareness about the significance of sustainable practices, enabling them to make informed choices in daily life. Learning opportunities extend to the development of skills related to waste management, eco-design, and the principles of a circular economy. Moreover, education empowers consumers to support businesses aligned with sustainable values. It acts as a catalyst for innovation and entrepreneurship, encouraging the creation of products and business models that prioritize environmental responsibility (Toman and Harris 2023).

1.3 United Nations Sustainable Development Goals (SDGs)

When discussing sustainability and the circular economy, it is important to have a firm understanding of the UN Sustainable Development Goals (SDGs). According to an article by sight savers (n.d.) Sustainable development goals were outlined by the UN in 2015 and Sustainable Development Goals (SDGs) aim to eradicate extreme poverty, improve healthcare for all, and promote gender equality.

Furthermore, According to United Nations Department of Economic and Social Affairs (n.d.), the SDGs are a set of 17 global goals adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet, and ensure that

Table 1. SDG goals (own elaboration, Toman and Harris 2023)

Goal	Title	What It's About	Key Indicators	Specific Goals
1	No Poverty	End poverty in all its forms everywhere	Poverty headcount ratio, social protection coverage	Reduce extreme poverty to below 3% by 2030
2	Zero Hunger	End hunger, achieve food security, and promote agriculture	Prevalence of undernourishment, food production	End malnutrition and double agricultural productivity
3	Good Health and Well-being	Ensure healthy lives and promote well-being	Infant mortality rate, universal health coverage	Reduce maternal and child mortality, combat epidemics
4	Quality Education	Ensure inclusive and equitable quality education	Literacy rates, school enrollment rates	Ensure free primary and secondary education for all
5	Gender Equality	Achieve gender equality and empower all women and girls	Women in leadership roles, gender pay gap	Eliminate gender-based discrimination and violence
6	Clean Water and Sanitation	Ensure availability and sustainable management of water	Access to clean water and sanitation	Provide universal access to safe drinking water
7	Affordable and Clean Energy	Ensure access to affordable, reliable, and sustainable energy	Renewable energy share, energy efficiency	Increase renewable energy share globally
8	Decent Work and Economic Growth	Promote sustainable economic growth and employment	Unemployment rate, GDP growth	Achieve higher levels of economic productivity
9	Industry, Innovation, and Infrastructure	Build resilient infrastructure and promote innovation	Investment in R&D, access to financial services	Increase research and technology infrastructure
10	Reduced Inequalities	Reduce income inequality within and among countries	Income distribution, social protection policies	Ensure equal opportunities and reduce disparities
11	Sustainable Cities and Communities	Make cities inclusive, safe, resilient, and sustainable	Urban population in slums, air pollution levels	Improve urban planning and housing accessibility
12	Responsible Consumption and Production	Ensure sustainable consumption and production patterns	Waste management, carbon footprint	Reduce waste generation and promote recycling
13	Climate Action	Take urgent action to combat climate change	CO2 emissions, climate resilience policies	Strengthen climate resilience and reduce carbon emissions
14	Life Below Water	Conserve and sustainably use the oceans and marine resources	Marine pollution levels, protected marine areas	Reduce marine pollution and regulate fishing
15	Life on Land	Protect, restore, and promote sustainable ecosystems	Deforestation rate, biodiversity loss	Halt deforestation and protect endangered species
16	Peace, Justice, and Strong Institutions	Promote peaceful and inclusive societies	Corruption index, human rights violations	Reduce violence, ensure access to justice
17	Partnerships for the Goals	Strengthen global partnerships for sustainable development	Foreign aid, technology transfer	Increase international cooperation and resource mobilization

all people enjoy peace and prosperity by 2030. The goals are integrated, recognizing that action in one area will affect outcomes in others, and that development must balance social, economic, and environmental sustainability. (United Nations Department of Economic and Social Affairs, n.d.) They tackle a range of pressing global issues, including widespread destitution, unfair distribution of re-sources, climate instability, environmental destruction, maintaining peace, and upholding justice (Toman and Harris 2023; Caporello and Kumar 2023) (Table 1).

2 Sustainable practices in Higher Education

The research questions for this paper are about what the current perceptions of students regarding sustainability practices in Universities are, what are the most common sustainability practices in higher education nowadays, how does practices compare among two small size universities in Europe and how can we improve and enhance the practices. Usually, small universities are in the range of less than 5.000 students, mid sizes are from 5.000 to 15.000, large sizes from 15.000 to 30.000 and very large have more than 30,000.

2.1 Most Sustainable Practices in Universities in the World

Some of the main related aspects of sustainability in higher education are categorized on these seven groups, their elements and examples are shown in Tables 4 and 5:

Sustainability on the Curriculum
Research related to Sustainability
Sustainable Campus Operations
Community Engagement and Partnerships
Tracking and Reporting Impact
Governance
Sustainable entrepreneurship and Innovation

Engage with SDGs embedding SDGs in Curriculum however we will realize that in small universities is not done so well, so there are still opportunities and challenges on how to integrate SDGs into their curricula.

2.2 Research Related to Sustainability.

Many research has been done related to SDGs objectives and now Scopus offers an option to identify research papers to specific SDGs (Fig. 2), the most addressed SDGs in research right now are: Good health and wellbeing (SDG 3), Sustainable energy (SDG 7), Industry, Innovation and infrastructure (SDG 9), Sustainable Cities and communities (SDG 11) and partnership for the goals (SDG17).

In table number 2 we can see the research papers classified by sustainability goals and could identify what are the most relevant in research for selected universities with the total number of papers for a specific SDG and the percentage of the total papers.

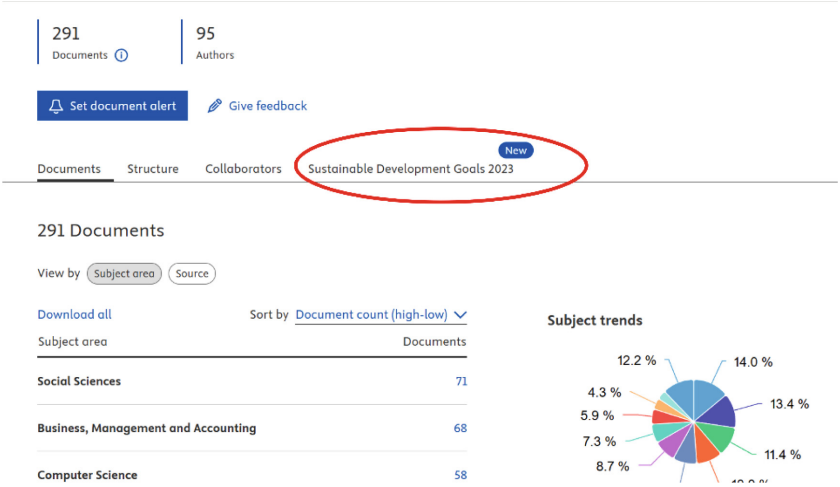

Fig. 2. Scopus new functionality for classifying research indexed papers related to SDGs

Table 2. SDGs related papers in different small and large size Universities. Own elaboration.

SDG	Seinajoki	Aschaffenburg	Flensburg	USM	Trento	Granada	Total	%
Goal 1: No poverty	3	-	1	29	193	357	583	1,3 %
Goal 2: Zero hunger	4	1	2	84	300	647	1 038	2,3 %
Goal 3: Good health and well-being	23	25	16	248	2 106	8 773	11 191	25,2 %
Goal 4: Quality education	27	16	2	70	413	1 812	2 340	5,3 %
Goal 5: Gender equality	3	-	1	21	224	1 138	1 387	3,1 %
Goal 6: Clean water and sanitation	1	-	4	178	413	1 508	2 104	4,7 %
Goal 7: Affordable and clean energy	11	27	99	856	1 361	1 329	3 683	8,3 %
Goal 8: Decent work and economic growth	11	1	7	119	696	1 067	1 901	4,3 %
Goal 9: Industry, innovation and infrastructure	19	76	36	271	1 024	1 239	2 665	6,0 %
Goal 10: Reduced inequalities	2	3	4	55	617	1 051	1 732	3,9 %
Goal 11: Sustainable cities and communities	2	23	3	303	1 030	1 956	3 317	7,5 %
Goal 12: Responsible consumption and produc	6	7	24	156	642	1 095	1 930	4,4 %
Goal 13: Climate action	4	2	11	128	426	921	1 492	3,4 %
Goal 14: Life below water	1	-	5	70	82	769	927	2,1 %
Goal 15: Life on land	5	-	1	88	421	1 081	1 596	3,6 %
Goal 16: Peace, justice and strong institutions	3	-	1	51	630	1 295	1 980	4,5 %
Goal 17: Partnership for the goals	10	6	25	692	898	2 860	4 491	10,1 %
TOTAL	135	187	242	3 419	11 476	28 898	44 357	

Regarding how many of the research papers of universities could be related to sustainability goals, for small universities the range is 38% to 47% of the total papers, in the case of large universities 26% to 28%. In the universities in Table 2, three small universities were considered, two large universities and one very large university, the period for the papers.

Sustainable Campus Operations

Universities use their campuses as living laboratories to model sustainability, addressing goals like:

Renewable energy use and carbon neutrality (SDG 7 and 13).
Water conservation and waste reduction (SDG 6 and 12).

Green buildings and biodiversity initiatives (SDG 11 and 15).

Community Engagement and Partnerships

Universities engage with local and global communities to promote SDGs through:

Volunteering programs and outreach projects targeting education (SDG 4), hunger (SDG 2), and health (SDG 3). Partnerships with governments, industries, and NGOs to work collaboratively on SDG-related initiatives.

2.3 Tracking and Reporting Sustainability Impact in Global Rankings

Many universities align their strategies with the SDGs and report progress in sustainability impact rankings, such as: Times Higher Education (THE) Impact Rankings: Measures university contributions to the SDGs. Sustainable Campus Network metrics, their characteristics are on Table 3.

Institutions use these frameworks to benchmark their progress and showcase their commitment to sustainability.

Universities usually do an annual sustainability report and have some own indicators about their sustainability advances, this metrics are very different and there is no standards available other than the rankings but usually the topics that are mentioned in reports are Carbon footprint (CO_2 emissions per student or per campus area), water consumption & wastewater management indicators, energy efficiency & renewable energy usage and waste management & recycling rates. Sometimes they also develop some indicators about sustainable transportation (e.g., bike-friendly, electric vehicles, public transport use).

Table 3. Sustainability rankings indicators (Own elaboration)

Aspect	THE Impact Rankings	UI GreenMetric Ranking	QS Sustainability Rankings
Purpose	Measures universities' contributions to the UN Sustainable Development Goals (SDGs) based on research, outreach, and stewardship	Evaluates universities' commitment to sustainability in campus management, environmental impact, and education	Assesses universities' environmental and social sustainability efforts, including impact on graduates and communities
Focus Areas	17 SDGs, with specific metrics for each (e.g., climate action, quality education, gender equality, etc.)	Six broad areas: infrastructure, energy and climate change, waste management, water usage, transportation, and education	Two dimensions: Environmental Impact (e.g., sustainable operations, research) and Social Impact (e.g., equality and employability)

(*continued*)

Table 3. (*continued*)

Aspect	THE Impact Rankings	UI GreenMetric Ranking	QS Sustainability Rankings
Metrics	– Each SDG has its own metrics (e.g., research publications, policies, outreach)	– Quantitative indicators such as % of green spaces, energy efficiency, water conservation, and waste recycling	– Combines performance on environmental and social metrics, with weight given to employability and graduate impact
Data Sources	– Self-reported data submitted by universities, supported by publicly available information	– Questionnaire-based self-reporting by universities	– Publicly available data and submissions by universities
Scoring and Weighting	– Weighted across different SDGs, with universities choosing a minimum of 4 SDGs for submission (including SDG 17, Partnerships for Goals)	– Equal weighting of six broad categories with a total score out of 10,000 points	– Environmental (50%) and Social Impact (50%), with sub-categories weighted according to priority metrics
Environmental Factors	Indirectly through SDG metrics (e.g., SDG 13 Climate Action, SDG 12 Responsible Consumption).	Significant emphasis on campus sustainability (e.g., energy use, green spaces, transportation systems)	Direct focus, including sustainable infrastructure, emissions reduction, and renewable energy use
Social Factors	Strong emphasis on social aspects like quality education (SDG 4), gender equality (SDG 5), and reduced inequalities (SDG 10)	Limited social focus; primarily environmental and educational	Balanced focus on social factors such as employability, equity, and diversity
Geographical Coverage	Global, inclusive of diverse universities of all sizes and locations	Global, but participants tend to be universities actively focused on environmental practices	Global, with an emphasis on leading institutions in sustainability and student employability outcomes

(*continued*)

Table 3. (*continued*)

Aspect	THE Impact Rankings	UI GreenMetric Ranking	QS Sustainability Rankings
Strengths	– Alignment with the UN SDGs provides a comprehensive framework for assessing universities' broader societal impact	– Focuses specifically on operational sustainability and environmental practices on campuses	-Combines environmental and social dimensions, providing a holistic view of sustainability in higher education.
Criticisms	– Relies on self-reported data, which can vary in reliability and quality	– Heavy reliance on self-reported data; limited focus on social impact beyond education	– Weighting may favor wealthier universities with better infrastructure for reporting and investment
Examples of Ranked Universities	– University of Auckland (New Zealand), University of Manchester (UK), University of Sydney (Australia)	– Wageningen University (Netherlands), University of Indonesia, University of Nottingham (UK)	– Stanford University (USA), University of Edinburgh (UK), University of British Columbia (Canada)

2.4 Sustainability Practices in Aschaffenburg University and Seamk University

Aschaffenburg University of applied Sciences.

Aschaffenburg University of Applied Sciences (TH AB) has been commitment to sustainability through various initiatives, one of the most important initiatives is its Green Office that was established to promote sustainable development within the university, the Green Office is a collaborative effort among students and staff. It supports, coordinates, and implements sustainable projects, serving as the primary contact point for sustainability-related inquiries and ideas.

- Established a green office that conducted a survey among students in 2021 and started a lot of initiatives based on that. Among them are:

Campus gardening. Students can plant their own vegetables and fruit on the campus
Campus bee-keeping together with planting a natural flora with a variety of wild blossoms.
Development of a green mobility concept, with more facilities to park and maintain bicycles
Development of a clear concept of waste separation together with the installation of suitable trash bins over the campus

Table 4. Some common sustainability practices in universities. (Source: own elaboration)

University Name	Country	Sustainability Practices	Number of Students	Sustainability Programs/ Courses	Sustainability Website
Aschaffenburg University of Applied Sciences	Germany	Emphasizes energy efficiency, sustainable construction, and green technologies.	3 200	Provides courses in Renewable Energy, Sustainable Building Design, and Environmental Engineering.	https://www.th-ab.de/en/education/facilities/green-office
Seinäjoki University of Applied Sciences	Finland	Focuses on sustainable food production, renewable energy, and sustainable business practices.	5 000	Offers programs in Sustainable Food Systems, Energy Technology, and International Business with a sustainability focus.	https://www.seamk.fi/en/aboutus/operating-methods-and-principles/sustainability/
Deggendorf Institute of Technology	Germany	Focuses on green campus initiatives, energy-efficient buildings, and renewable energy technologies, with research in sustainable mobility and environmental protection.	8 000	Provides programs in Sustainable Energy Systems, Environmental Engineering, and Green Technologies.	Sustainability at DIT
Mendel University in Brno	Check R	Strong focus on sustainability through the "Year of Sustainability" initiative, renewable energy research, and Corporate Social Responsibility (CSR) activities.	8 300	Offers programs like Environmental Management, Renewable Energy, and Sustainable Engineering.	Sustainability at Mendel
Massachusetts Institute of Technology (MIT)	USA	Focuses on sustainable campus initiatives, energy efficiency, and offers a wide range of sustainability courses and programs.	11 500	Provides over 60 sustainability courses institute-wide through the MIT Sloan Sustainability Initiative	https://sustainability.mit.edu/
Wageningen University & Research	Netherland	Ranked first in the UI GreenMetric World University Rankings for multiple years; focuses on sustainable agriculture, food production, and environmental health.	12 000	Offers a range of sustainability-related programs, including Environmental Sciences, Organic Agriculture, and Climate Studies.	https://www.wur.nl/en/about-wur/sustainability.htm
University of Eastern Finland	Finland	Integrates sustainability into research and education, focusing on environmental science, forestry, and health.	15 500	Offers programs in Environmental Science, Forestry, and Public Health with sustainability components.	Sustainability at UEF
University of Trento	Italy	Focuses on sustainable development, renewable energy research, and ecological innovation.	16 000	Offers programs in Environmental Engineering, Sustainable Energy, and Innovation Management.	Sustainability at UniTrento
Universidad Federico Santa María	Chile	Focuses on energy efficiency, sustainable construction, and renewable energy research.	18000	Offers courses in Renewable Energy, Sustainable Engineering, and Environmental Management.	
University of Bremen	Germany	Engages in marine research, climate change studies, and promotes sustainable campus management.	19 000	Offers programs in Environmental Physics, Marine Biology, and Sustainability Economics.	Sustainability at Uni Bremen
Aalborg University	Denmark	Integrates environmental, financial, and social sustainability at all levels; offers programs focusing on urban planning, energy, and environmental management.	20 000	Offers master's programs in Environmental Management and Sustainability Science and Cities and sustainability	https://www.en.aau.dk/about-aau/profile/sustainability?utm_source=chatgpt.com
University of Helsinki	Finland	Integrates sustainability across disciplines, focusing on climate research, biodiversity, and sustainable urban development.	31 000	Provides courses in Environmental Change and Global Sustainability, Urban Studies, and Ecology.	Sustainability at UH
University of Tasmania	Australia	Achieved carbon neutrality since 2016; excels in climate action, life on land, and life below water initiatives.	34 000	Provides courses in Environmental Management, Marine and Antarctic Science, and Sustainability.	Sustainability at UTAS
University of California, Davis	USA	Recognized for sustainable transportation programs, energy efficiency, waste reduction, and sustainable agriculture research.	39 000	Offers programs like Sustainable Agriculture and Food Systems, Environmental Policy Analysis, and Energy Efficiency courses.	UC Davis Sustainability
University of Hamburg	Germany	Committed to climate protection, sustainable campus operations, and interdisciplinary sustainability research.	42 000	Provides courses in Environmental Studies, Climate Science, and Sustainable Economics.	Sustainability at Uni Hamburg
University of Nottingham	United kingdom	Implements comprehensive sustainability strategies, including carbon management plans, sustainable campus initiatives, and integration of sustainability into curricula.	45 000	Provides various courses such as Environmental Science, Sustainable Energy Engineering, and Environmental Management.	Sustainability at Nottingham
Western Sydney University	Australia	Ranked first globally in the Times Higher Education Impact Rankings for three consecutive years; focuses on gender equity, responsible consumption, and life on land.	48 000	Offers programs such as Sustainable Agriculture and Food Security, Environmental Health, and Urban Planning.	Sustainability at WSU
University of Granada	Spain	Implements sustainable campus initiatives, waste reduction, and promotes environmental education.	60 000	Provides courses in Environmental Sciences, Sustainable Architecture, and Ecology.	Sustainability at UGR
Arizona State University	USA	Established the School of Sustainability; requires all incoming students to take a sustainability course; leads research in carbon capture, water security, and renewable energy.	74 000	Offers a wide variety of courses focused on sustainability, including degrees in Sustainability and related fields.	ASU Sustainability
University of Toronto	Canada	Nearly 30% of undergraduate courses have a sustainability orientation; offers over 100 graduate and PhD programs with sustainability content.	93 000	Provides a multitude of sustainability-oriented courses across various departments.	Sustainability at U of T

Social sustainability fostered, particularly through the women's office:

High quota of female professors, also in technical programs. Active programs to motivate women to make their PhD and to apply for professorships. E.g. by offering coached simulations of recruiting events.
Many initiatives to motivate females to study MINT programs. E.g. frequently offered workshops in robot programming for girls.
(Re-)certified as family friendly campus
Yearly organization of diversity days, to fight discrimination

Seinajoki University of applied Sciences.

Seinäjoki University of Applied Sciences (SeAMK) in Finland is committed to sustainability through various initiatives:

Emphasizes sustainable development research and collaborates on the European Universities Alliance HEROES promoting this research among the members.
Integration of sustainable development and circular economy into the Business and Engineering curricula with a minor specialization.
International Sustainability Rankings: SeAMK participates in international sustainability assessments, such as the UI GreenMetric World University Ranking (408 rank), and the THE sustainability impact ranking (1.001 to 1500 rank).
Sustainability committee in charge of coordinating and promoting sustainability efforts with representatives of many departments and areas.
Research group specialized in Sustainability and Circular Economy.

In Table 4th the most common sustainability practices in Universities are indicated.

3 Enhancing Practices and Students' Perceptions

3.1 The SECI Model

In order to enhance the process of sustainability and SDGs adoption in universities, we proposed a simple Knowledge Management approach by using an initial SECI model approach for knowledge acquisition and transfer. The SECI model was selected since is one of the fundamental models in Knowledge Management theory (Baskerville R, Dulipovici A. 2006). And is easier to implement than other models like Inukshuk model at an early stage (Girard J. 2005; Medina V.H., Angulo L., Medina L. 2024).

Our approach is based on the SECI Model as can be seen on Fig. 2, consist of applying the model to transfer Knowledge through a sequence of tacit and explicit processes involving socialization, externalization, combination and internalization.

The first one, **Socialization**, is about an informal sharing of experience (e.g. between master and apprentice), for this process a general survey was conducted among current students to identify general knowledge and perceptions. Also, a diagnostic process was aimed in terms of sharing and basic information that was used for participating in one of the sustainability impact rankings.

During this stage we evaluated the general knowledge of students in these matters and if it was acquired on the university or somewhere else, the general knowledge of

concepts and policies were prompted in order to have a general diagnostic, general material or contents about Sustainability and Circular economy were reviewed.

The second key process in the model, **Externalization**, is about the formalization of tacit knowledge, here a series of interviews were conducted, the interviews helped to identify documents posted, and general process related to the Sustainability and Circular economy practices at the universities, usually the Green Office or Sustainability committee are in charge of initiatives. In this case the results of the surveys interviews were built into a first report on Sustainability, a list of policies, and general information was gathered, then was used on the submission of the Times Higher Education Sustainability Impact Ranking for Seamk university. A Web Site regarding sustainability was updated in order to connect the academic and students' community and share some of the findings and information.

The third process in the SECI model implemented was **Combination**, related to the construction of explicit knowledge from tacit knowledge, a series of practices were identified, and a series of surveys with the participation of more than 100 students. If the university participates in rankings the data analysis is a good source of combination of knowledge related to practices. Some of the research could be incorporated to the curricula with the collaboration of researchers and academics.

The fourth one, **internalization**, is the transformation of explicit knowledge into tacit knowledge through the creation of a documents, information and practices, the idea is to implement an updated of important information, include courses in the curricula and formalize some initiatives among students. Later with the development of a public data base of general and important indicators and initiatives for the community.

There are many ways to incorporate or try to use Knowledge management in Universities, for several purposes, usually, the SECI models is considered for this (Medina García, V.H., González, F.V., Medina Estrada, L.M. 2021) (Fig. 3).

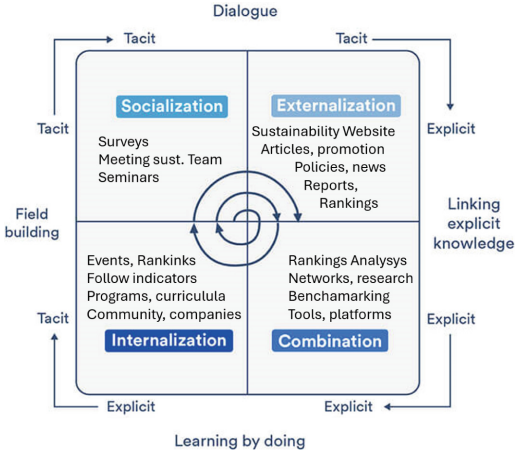

Fig. 3. "SECI MODEL for Enhancing Sustainability at Universities (own elaboration)

4 Findings and Discussion

Two studies were conducted among students at the University of Aschaffenburg and the University of Seinajoki with very similar questions. A total of 91 answers were collected from Aschaffenburg university, 56% on first year and the rest on second to four years at the University. For this study, we used a convenience sampling methodology to collect data, selecting participants based on their accessibility and willingness to respond.

Table 5. Sample general characteristics.

University Name	Country	Number of Students	Survey Sample	Female	Male	Other	First Generation
Aschaffenburg University of Applied Sciences	Germany	3 200	91	42,86 %	53,85 %	3,30 %	51,11 %
Seinäjoki University of Applied Sciences	Finland	5 000	87	59,26 %	59,26 %	1,85 %	42,59 %

4.1 Student Perceptions

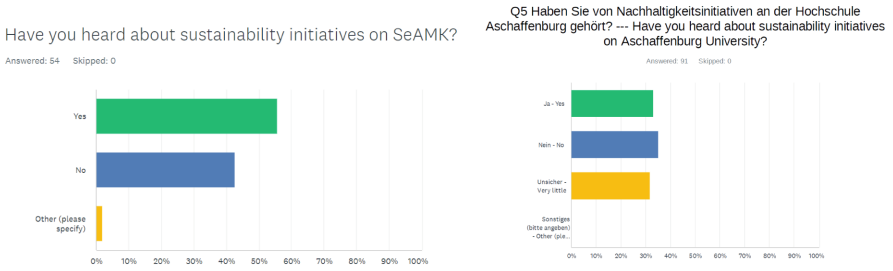

Fig. 4. Students knowledge of sustainability initiatives at the university (comparison)

In the case of SEAMK university the students know more about sustainability initiatives.

Since Seinäjoki University does participate in the Greenmetrics ranking and the Times Higher Education impact ranking, the general knowledge of this was also inquire with no real awareness of this participation by students (Figs. 4, 5, 6, 7, 8, 9, 10 and 11).

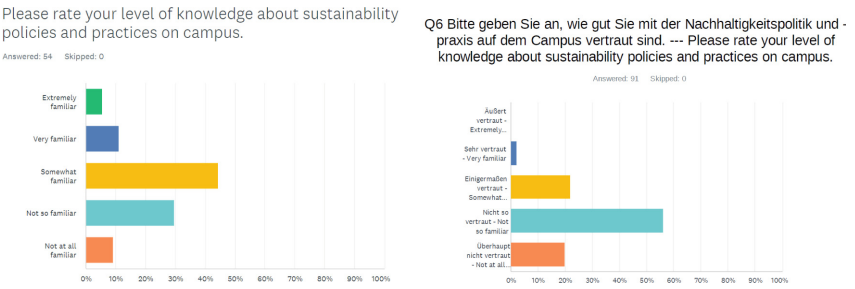

Fig. 5. Students' knowledge about sustainability policies and practices in campus.

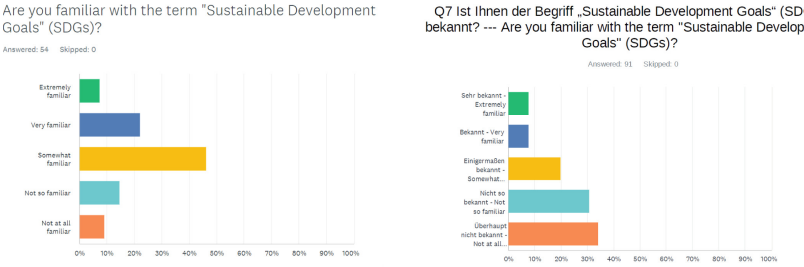

Fig. 6. Knowledge of SDGs goals students' perceptions

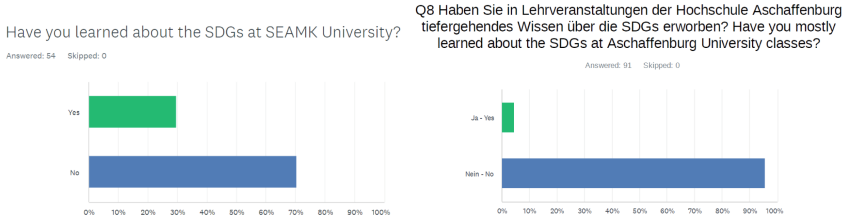

Fig. 7. Do the students learn about SDGs at the University.

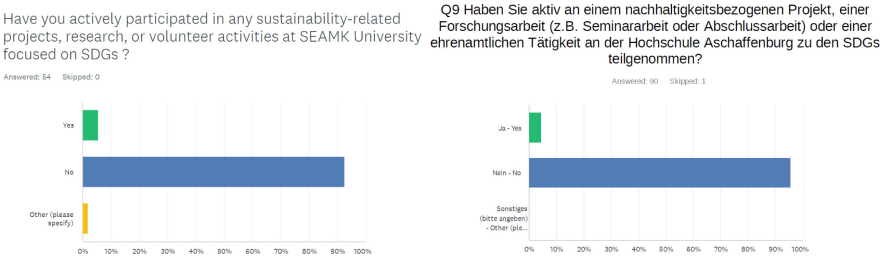

Fig. 8. Participation on sustainability projects at the University.

Seamk university has been using the SECI model approach at the University for longer and TH Aschaffenburg for less time, that may affect the general knowledge and

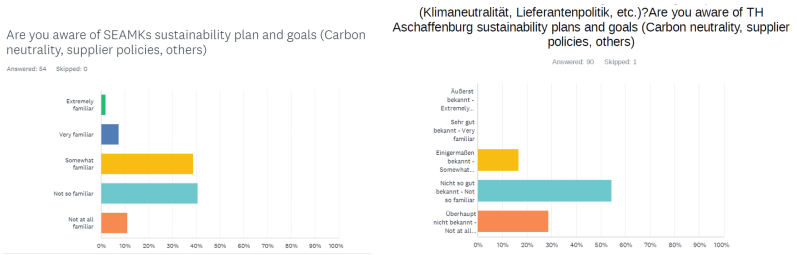

Fig. 9. Students' knowledge of the sustainability goals at the University.

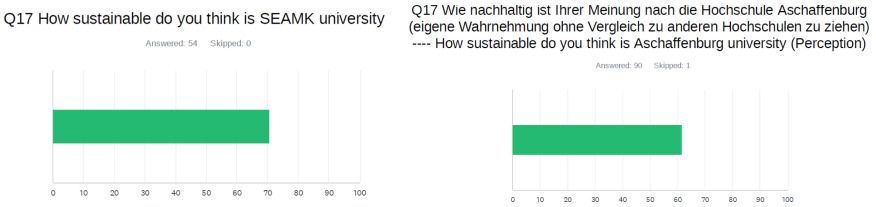

Fig. 10. Evaluation of sustainability at the University.

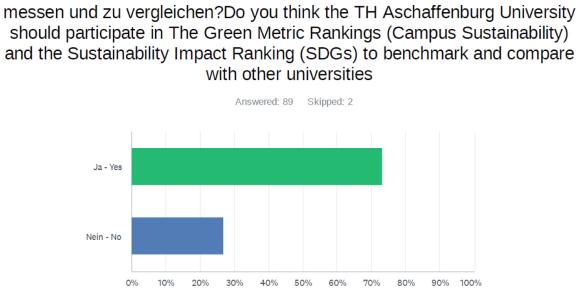

Fig. 11. Do you believe the University should participate in Sustainability University Rankings (new question)

diffusion of the practices, and it has a lower score from students, around 60% with a positive review versus 70%.

4.2 Sustainability Program and Practices Recommendations

See Tables 6 and 7.

Table 6. Sustainability areas and practices 1st part (Own Elaboration)

Aspect	Related Practices	University Examples
Sustainability on the Curriculum	Embedding sustainability and SDGs across all disciplines	– University of British Columbia (Canada): Offers undergraduate and graduate programs in sustainability
	Interdisciplinary programs (e.g., Environmental Science, Sustainable Development).	– Arizona State University (USA): Integrates SDGs across various disciplines
	Experiential learning through fieldwork and study-abroad programs related to sustainability	
	Compulsory 1–2 courses on Sustainability/Circular Economy in all programs	
	Making specific programs such has Master in Sustainability/Circular economy, Environmental Engineering	
	Use sustainable available games/simulations CESIM, Inchainge	
	Develop your own experiential learning modules, such has roadmap to Circularity, circular economy business models cards, CO2 emissions workshops	
Research related to Sustainability	Conducting research on renewable energy, climate change, sustainable cities, and biodiversity	– University of Cambridge (UK): Research on climate solutions and SDG-aligned policies.
	Interdisciplinary collaboration addressing global sustainability challenges	– National University of Singapore (NUS): Urban development and renewable energy research.
	Develop areas on research centers devoted to sustainability	
	Provide specific founding for Sustainability research	
	Collaborate in joint ventures on Sustainability projects	

(*continued*)

Table 6. (*continued*)

Aspect	Related Practices	University Examples
	Collaborate with Government and institutions on sustainability research	
	Public and Share research impact on sustainability	The University of Cambridge actively shares its sustainability research through its Cambridge Zero initiative
	Participate in conferences, seminars, and workshops on sustainability.	
Sustainable Campus Operations	Energy-efficient buildings and facilities , LED lighting, smart thermostats, motion sensors others	University of Bremen uses since 2011 some solar energy production on the campus and could ever since save around 4000 tons CO2
	Zero-waste initiatives and sustainable food systems	- University of Gothenburg (Sweden): Implements green campus operations and sustainable procurement.
	Green Mobility facilities and initiatives	University of Seinajoki and Aschaffenburg have more facilities to park sustainable cars and maintain bicycles
	Recycle buildings and Facilities	
	Green buildings standards, construct and retrofit buildings to meet LEED (Leadership in Energy and Environmental Design) or equivalent certifications. Focus on water conservation, energy efficiency, and sustainable materials	Harvard University has over 100 LEED-certified buildings on its campus
	Sustainable energy production or use (Eolic, Solar, Geothermal, others)	University of California, Davis (USA): Uses solar energy and has a zero-waste campus initiative. University of Bremen uses since 2011 some solar energy production on the campus and could ever since save around 4000 tons CO2

(*continued*)

Table 6. (*continued*)

Aspect	Related Practices	University Examples
	Waste Management, Implement recycling programs and composting initiatives across campus Reduce single-use plastics by promoting reusable containers and alternatives	University of California, Davis (USA): Uses solar energy and has a zero-waste campus initiative
	Campus Engagement programs such has create sustainability awareness programs for students, faculty, and staff. Organize sustainability challenges, green certification programs, and volunteer opportunities	The University of Edinburgh runs sustainability workshops and climate-focused events for the campus community
	Biodiversity Conservation by preserving natural ecosystems on campus by promoting tree planting, creating green spaces, and protecting wildlife habitats	University of Freiburg (Germany), University of Tasmania (Australia), University of Eastern Finland (Finland)

Table 7. Sustainability areas and practices 2st part (Own Elaboration)

Aspect	Related Practices	University Examples
Community Engagement and Partnerships	– Collaborating with local governments and NGOs to address sustainability challenges	– University of Cape Town (South Africa): Engages with local communities on water and sanitation initiatives
	– Offering student and faculty volunteering programs for community-based sustainability projects	– University of Melbourne (Australia): Partnerships for SDG 11 (Sustainable Cities and Communities)
	Work with industries to research sustainable practices and technologies, focusing on clean energy, circular economies, and sustainable supply chains	The Technical University of Denmark (DTU) collaborates with companies to develop green technologies and solutions

(*continued*)

Table 7. (*continued*)

Aspect	Related Practices	University Examples
	Establish sustainability initiatives for the community to engage	University of Aschaffenburg has initiatives such as Campus gardening. Students can plant their own vegetables and fruit on the campus and Campus bee-keeping together with planting a natural flora with a variety of wild blossoms
Tracking and Reporting Impact	Participating in sustainability rankings like the THE Impact Rankings and UI GreenMetric Rankings	University of Edinburgh (UK): Publishes SDG progress and sustainability reports annually
	Publishing annual sustainability reports and SDG progress updates	Monash University (Australia): Reports on carbon neutrality efforts and other sustainability metrics
	Measures the carbon footprint for facilities, laboratories, travel 24, campus restaurants, and procurements. Define a specific goal to be carbon-neutral	University of East Finland measures the carbon footprint and it has reduce the yearly carbon footprint per person from 849 kg CO2 (in 2019) to 671 kg CO2 (in 2023). Also sets the carbon-neutral goal at the end of 2025
	Sustainability indicators, % of research that is related to SDGs, % of green energy used on the facilities, CO2 emission per person	
Governance	Establishing sustainability councils and offices to oversee campus-wide initiatives	– University of Oslo (Norway): Has a dedicated sustainability office and governance structure
	Aligning institutional policies with SDG goals and sustainable practices	– Harvard University (USA): Sustainability committees drive climate action and campus transformation

(*continued*)

Table 7. (*continued*)

Aspect	Related Practices	University Examples
	Develop sustainability committee or office	University of Bremen has established the Commission for Sustainability, Climate Justice, and Climate Neutrality for staff and students since 2019 and a green office in 2022
	Allocate budget for sustainability practice	
	Participate in Sustainability Rankings	
	Publish a sustainability year report	
	Make a sustainability road map establishing year goals	
	Develop and maintain a Sustainability Website and news channel	
	Sustainable Finance Practices such as divesting from fossil fuels, adopting socially responsible investment strategies, and funding sustainability-focused projects.	
	Promote and community Sustainability efforts every year	
	Define policies related to Sustainability goals	University of east Finland define psychological health care for students or anti-discrimination programs
Sustainable Entrepreneurship and Innovation	Creating incubators and funding for green startups and social enterprises	–Stanford University (USA): Hosts sustainable innovation programs through the TomKat Center
	Hosting hackathons and innovation competitions focused on sustainability challenges.	– Universidad de los Andes (Colombia): Supports sustainable entrepreneurship through its innovation hub

5 Conclusions

The aim of the study was to identify general practices for sustainability in Higher Education institutions and develop a Knowledge Management approach to enhance the practices in universities, multiple practices were identified and expressed in seven categories related to Sustainability in Higher Education to encompass the different practices.

Embracing Sustainability in universities is a crucial step toward shaping future leaders who are aware of environmental challenges and solutions in the world (Sanchez and Cadarso 2021). However, implementing sustainability practices can be particularly challenging for smaller universities due to budget constraints and multiple resource limitations however with some basic efforts Universities can enhance their practices, one of them being the incorporation to sustainable university rankings that will provide some basic background and guidance towards sustainability plus an own benchmark. While investing in green infrastructure, renewable energy, and large-scale sustainability projects may not always be feasible, alternative approaches can still make a significant impact.

One of the most effective an easy way to embed sustainability within an academic institution is through curriculum integration. By incorporating sustainability and circular economy principles into various programs, universities can ensure that students develop an understanding of sustainable development and responsible resource management and get familiar with practices at enterprises. This not only prepares graduates for a changing job market but also fosters a culture of environmental responsibility within the academic community.

Beyond the classroom, universities can engage students through hands-on sustainability activities, such as recycling programs, sustainability workshops, and collaborative projects with local communities. Encouraging student-led initiatives and research on sustainability topics can also amplify awareness and promote innovative solutions. In general, small universities have a big improvement space to communicate these actions and programs at the university, calls the attention that most of the students (higher than 90%) learn about SDGs outside the university and that they largely do not know policy or activities related to sustainability, in terms of SECI model there are tremendous opportunities to improve the externalization process at the universities.

Moreover, clear communication of sustainability policies, success stories, and institutional commitments can help build momentum and encourage both students and staff to participate in green initiatives. Universities that effectively communicate their sustainability efforts tend to inspire greater engagement and long-term commitment from their community.

Additionally, applying knowledge management methodologies, such as the SECI model (Socialization, Externalization, Combination, and Internalization), could significantly enhance sustainability practices. By fostering more socialization through collaborative efforts, sharing best practices, and encouraging discussions among faculty, students, and external partners, universities can strengthen their sustainability culture. The combination and internalization of knowledge related to sustainability will ensure that successful strategies are continuously improved and embedded into institutional policies and day-to-day operations.

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Exploring Students' Perceptions of Co-Curricular Educational Excursions as a Form of Experiential Learning: A Case Study

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Abstract. Experiential learning has been widely recognized as an effective pedagogical approach in higher education that can enhance students' engagement, motivation, and knowledge retention. In particular, curricular and co-curricular work-integrated learning activities, such as hackathons, practicums, and educational excursions, equip students with real-world, hands-on experiences that reinforce theoretical knowledge through interactions with the industry. This research work explores students' perceptions of co-curricular excursions as a form of experiential learning in higher education, focusing on their perceived educational impacts, benefits, and challenges, including from a knowledge management perspective. Using a mixed-method approach, qualitative and quantitative data were collected through group reflections and a self-administered survey with postgraduate Master's students who participated in two excursions as a part of an Advanced Software Engineering course. The research findings suggest that excursions are highly valued by students who recognize their benefits, namely in terms of providing real-world industry context to coursework, strengthening conceptual understanding, and exposure to emerging technologies and trends. Additionally, students report increased motivation, career inspiration, and networking opportunities as key outcomes of attending excursions. Compared to other learning activities, such as guest lectures and online courses, excursions are ranked highly for new knowledge acquisition yet should be considered complementary to traditional classroom-based teaching approaches.

Keywords: Higher Education · Software Engineering Courses · Experiential Learning · Co-Curricular Activities · Work-Integrated Learning · Field Trip · Site Visit · Excursion · Student Perceptions

1 Introduction

Traditional classroom-based teaching approaches in *higher education* (HE), such as lectures and seminars, predominately position students as passive recipients of

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knowledge. These educator-centered learning environments encourage students to conform to the behavioral expectations of the traditional learner role, which is characterized by a propensity for passive and rote learning [18]. As a means of enhancing student engagement, motivation, and knowledge retention, learner-centered learning approaches have gained significant attention, complementing traditional classroom-based learning experiences in modern HE [2,12]. Among these approaches, *work-integrated learning* (WIL) activities, such as guest lectures, projects, and educational excursions, as a part of *experiential learning* (EL) provide students with real-world, hands-on experiences that reinforce theoretical knowledge through interaction with the industry [1]. EL activities do not only foster motivation and increase active student engagement but also aim to facilitate a deeper understanding of coursework [12,19]. From the perspective of EL, knowledge is constructed through the transformation of experience [10,11]. An educational excursion (also commonly referred to as a field trip or site visit), in particular, serves as a valuable EL activity that provides an authentic learning experience with a high level of industry engagement by immersing students in an industry context [4].

While excursions are recognized as effective learning activities within a HE context by extending learning beyond the confines of the classroom, research on students' perceptions of them remains limited, particularly in Engineering-related courses. Most research efforts have primarily focused on other forms of EL, such as guest lectures [16] and hackathons [17], or on integrating EL into curricula [2,13]. However, as highlighted in a recent systematic literature review by Tembrevilla et al. [19], excursions remain an underexplored area of study. Existing research on excursions has primarily examined aspects such as perceived value, curriculum-to-career connections, differences in learning experiences between students, and the influence on university-industry partnerships [4], leaving gaps in understanding how students perceive co-curricular excursions from the perspective of knowledge management, especially in comparison to other learning activities. To address this gap, this research work employs a mixed-method approach, gathering both qualitative and quantitative data through students' reflections and a survey. By analyzing student perceptions, this research contributes to the discourse on excursions as a form of EL in HE, identifying perceived educational impacts, benefits, and challenges. Additionally, this work examines excursions in relation to other learning activities.

The rest of this research paper is structured as follows. Section 2 provides an overview of the background and related work relevant to this research. Section 3 outlines the research objectives and design. Section 4 presents and discusses the research findings. The limitations of this research are addressed in Sect. 5. Finally, Sect. 6 summarizes the key findings and suggests directions for future research endeavors.

2 Background and Related Work

Kolb [10] defined EL as *"the process whereby knowledge is created through the transformation of experience"*. Central to this process is the notion that learning

occurs through a continuous cycle of experiences [10,15]. This cycle, as illustrated in Fig. 1, consists of four stages: *(1) Concrete Experience*, where a learner engages in an experience; *(2) Reflective Observation*, where they reflect on the experience, considering various perspectives; *(3) Abstract Conceptualization*, where they formulate theories or generalizations based on reflections; and *(4) Active Experimentation*, where these theories are applied in new situations, leading to new experiences that restart the cycle [10,11]. From an experiential perspective, the focus is on learning as a process rather than the learning content or behavior outcomes [10,15]. Knowledge itself is not considered as being an independent entity to be acquired or transmitted from one individual to another, but rather a transformation process, meaning that it is continuously (re)created from experiences of the learner [10]. Knowledge results from a combination of grasping experience through two opposing modalities, i.e., apprehension and comprehension, and transforming the grasped experience through another two opposing modalities, i.e., intention and extension, by the learner [10,11]. This aligns with the constructivist view of learning, in which the learner actively constructs knowledge through meaningful interactions with its environment [15]. The EL perspective suggests that learning extends beyond mere cognitive processing, involving the transformation of experience into both objective and subjective forms, thereby emphasizing the holistic nature of knowledge construction [10,15].

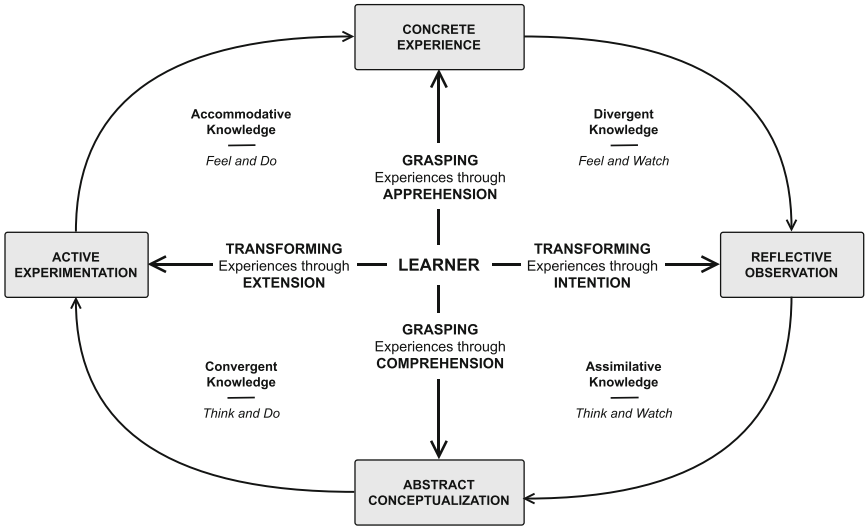

Fig. 1. The four-stage EL cycle by Kolb [10,11] with the two dimensions of the learning process and basic knowledge forms that result from learning.

Traditional teaching approaches in HE often emphasize passive, classroom-based learning [18], whereas EL encourages learner-centered education and can

play a supportive role in modern HE [9,12]. The pillars of EL underpin various teaching and learning activities in HE, including curricular, co-curricular, and extra-curricular WIL activities, which foster learning through experience at the intersection of theoretical and practical from real-world workplace contexts [1,4,5]. In such activities, learning shifts from an educator-centered approach – where teaching is largely transmissive, often leaving students unmotivated and disengaged – to one that actively engages students through real-world problem-solving [2,5,12]. The educator's role transitions from directing to facilitating student learning [5]. WIL serves as a strategy for developing knowledge workers who are not only proficient in specific vocational skills but also capable of understanding the interconnections between theoretical, practical, and general life experience knowledge [5]. Figure 2 presents examples of WIL activities relevant to Software Engineering education, categorized by their authenticity and industry engagement levels. A common simulated WIL activity with low industry engagement is a guest lecture, whereas highly authentic WIL activities with high industry involvement include work placements, internships, practicums, and educational excursions. In this research, we focus on a specific WIL activity – educational excursion – where students visit a company or an organization and are directly exposed to real-world industry environments, offering an immersive learning experience [4]. More specifically, we focus on co-curricular educational excursions, where the term co-curricular refers to activities that are not a part of the formal curriculum. However, they complement and enhance it by providing EL opportunities outside the traditional classroom setting.

Exploring EL in the context of HE is an active area of research. Agwa-Ejon and Pradhan [1] conducted a survey to examine students' perceptions of the impact of WIL activities in Engineering education in general without focusing on a specific activity. In contrast, Karim et al. [8] centered their research on project-based learning in postgraduate Engineering education, while Sotaquirá-Gutièrrez et al. [17] explored hackathons, and Pepple et al. [16] focused on guest lectures. Some recent research works have also examined virtual field visits [3]. Carbone et al. [4] utilized a multi-question survey, including open-ended questions, to assess undergraduate Engineering students' and academic staff's perceptions of learning experiences from two industry-facilitated co-curricular site visits. Their research highlighted key aspects such as the perceived value of these visits, their impact on students' career perceptions and employability, curriculum-to-career connections, differences in learning experiences between junior and senior students, and the role of such visits in fostering university-industry partnerships. In contrast, the present research work places greater emphasis on knowledge management – particularly tacit knowledge – and EL from a learner's viewpoint, employing a mixed-method research design. For a more comprehensive review of existing EL research in Engineering education, refer to the literature reviews of Jamison et al. [7] and Tembrevilla et al. [19]. Additionally, EL activities have also been widely explored for education across various other fields [6,14].

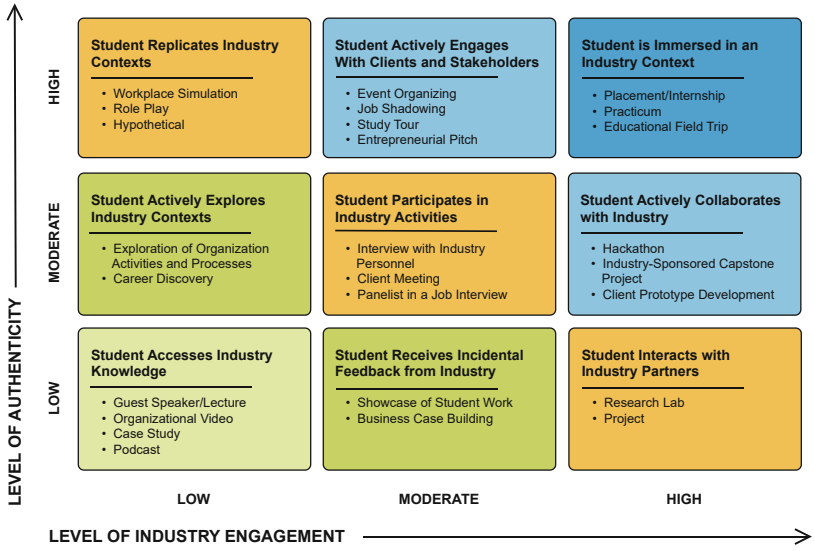

Fig. 2. Examples of WIL activities based on the level of authenticity and the level of industry engagement (adapted from the Industry Engagement Framework from work by Carbone et al. [4] for Software Engineering education).

3 Methods

3.1 Research Objectives and Questions

This research work explores students' perceptions of co-curricular educational excursions as a form of EL. Specifically, it investigates how students experience, interpret, and evaluate these excursions, including their role in knowledge acquisition and management. Additionally, the study seeks to identify key educational benefits, challenges, and areas for improvement in leveraging educational excursions for learning. Accordingly, the primary research objectives of this work are three-fold: *(i)* To examine students' perceptions of co-curricular educational excursions as a form of EL and their role in knowledge acquisition and transfer; *(ii)* To identify the perceived educational benefits and challenges of co-curricular educational excursions in enhancing learning and knowledge management; *(iii)* To compare students' perceptions of educational excursions with other learning activities in terms of knowledge acquisition. Based on these objectives, the following two research questions (RQs) guided the investigations of this research work:

RQ1 What are the perceived educational benefits and challenges of co-curricular educational excursions?

RQ2 How do students perceive educational excursions in relation to other learning activities in terms of new knowledge acquisition?

3.2 Research Context

This research was conducted as part of an Advanced Software Engineering course, focusing on agile software development methodologies, automated pipelines for continuous integration and deployment, and software quality assurance with metrics. For students enrolled in this course (i.e., postgraduate Master's students), two educational excursions were organized as voluntary co-curricular activities aimed at bridging academic learning with practical industry exposure. These excursions provided insights into software engineering practices, technological stacks, frameworks, tools, and operational workflows while also offering perspectives on business structures and organizational processes. Consequently, they can be viewed as a blend of technical and business-oriented visits. The selected companies for these excursions were all globally recognized and successful in leveraging modern software engineering practices and technologies.

The first excursion, a full-day visit, took place in the eighth week of the fifteen-week semester and involved visits to two companies. The first company, which we will refer to as Company A, is a medium-sized enterprise specializing in software products for highly regulated industries such as healthcare, telecommunications, and finance. The visit featured four speakers – the founder & CEO, the Vice President of Engineering, a Dev(Sec)Ops Engineer, and an HR Manager – who discussed the company's agile organizational structures, business strategies, operational workflows, and technical team roles, as well as specific technical aspects, including Dev(Sec)Ops methodologies, DORA metrics, cloud technologies, and platform engineering. Students could observe live CI/CD pipeline demonstrations, providing them with real-time insights into system efficiency and resource management. The second company, Company B, is a medium-sized enterprise specializing in software and hardware solutions, primarily catering to the retail, business, health, and wellness sectors. Presentations from the Head of Development and the Product Manager covered the challenges and methodologies in developing and distributing software products for global markets. They also shared their experiences establishing strategic partnerships with major corporations like IBM and Mayo Clinic, emphasizing the significance of interdisciplinary collaboration and multicultural client engagement.

The second excursion was a local half-day visit to Company C, a medium-sized software development enterprise primarily operating in the insurance sector that took place in the tenth week of the semester. The visit, led by the Chief Technology Officer, focused on the company's transition from micro to medium-sized enterprise, the transition from Extreme Programming to a customized agile enterprise framework, cloud technologies, and their role in CI/CD processes. Additionally, students gained valuable insights into real-world artifacts, including planning documents, cost estimations, and workflow management strategies.

From the four-stage EL cycle perspective, both excursions offered valuable learning opportunities by immersing students in concrete experiences, reflective observations, abstract conceptualizations, and active experimentation. The visits enabled students to observe real-world software engineering environments and

engage in discussions with industry professionals, bridging the gap between theoretical concepts and practical applications. Discussions and post-visit reflections also encouraged students to analyze and interpret their experiences, fostering deeper connections between theory and industry practices. Through hands-on demonstrations, interactive sessions, and follow-up lab exercises integrated into the formal curriculum (for select excursion topics only), students could apply theoretical principles in real or simulated industry settings, reinforcing the comprehension of coursework content.

3.3 Research Design

To explore students' perceptions of excursions, a mixed-methods approach was employed. The data collection process consisted of two phases. In the first phase, students participated in three rounds of structured group reflections, focusing on the connection between excursions and coursework content, the perceived educational benefits of excursions, and the perceived challenges of excursions and areas for improvement. These reflections, facilitated by an educator, were conducted in small groups to encourage active participation and discussion. In the second phase, students completed an anonymous, self-administered online survey. The survey consisted of a combination of open-ended questions allowing students to elaborate on their perceptions of excursions and closed-ended questions. Among these, one question specifically asked students to rank various learning activities based on their contribution to new knowledge acquisition. This ranking provided comparative insights into how students perceive excursions relative to other educational activities. Qualitative data from reflections and open-ended survey responses were iteratively coded and categorized using inductive thematic analysis, allowing themes to emerge from the data rather than being predetermined. To enhance validity, triangulation was applied by comparing findings from group reflections and survey responses, leveraging multiple data collection methods. Quantitative survey data were analyzed using descriptive statistics.

4 Results and Discussion

4.1 Demographics

A total of thirty students responded to the survey. The majority ($N = 18$ or *60%*) participated in both excursions. Among the remaining respondents, five (*16.7%*) attended only the first excursion, which included visits to Company A and Company B, while seven (*23.3%*) participated only in the second excursion, which involved a visit to Company C. Notably, eight students (*26.7%*) reported having attended more than five excursions during their HE altogether. For the remaining responses, the median number of excursions attended was three.

4.2 RQ1: Perceived Educational Benefits and Challenges of Co-Curricular Educational Excursions

Students reported several benefits of co-curricular educational excursions that contribute to their academic, professional, and personal development in meaningful ways. One of the primary benefits highlighted by students is the **connection between theory and practice**. Excursions provide practical insights into how theoretical concepts are applied in real-world industrial settings. By observing workflows, organizational structures, and problem-solving strategies in companies, students develop a more comprehensive understanding of industry operations. Many emphasized that these visits offer a **realistic perspective** on how work is organized, how teams collaborate, and how companies respond to challenges. Another key benefit of excursions is the **exposure to emerging technologies and industry trends**. Students reported that by participating in excursions, they are introduced to the latest tools, techniques, and methodologies used in their field. This exposure enhances their awareness of industry relevance and job market demands. Seeing these technologies in action deepens their understanding of practical applications and fosters curiosity, encouraging continuous learning. Excursions also play a crucial role in **motivation and career exploration**. Experiencing different work environments allows students to gain a clearer understanding of potential career paths and professional roles. Engaging with industry professionals helps them envision themselves in similar positions, reinforcing their academic and career goals. Many students noted that such experiences often spark new interests and provide inspiration for their future career decisions. Another significant benefit of excursions is the **networking opportunities** they offer. These visits facilitate interactions between students, educators, and industry professionals, fostering connections that could lead to internships, collaborations, or employment opportunities. Many students emphasized the value of engaging with company representatives, as it allows them to gain industry insights, discuss career prospects, and establish professional relationships. Furthermore, a majority of students expressed a strong desire for **more curricular or co-curricular excursions across different courses**.

While excursions provide valuable learning opportunities, students also identified several challenges that could impact their overall effectiveness, particularly regarding **time constraints and the depth of engagement** during visits. Some students noted that the duration of excursions might not be sufficient to fully explore each company and gain a deeper understanding of industrial practices and work environments. Limited time restricts opportunities for in-depth discussions with professionals and a comprehensive insight into company operations. As a result, some students felt that a more extended or structured approach to excursions could enhance their overall learning experience.

4.3 RQ2: Comparative Perceptions of Educational Excursions and Other Learning Activities in Knowledge Acquisition

Table 1 presents the survey results on students' rankings of seven learning activities – lectures, labs, educational excursions, guest lectures, the use of web

resources (e.g., blogs, forums etc., such as StackOverflow, W3Schools, Medium, Dev.to), AI-based tools (e.g., ChatGPT, Gemini, Cloude), and online courses (e.g., Coursera, Udemy, Udacity, edX). With a mean rank of 2.4, labs received the highest percentage of first-place rankings (*46.7%*), making them the most frequently chosen top-ranked activity. This suggests that students perceive lab sessions as the most effective method for new knowledge acquisition, likely due to their hands-on, applied nature. Conversely, with a mean rank of 5.3, online courses were ranked last by 36.7% of students, making them the most frequently chosen lowest-ranked activity. This suggests that students generally perceive online courses as less effective than other learning methods, potentially due to limited direct interaction and engagement issues. Educational excursions received a mix of rankings; in general, while they were not rated as highly as labs or lectures, they still ranked above the use of AI-based tools, the use of web resources, guest lectures, and online courses. This indicates that students do not perceive excursions as a primary method for acquiring knowledge but still recognize their value. The relatively high ranking of excursions underscores their supplementary role in learning to lectures and labs. They should be used to complement – not replace – primary traditional learning methods in Software Engineering education and serve as an effective bridge between theory and practice.

Table 1. Students' rankings of different learning activities based on perceived importance for new knowledge acquisition.

	1^{st}	2^{nd}	3^{rd}	4^{th}	5^{th}	6^{th}	7^{th}	Mean
Labs	14	7	2	2	1	2	2	**2.4**
	46.7%	23.3%	6.7%	6.7%	3.3%	6.7%	6.7%	
Lectures	5	7	6	5	2	3	2	**3.3**
	16.7%	23.3%	20.0%	16.7%	6.7%	10.0%	6.7%	
Educational Excursions	5	3	5	4	9	3	1	**3.7**
	16.7%	10.0%	16.7%	13.3%	30.0%	10.0%	3.3%	
Use of AI-Based Tools	1	1	12	5	7	3	1	**4.0**
	3.3%	3.3%	40.0%	16.7%	23.3%	10.0%	3.3%	
Use of Web Resources	1	6	2	7	2	5	7	**4.5**
(blogs, forums, etc.)	3.3%	20.0%	6.7%	23.3%	6.7%	16.7%	23.3%	
Guest Lectures	1	4	1	6	7	5	6	**4.8**
	3.3%	13.3%	3.3%	20.0%	23.3%	16.7%	20.0%	
Online Courses	3	2	2	1	2	9	11	**5.3**
	10.0%	6.7%	6.7%	3.3%	6.7%	30.0%	36.7%	

Students ranked the activities from 1^{st} (most important) to 7^{th} (least important).

5 Limitations

While this research provides valuable insights into students' perceptions of excursions as a form of EL, several limitations must be acknowledged. Firstly, not all students participated in both excursions, making it challenging to assess their individual excursion experiences comprehensively. Additionally, data collection was carried out three weeks after the last excursion, which may have introduced recall bias, as students' reflections and perceptions could have evolved during that period. Secondly, this research focuses solely on a single course from the domain of Software Engineering, with an emphasis on advanced software development methodologies and supporting technologies. Consequently, the findings may have limited generalizability to other courses and curricular contexts. Another limitation stems from our extensive and longstanding experience – gained over the past fifteen years – in planning and executing excursions. We recognize that the excursions included in this research benefited from this expertise, ensuring timely announcements, efficient registration processes, and well-planned logistical arrangements (e.g., transportation and meals). Furthermore, the presenters and their content were carefully coordinated, with most industry partners and presenters already familiar with the excursions from the past years and previous student cohorts. This prior experience and alignment may have contributed to the overwhelmingly positive student perceptions, making it difficult to isolate the impact of the excursions themselves from the influence of strong organizational execution and content alignment of coursework and excursion topics. As a co-curricular activity, each excursion was carefully coordinated to complement topics already covered in lectures and labs, ensuring that students could integrate new insights effectively. However, this pre-existing familiarity with certain topics might have influenced students' evaluations, as they were not encountering the topics for the first time. Furthermore, all industry presenters shared lessons learned from real-world challenges, focusing on common mistakes, pitfalls, corrective actions, and best practices. While this provided students with valuable practical insights, it may have also shaped their perceptions differently from excursions with a more exploratory format, where the excursion content and topics are less structured and not predetermined. We also acknowledge that the students involved in this research are a diverse group with varying socioeconomic backgrounds and other individual traits, such as preferred learning styles, all of which shape their perceptions of excursions as a form of EL. Lastly, since the excursions in this research were conducted as voluntary co-curricular activities, the findings might differ if they were implemented as part of the curriculum or as mandatory co-curricular activities.

6 Conclusions and Future Work

Educational excursions are a valuable form of EL, providing students with direct exposure to industry environments and fostering high-level industry involvement.

This research work explored students' perceptions of excursions in the HE context, focusing on their educational value from a knowledge management perspective. It also examined how excursions compare to other learning activities, along with the educational benefits and challenges of excursions the students perceive. A mixed-method approach was employed to gather qualitative and quantitative data. This was achieved through group reflections and a self-administered survey conducted with postgraduate students who took part in excursions as a co-curricular activity of a Software Engineering-related course. The research findings confirmed that excursions are not only a well-established practice in our case – having been integrated as a co-curricular EL activity for over fifteen years – but are also well-received and highly valued by students who expressed a strong interest in participating in them as part of their ongoing education. Analysis of the results highlights that students perceive excursions as particularly beneficial for knowledge acquisition, providing real-world industry context to coursework, and strengthening conceptual understanding. Notably, excursions are ranked as one of the most significant activities for acquiring new knowledge among the compared learning activities, third only to hands-on lab sessions and lectures. In conclusion, this research work underscores the importance of co-curricular educational excursions as a highly effective and valued form of EL in HE, reinforcing their role in bridging academic learning with real-world industry exposure.

While this research focused solely on the student perspective, future research should explore the dual perspective of both students and educators, as well as a multi-view perspective additionally incorporating industry partners. Given the diverse nature of excursions, future research should analyze each excursion individually to provide a more granular assessment of their contributions to students' learning experiences. Since students generally prefer excursions where their active participation is not strictly required – particularly in the form of quizzes – this highlights the need for further investigation into the impact of interactivity within excursions. Future studies could draw on Albert Bandura's social learning theory and reflection-based EL theories to examine how increased interaction influences learning outcomes, motivation, engagement, and long-term knowledge retention. Additionally, many students already have prior experience working within industry environments – a median duration of 6,5 months per student in our case – which raises important questions about how these experiences shape their perception of excursions. Specifically, future research should investigate how prior industry exposure influences students' views on the relevance, effectiveness, perceived value, and knowledge transfer potential of excursions.

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Assessing the Effect on Management Education for the Nursing Staff in Elderly Care Facilities

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Abstract. This study evaluates the understanding of business management concepts among nursing staff for the elderly in Japan. Text data comprising 325 answers and 3,080 sentences from 26 participants' reports collected from October to December 2024 were analyzed. Morphological analysis and deep learning models (T5(Text-to-Text Transfer Transformer) and BERT (Bidirectional Encoder Representations from Transformers)) were used to classify two groups by scores, achieving high accuracy and F1 scores. The difference between the two groups was whether the seminar participants merely understood the lecture or were trying to take it back to the workplace and put it into action. By analyzing the reports submitted by seminar participants, using Topic Modeling with NMF (Non-Negative Matrix Factorization) and BERTopic, the key themes were identified as strategic planning, community welfare, organizational philosophy, and actionable insights. By applying Topic Modeling to the seminar participants' LINE conversations, it was found that the LINE data captured more practical and personal concerns, such as scheduling, punctuality, and emotional impressions. This study demonstrated the potential for automated evaluation of training programs and aligning participant engagement with organizational goals.

Keywords: Elderly care · Classification · Topic modeling

1 Introduction

This paper assesses the understanding of business management by nursing executives and staff for the elderly in Japan. According to a survey by the Ministry of Health, Labor, and Welfare, it is predicted that there will be a shortage of approximately 340,000 nursing care workers by 2025. The high turnover rate of nursing care workers for the elderly is due to low wages and tough work, and securing and retaining them is an urgent issue.

The nursing care industry currently faces the following two issues. 1) Focus on outcomes: Because there are concerns that social security costs will increase due to

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population estimates, to improve the sustainability of the system, it is necessary to shift the focus from the current system of providing care to preventing the deterioration of the condition of elderly people requiring care and improving the level of care required. 2) Influx of inexperienced people: There is a shortage of people currently working in the industry compared to the number of people required for nursing care, and the influx of people with no experience in the field and those who have not yet obtained national qualifications is increasing.

The government is also taking various measures to secure nursing care workers. The training program for care workers has been revised, and the amount of time spent learning about "leadership and team management" has been doubled as part of the "expansion of educational content to foster team management skills". The on-site leader is a middle manager, acting as a "playing manager" and carrying out on-site work and management duties. However, there is a staff shortage on-site, and most of the time is spent focusing on on-site work, with little time for management. This situation leads to a vicious cycle of poor teamwork due to a lack of communication, frequent accidents, and complaints due to a decline in service quality, staff turnover, and a decline in business performance. It has become an urgent issue for staff at elderly care facilities to learn about business management.

The company where one of the authors works has held a seminar on business management for them. This study analyzed the text data from the assignments submitted by the participants in this seminar and the social media platform LINE from October to December 2024. Such a seminar is expected to offer the opportunity for the nursing executives and staff for the elderly care facilities, and the effect should be assessed. Management and leadership will verify the educational effect after returning to each elderly care facility. We thought we could ascertain the participants' awareness through the text data. Until now, the company that has organized the seminars has reviewed the issues submitted by the participants. However, no data analysis has been carried out. We believe that the analysis in this study will be useful for both the company that has organized the seminars and the executives and staff of the elderly care facilities to which they belong. As the computer learns the patterns of the text data in the accumulated reports, we hope to automatically assess the participants' proficiency level based on the text level in the newly submitted assignments.

2 Literature Review

Population aging has significantly increased the global demand for elderly care services. Successful systems in European and Asian countries emphasize coordination among agencies, long-term care (LTC) insurance, and home-based services. In contrast, Iran faces substantial challenges in meeting these needs, underscoring the necessity of adopting integrated and well-coordinated policies informed by proven international practices [1].

The global population aged 80 and over is projected to rise from less than 1% in 1950 to nearly 10% by 2050 in OECD countries, creating a growing need for community-based care for frail seniors as weakening family ties, increased female workforce participation, and reduced early retirement policies shrink the pool of family carers [2].

Japan's elderly care system similarly confronts multifaceted challenges stemming from its rapidly aging population and the need to balance quality and efficiency in long-term care services. Previous studies have highlighted systemic, organizational, and workforce-related issues affecting care delivery and provided insights into potential pathways for improvement. The long-term care insurance system, introduced in 2000, was intended to integrate fragmented welfare and health insurance systems, enabling elderly individuals to access comprehensive health, medical, and welfare services according to their choices. This system supports institutional care through facilities such as special nursing homes for the elderly and long-term care hospital beds, each managed by different entities. However, significant challenges remain in fostering effective collaboration among these components, necessitating further reforms to meet the growing demands of an aging population [3].

Budget constraints have also led to outsourcing care provision to private sectors. Sharing organizational missions among stakeholders is key to improving care quality and efficiency, highlighting the importance of collaboration and shared goals [4]. In addition, high turnover rates among professional caregivers exacerbate challenges in elderly care. A qualitative study using the Healthy Work Organization (HWO) model identified three primary factors contributing to caregiver turnover: the demanding nature of care services, insufficient labor and personnel management systems, and underdeveloped organizational policies and structures. Targeted interventions are necessary to improve job conditions, enhance management systems, and foster supportive organizational cultures [5].

These studies underscore systemic inefficiencies in Japan's long-term care insurance system, quality concerns arising from outsourcing, and workforce instability as interconnected issues. Addressing these challenges requires a more integrated and stakeholder-inclusive approach that prioritizes the alignment of institutional frameworks, empowers care providers, and creates supportive work environments. Achieving sustainable, high-quality care for Japan's aging population hinges on coordination, innovation, and active stakeholder engagement in designing effective elderly care systems.

With an aging population outside of Japan as well, elderly care is seeking to establish innovative care provision models that align with users' needs [6–8].

We introduce previous research on methodology. Previous research shows that using big data in nursing care is effective. EmbedHDP, a new evaluation model for nursing care records, addresses limitations in existing metrics like BERTScore, cosine similarity, ROUGE, and BLEU by effectively aligning with caregiver judgments, handling diverse sentence structures and medical terminology, and outperforming others with a 61% correlation coefficient [9]. This study uses nursing care records in the research of elderly care. Westra and Peterson[10] explored methods to improve the quality of perioperative nursing data and provided examples of how these data can be combined with broader nursing data for quality improvement. A national action plan for nursing knowledge, big data science, and how perioperative nurses can collaborate to transform health care is discussed [10]. Although not limited to elderly care, numerous studies have been conducted in the research field of care using text mining ([11–13]).

Machine learning and deep learning are conducted to evaluate automated, easy scoring systems ([14–18]). Automated essay scoring (AES) is a computer-based assessment

system that automatically scores or grades the student responses by considering appropriate features [14]. Salim et al. [15] proposed an XGBoost Machine Learning classifier to assess the essays. The algorithm trained on features like word count, POS, parse tree depth, and coherence in the articles with sentence similarity percentage; cohesion and coherence are considered for training. Ke et al. [16] used a support vector machine to find the response score. Dong et al. [17] built a hierarchical sentence-document model to represent essays, using the attention mechanism to automatically decide the relative weights of words and sentences. Results show that our model outperforms the previous state-of-the-art methods, demonstrating the effectiveness of the attention mechanism. Riordan et al. [18] investigated how several basic neural approaches similar to those used for automated essay scoring perform on short answer scoring.

3 Methodology and Results

3.1 Classification of Participants' Reports: Methodology

Every month, the participants report their understanding of the seminar and its contents on business management to the company where the seminar is held and their supervisor of the elderly care facilities. 26 participants from 23 facilities are included in the analysis. This paper analyzed this report from October to December 2024. Although the sample size is small, the elderly care facilities analyzed in this study consist of social welfare corporations, medical corporations, and private companies. Additionally, the dataset includes organizations from both urban and rural areas. Therefore, using this data to discuss elderly care facilities across Japan could be considered a valid first step in the analysis.

The contents of this seminar include: (1) Overview of the elderly care business; (2) Trends and future vision of the elderly care industry; (3) Initiatives for the implementation of self-reliance support-type nursing care service; (4) Development of a system for providing total care management; (5) Utilizing regional characteristics and resources; (6) Understanding the needs of the local community surrounding your company; (7) Understanding the corporation and deepening your connection with it–walking through the history of the corporation and the facility; (8) Understanding management resources of your own organization. Each item has both awareness from the study of management and action plans that will lead to the participant's behavior after studying. This is crucial because this seminar aims to cultivate leaders in elderly care facilities who possess management skills and a sense of business acumen.

In addition to the lecturer's lecture, the course includes discussions, interviews at the participant's facility, framework thinking such as SWOT(Strengths, Weaknesses, Opportunities, Threats) analysis, and analytical tools such as BSC(Balance Score Card). SWOT analysis was used in many of the participants' reports to analyze the strengths and weaknesses of their organizations. In (7) of the lecture content above, participants learn about the importance of principles in organizational management. Many participants interviewed the founder to learn about the philosophy of the organization they belonged to. Disseminating principles and SWOT analysis is about understanding management,

the organization to which they belong, and how they work. By learning about the current situation and future of elderly care, we found that some participants were not just acquiring knowledge but also thinking about their own organizations and communities.

The reports include 325 answers from twenty-six participants from October to December 2024. Each answer has several sentences, for a total of 3080 sentences. Firstly, we performed a morphological analysis to decompose sentences by parts of speech and extracted nouns, verbs, and adjectives. We classified answers, including several sentences, based on the analysis of distinctive terms gained by morphological analysis, into four categories: (1) the stage of understanding the contents related business management at each class, (2) the stage where they connect what they have learned to reflections on them and the organization they belong to, (3) the stage where participants try to put what they have learned into practice, and (4) the same practical stage as (3), but the practical contents are described in more detail, and there is a high possibility of taking action in this stage. The phrase "considering in Japanese" is commonly used when something is not done, and sentences that end with the word "think" are also not directly connected to action, so if the action plan concludes with these words, it is not classified as stage (3). Answers (1)-(4) were scored from 1 to 4 points, and the number of answers and sentences by score is described. If we are only analyzing small amounts of data, this may be sufficient; however, we must move on to text classification using deep learning to make predictions using new data. The number of answers and sentences for score 1 is small, while score 3 is significantly higher, showing a strong bias that must be considered in further data analysis.

The classification using the previous feature words was verified using deep learning, with cases where the score was 1 or 2 grouped together as 1 and cases where the score was 3 or 4 grouped together as 2. The difference between the former and the latter integrated in this way is whether terminologies that directly relate to action plans and actions were used. We adopted T5 (Text-to-Text Transfer Transformer) and BERT (Bidirectional Encoder Representations from Transformers) for the classification by deep learning because both are good for Japanese language analysis. T5 and BERT use the transformer architecture. Transformers are a neural network model consisting of a self-attention mechanism and a multi-layer encoder/decoder. T5 and BERT have multi-layer encoders and decoders, and each layer extracts and processes text features. This enables a deep understanding of contextual information and the realization of advanced tasks such as text classification and summarization.

In this study, we chose T5 and BERT for the classification task due to their unique advantages in handling Japanese text. T5, as a text-to-text model, offers a flexible framework for classification by allowing label generation as a sequence-to-sequence task. This capability makes it highly effective for tasks requiring nuanced text transformations. On the other hand, BERT is well-suited for capturing bidirectional contextual information, which is crucial for assessing Japanese text's specificity and logical coherence.

Other analysis methods besides T5 and BERT could be RoBERTa and GPT-3. We did not employ RoBERTa because, although it is an optimized version of BERT, it removes the Next Sentence Prediction (NSP) objective. Given that our task involves evaluating textual coherence and relationships, the lack of NSP may weaken its ability to capture sentence dependencies in Japanese. Moreover, RoBERTa's pretraining data primarily

focuses on English, and existing Japanese adaptations may not be as robust as Japanese-specific BERT models. Similarly, we opted not to use GPT-3, as it is primarily designed for generative tasks rather than classification. Its autoregressive nature makes it less suitable for fine-grained text classification, whereas T5 and BERT are better optimized for structured classification tasks. Based on these considerations, we determined that T5 and BERT provide the most effective framework for our classification task in Japanese.

3.2 Classification of Participants' Reports: Results

As mentioned previously, Scores 1 to 4 were divided into two groups. The sentences in the groups with scores of 1 and 2 showed that the participants understood the lecture on business management, while the sentences in the groups with scores of 3 and 4 showed that the participants had a plan to implement what they had learned in the lecture in their work (Table 1).

After splitting the dataset into 70% for training and 30% for testing, we trained the T5 and BERT models over 10 epochs, ensuring they did not overfit. Once training was complete, we evaluated the models on the test dataset, measuring the accuracy rate and F1 score (Table 2). The accuracy rate represents the proportion of correct predictions out of all cases. The F1 score provides a balanced assessment by considering both precision (how many predicted positives were correct) and recall (how many actual positives were correctly identified). On the test dataset, the accuracy rate was 0.95, and the F1 score was 0.89, demonstrating that the model effectively classified the two groups.

Table 1. The number of answers and sentences by score.

score	answer	sentence
1	10	74
2	41	370
3	234	2295
4	40	341

3.3 Topic Modeling for Participants' Reports: Methodology

We analyzed the text data written by participants to identify which topics they were interested in or exchanged information about during the study sessions. Our purpose was to explore the topics that participants were interested in or found memorable and to identify the subjects being discussed in online communication among the participants. We compared reports submitted to the persons in charge of their organization and text data in LINE, one of the social media, by considering that analyzing the casual communication

Table 2. Accuracy rate and F1 Score by T5 and BERT.

	T5		BERT	
Epoch	Accuracy rate	F1 Score	Accuracy rate	F1 Score
1	0.9605	0.9613	0.8947	0.8947
2	0.9605	0.9613	0.8947	0.8947
3	0.9474	0.9487	0.8947	0.8947
4	0.9474	0.9487	0.8947	0.8947
5	0.9474	0.9487	0.8947	0.8947
6	0.9474	0.9487	0.8947	0.8947
7	0.9474	0.9487	0.8947	0.8947
8	0.9474	0.9487	0.8947	0.8947
9	0.9474	0.9487	0.8947	0.8947
10	0.9474	0.9487	0.8947	0.8947

added to the formal report was meaningful. We adopted topic modeling to identify the topics in those text data.

LDA (Latent Dirichlet Allocation), NMF (Non-Negative Matrix Factorization), and BERTopic are widely used methods for topic modeling. Each leverages distinct computational approaches to extract latent topics from text data. Latent Dirichlet Allocation (LDA) is a probabilistic generative model that Blei et al. [19] introduced for uncovering hidden thematic structures within a corpus. LDA assumes that each document is represented as a mixture of latent topics and that a word distribution characterizes each topic. Specifically, the model operates by assigning a Dirichlet prior to the document-topic distributions and topic-word distributions, ensuring sparse and interpretable results. In the generative process, a topic is first sampled from the document's topic distribution, followed by sampling a word from the corresponding topic's word distribution. The parameters of LDA are typically estimated using techniques like variational inference or Gibbs sampling. While LDA excels in its interpretability and the probabilistic nature of the topic assignments, its computational demands can become a limitation when applied to large datasets. Non-Negative Matrix Factorization (NMF) is a matrix decomposition technique used to extract latent features from data, including textual corpora ([20]). NMF captures additive combinations of terms that represent topics by factorizing a term-document matrix into two non-negative matrices. The resulting factorization provides a straightforward interpretation, as the non-negativity constraint ensures that all contributions to a topic are additive and intuitive. Optimization is achieved through iterative methods, such as multiplicative updates. Compared to LDA, NMF is computationally efficient and well-suited for applications requiring a fast and interpretable analysis. However, it lacks the probabilistic framework of LDA and does not incorporate semantic

relationships between words. BERTopic represents a modern advancement in topic modeling by integrating contextual embeddings and clustering techniques to identify latent topics. Developed by Grootendorst [21], BERTopic leverages pre-trained language models like Sentence Transformers to generate high-dimensional embeddings that capture semantic nuances. Topics are then defined by extracting the most representative keywords from each cluster. BERTopic also allows for dynamic topic modeling, enabling tracking topic evolution over time. While its reliance on deep learning models provides a richer understanding of semantic relationships, it is computationally more demanding than traditional approaches like LDA and NMF.LDA, NMF, and BERTopic each offer unique strengths and trade-offs. LDA is ideal for probabilistic topic modeling with high interpretability. NMF excels in computational efficiency and simplicity, and BERTopic provides state-of-the-art results for applications requiring contextual and semantic richness. The specific objectives, data characteristics, and computational resources should guide the choice among these methods.

3.4 Topic Modeling for Participants' Reports: Results

The results of analyzing the topic in the report (Tables 3, 4 and 5) and the communication by LINE (Tables 6, 7 and 8) were described. The results of LDA were described in Tables 3 and 6, NMF in Tables 4 and 7, and BERTopic in Tables 5 and 8.

This paper decided on the optimum number of topics in LDA by coherence (Graphs 1 and 2). Coherence or perplexity is usually used to determine the number of LDA topics. Coherence focuses on the interpretability of topics by assessing the semantic similarity between top words within each topic. Higher coherence scores indicate that the topics are more meaningful and align better with human understanding, often calculated using word co-occurrence statistics. Perplexity measures the model's generalization performance, quantifying how well it predicts unseen data. It is based on the log-likelihood of test data, where lower perplexity scores signify better predictive accuracy. While coherence emphasizes human interpretability, perplexity prioritizes statistical soundness. Graph 1 indicated the maximum point of coherence was eight, and on the other hand, perplexity was constantly declining. It is difficult to interpret the meaning of topics in too many topics. Therefore, we chose the eight topics, considering that we aimed to understand what topics meant. The result of LDA seemed too poor to find the meaning of topics because the same words were seen in several topics, and it was difficult to interpret what they meant (Table 3).

NMF is considered easier to interpret than LDA, depending on the simple algorithm that offers topics that fit human intuition. In NMF, each topic is represented by words with non-negative weights that directly indicate their importance. This straightforward representation makes it intuitive to identify the dominant words and infer the topic's meaning; however, the number of topics must be determined. In this paper, the number of topics in NMF was determined within a range that allows for the interpretation of the topics. By conducting NMF, each topic was interpreted as follows: Topic 1:Staff and Management focusing on human resources and organizational philosophy; Topic 2: Administration and Resources related to resource allocation and administrative functions, including service delivery and unique organizational characteristics; Topic 3: Independence and Care, Topic 4: Strategy and Execution, Topic 5: Sales and Activities

revolving around sales strategies, competitive analysis, and marketing activities; Topic 6: Personal Development which was centered on individual growth and future planning. This topic included themes of self-reliance and time management. Topic 7: Care and Knowledge, which highlighted caregiving, knowledge acquisition, and quality improvement, possibly in healthcare or education; Topic 8: Philosophy and Corporate Establishment, which focused on corporate philosophy and foundational principles, emphasizing leadership and organizational thinking; Topic 9: Corporate Thought and Study, and Topic 10: SWOT Analysis emphasizing the assessment of strengths, weaknesses, and corporate strategy (Table 4).

In BERTopic, the number of topics is automatically determined by the clustering algorithm, typically HDBSCAN (Hierarchical Density-Based Spatial Clustering of Applications with Noise). This approach dynamically identifies clusters in the data without requiring a predefined number of topics. According to Table 5, the interpretation of the topics generated by BERTopic in the participant's report was as follows: Topic 1: Strategic Planning and Execution, which focused on strategic planning and execution, emphasizing SWOT analysis, strengths, and weaknesses, alongside management and organizational thoroughness. It likely represents the process of assessing and implementing strategies within corporations. Topic 2: Sales and Business Operations. This topic revolved around sales strategies and business operations, covering geographic areas, corporations, sales points, and competitive analysis. It emphasizes business activities and the effective use of information. Topic 3: Care and Staff Development. This topic highlighted care services and staff development, focusing on improvement, the necessity of support, and independence. It also touches on occupations and the use of resources in caregiving environments. Topic 4: Philosophy and Personal Growth. This topic emphasizes philosophy and personal growth, focusing on individual responsibility, self-reliance, and establishing businesses. It also explores corporate values, communication, and long-term thinking. Topic 5: Regional Services and Demographics. This topic focused on regional service delivery and demographic trends, highlighting care, administration, and the specific needs of the elderly population. It also touched on resource management and planning for the future. Topic 6: Care and Independence Support. This topic emphasizes care services and supporting independence, focusing on self-sufficiency, family-oriented care, safety, and goal-setting for better outcomes. Topic 7: Philosophy and Organizational Management. This topic combines organizational philosophy and management, highlighting the penetration of ideas into areas, coping mechanisms, profit, and control. It emphasizes the necessity of management strategies in various situations.

As mentioned, we found that NMF and BERTopic could arrange sentences in the report and reveal the meaning of each topic. The combined analysis of NMF and BERTopic highlighted the diverse dimensions of business, organizational management, care services, and the underlying philosophy of the participants' organization. Central themes included strategic planning and execution, using tools like SWOT analysis, effective management practices, and resource allocation. Sales strategies and operational efficiency were emphasized, reflecting efforts to optimize business activities, enhance competitive advantage, and utilize information effectively. Both analyses underscored

the significance of care services, focusing on improving caregiving, supporting independence, and addressing the unique needs of the elderly population. This was coupled with developing skilled staff and fostering a culture of quality improvement. The philosophy and personal growth of the organization are key pillars, emphasizing self-reliance, corporate values, leadership, and long-term vision. Additionally, there was a clear focus on regional services and demographic considerations, highlighting the need for tailored approaches to meet societal challenges and adapt administrative resources. The analyses discussed fostering collaboration, inter-company relations, and knowledge-sharing as strategies for continuous learning and organizational growth. NMF and BERTopic results provided a holistic view of the organization's priorities, balancing strategic objectives, operational excellence, caregiving, and a philosophy-driven approach to leadership and growth. This comprehensive understanding can guide future initiatives and decision-making.

3.5 Topic Modeling for Communication Among Participants by LINE: Methodology

Next, the LINE text data was analyzed using the same topic modeling method, and the results were compared with the analysis in the report above. We conducted LDA using six topics, which the coherence graph indicated (Graph 2), and the result was described in Table 6. We noticed 'enjoyment," impressions,' and 'will' which suggested the participant's emotion.

We conducted NMF and summarized the characteristics of each topic (Table 7). Topic 1: Participation in Lectures; Topic 2: Scheduling and Enjoyment; Topic 3: Philosophy and Leadership, which focused on philosophical principles and leadership, emphasizing organizational vision and thought leadership; Topic 4: Impressions and Communication; Topic 5: Community and Welfare, which emphasized corporate welfare and community involvement, with a focus on healthcare and regional aspects; Topic 6: Requests and Support, which suggested requests for support and future collaboration, with a forward-looking perspective; Topic 7: Management and Planning related to management, planning, and strategic understanding, emphasizing organizational focus and problem-solving; Topic 8: Organizational Culture and Strategy, which highlighted organizational culture and strategies for change, emphasizing adaptability and alignment; Topic 9: Team and Visual Representation; Topic 10: Personal Reflection and Care, which focused on personal reflections, self-care, and participation, emphasizing individual involvement in broader activities.

3.6 Topic Modeling for Communication Among Participants by LINE: Results

The results of conducting BERTopic were summarized (Table8): Topic 1: Philosophy and Individual Reflection; Topic 2: Lecture Engagement; Topic 3: Anticipation and Enjoyment, which suggested anticipation and enjoyment in activities, reflecting positive attitudes toward future participation; Topic 4: Impressions and Program Participation; Topic 5: Media and Archiving; Topic 6: Community and Welfare.

We found in the topic modeling of LINE that we noticed several words different from the case of a report; however, the result of LDA was less meaningful, and we could draw more valuable findings in NMF and BERTopic. The importance of philosophy and reflection within the organization was highlighted. "Philosophy and Leadership" emphasized organizational vision and thought leadership, while "Philosophy and Individual Reflection" focused on personal and organizational thought processes. These themes underscored the centrality of philosophical principles and self-reflection in shaping the participants and the organization's direction. Another shared theme was lecture participation and engagement. "Participation in Lectures" and "Lecture Engagement" emphasized active involvement in educational activities. Additionally, the analyses reflected logistical aspects, such as punctuality and scheduling, suggesting that these were significant participant considerations. Community and welfare emerged as key themes. "Community and Welfare" highlighted corporate involvement in healthcare and regional welfare initiatives, while "Community and Welfare" aligned closely by emphasizing regional support and medical care. This alignment reflected the organization's focus on fostering community and addressing societal needs. Impressions and communication were also emphasized. "Impressions and Communication" and "Impressions and Program Participation" captured participants' reflections and feedback on programs, highlighting the importance of engagement and personal experiences in organizational activities. Adaptability and strategy were identified as central themes. "Organizational Culture and Strategy" focused on strategies for change and alignment, while similar ideas were reflected in the emphasis on strategic thinking and cultural considerations. In summary, the analysis's commonalities—philosophy and reflection, lecture engagement, community welfare, impressions, and strategic adaptability—demonstrated the organization's balanced focus on individual growth, collective engagement, and strategic priorities. These recurring themes provided a unified narrative for understanding the organization's values and participants' experiences (Figs. 1 and 2).

Table 3. The result of Latent Dirichlet Allocation for Topic Modeling in analyzing report.

topic1	care	0.017	area	0.017	staff	0.016	necessary	0.008	thinking	0.008
topic2	area	0.017	facility	0.012	care	0.012	necessary	0.012	be made	0.010
toipc3	care	0.012	staff	0.012	human	0.010	area	0.009	thinking	0.009
topic4	area	0.013	business	0.012	corporation	0.011	care	0.011	sales	0.010
topic5	philosophy	0.019	corporatio	0.015	strategy	0.014	myself	0.010	management	0.009
topic6	thinking	0.010	analysis	0.010	area	0.010	care	0.009	necessary	0.009
topic7	area	0.016	necessary	0.011	care	0.010	thinking	0.010	service	0.008
topic8	care	0.014	staff	0.011	support	0.010	necessary	0.009	philosophy	0.008

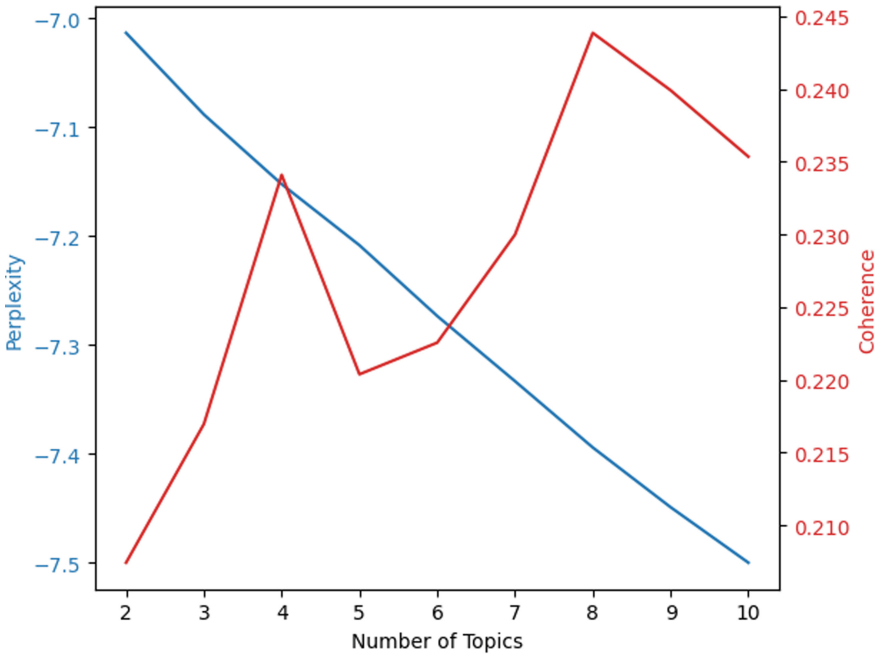

Fig. 1. Graph 1 Determining the optimum number of topics by coherence in report

Table 4. The result of Non-Negative Matrix Factorization for Topic Modeling in analyzing report.

topic1	staff	0.946	philosophy	0.622	area	0.574	management	0.497	on- site	0.421
topic2	area	1.155	resources	0.317	administration	0.315	service	0.302	special characteristic	0.290
toipc3	care	0.645	Support for Independence	0.564	Target	0.394	motion	0.315	use	0.280
topic4	strategy	1.059	execution (e.g. program)	0.572	thoroughness	0.516	appropriate	0.428	management	0.388
topic5	sales	1.312	information	0.416	activity	0.338	sales point	0.336	opponent	0.329
topic6	myself	0.723	term	0.397	by oneself	0.334	hours	0.295	future	0.295
topic7	care	0.809	care	0.454	knowledge	0.326	improvement	0.320	high	0.294
topic8	philosophy	0.897	establishment (of a business, etc.)	0.576	corporation	0.570	director	0.397	thought	0.353
topic9	thought	0.608	one's company	0.407	other company	0.285	study	0.265	necessary	0.177
topic10	swot analysis	0.630	strengh	0.593	weakness	0.494	corporation	0.236	business	0.216

Table 5. The result of BERTopic for Topic Modeling in analyzing report.

topic1	strategy	0.075	swot analysis	0.059	strengh	0.040	management	0.040	weakness	0.035
topic2	sales	0.120	area	0.059	corporation	0.052	information	0.052	business	0.051
toipc3	care	0.068	care	0.067	necessary	0.046	improvement	0.039	staff	0.037
topic4	philosophy	0.099	myself	0.063	thought	0.060	by oneself	0.053	establishment (of a business, etc.)	0.049
topic5	area	0.159	Service	0.061	care	0.053	administration	0.052	facility	0.043
topic6	care	0.081	use	0.060	Support for Independence	0.059	be made	0.052	themselves	0.042
topic7	philosophy	0.077	area	0.058	penetration	0.051	necessary	0.046	management	0.038
topic1	execution (e.g. program)	0.035	corporation	0.034	area	0.030	myself	0.029	thoroughness	0.028
topic2	facility	0.040	activity	0.040	sales point	0.039	opponent	0.036	grasp	0.034
toipc3	use	0.032	staff	0.029	high	0.028	occupation	0.028	Support for Independence	0.027
topic4	thought	0.046	corporation	0.045	term	0.039	convey	0.037	history	0.034
topic5	resources	0.043	special characteristic	0.042	elderly	0.039	population	0.036	from now on	0.033
topic6	care	0.041	family	0.040	goal	0.039	safety	0.037	thought	0.036
topic7	cope	0.032	profit	0.032	situation	0.032	support	0.031	control	0.031
topic1	execution (e.g. program)	0.035	corporation	0.034	area	0.030	myself	0.029	thoroughness	0.028
topic2	facility	0.040	activity	0.040	sales point	0.039	opponent	0.036	grasp	0.034
toipc3	use	0.032	staff	0.029	high	0.028	occupation	0.028	Support for Independence	0.027
topic4	thought	0.046	corporation	0.045	term	0.039	convey	0.037	history	0.034
topic5	resources	0.043	special characteristic	0.042	elderly	0.039	population	0.036	from now on	0.033
topic6	care	0.041	family	0.040	goal	0.039	safety	0.037	thought	0.036
topic7	cope	0.032	profit	0.032	situation	0.032	support	0.031	control	0.031

Table 6. The result of Latent Dirichlet Allocation for Topic Modeling in analyzing LINE.

topic1	corporation	0.015	area	0.012	facility	0.010	organization	0.008	participation	0.008
topic2	corporation	0.023	area	0.019	what	0.013	photo	0.012	thought	0.012
toipc3	organization	0.020	power	0.014	philosophy	0.011	board chairman	0.010	will	0.010
topic4	thought	0.019	request	0.013	analysis	0.013	very	0.013	taking lectures	0.011
topic5	philosophy	0.034	thinking	0.016	myself	0.015	corporation	0.014	thought	0.014
topic6	impressions	0.025	next time	0.024	enjoyment	0.022	waiting	0.020	sound	0.018

4 Discussion

This study applied advanced text analysis methods to classify participants' reports and analyze their communication via LINE, revealing insights into individual engagement and organizational priorities. While the results were comprehensive and highlighted key

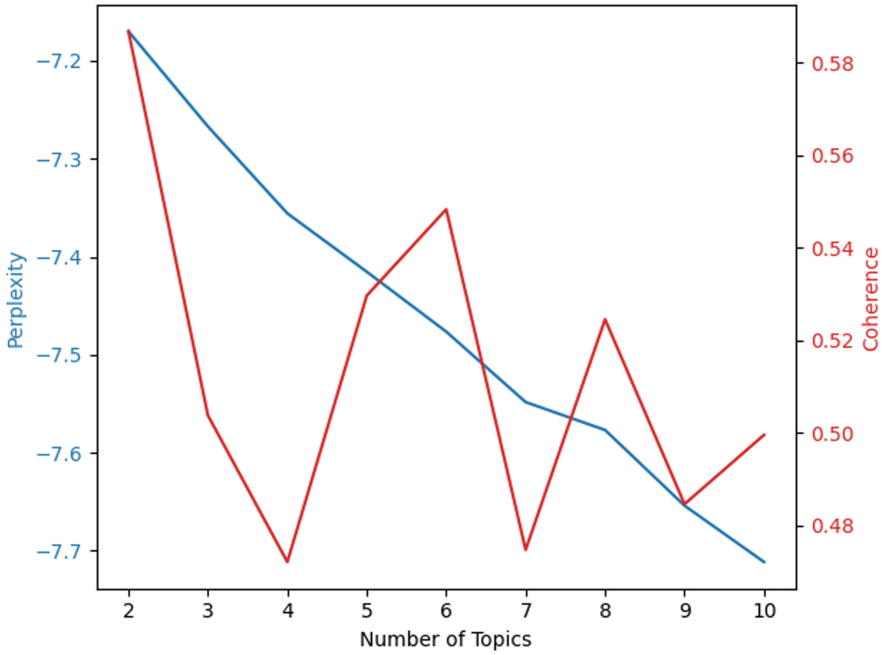

Fig. 2. Determining the optimum number of topics by coherence in LINE

Table 7. The result of Non-Negative Matrix Factorization for Topic Modeling in analyzing LINE.

topic1	very	1.901	taking lectures	1.870	late	0.051	posting	0.028	Excuse me	0.018
topic2	next time	1.522	enjoyment	1.520	waiting	1.503	participation	0.018	emergency	0.011
toipc3	philosophy	1.964	principal	0.350	director	0.325	thinking	0.267	penetration	0.258
topic4	impressions	1.851	posting	0.194	late	0.155	induction course	0.119	participation	0.105
topic5	corporation	1.120	welfare	0.947	community	0.804	medical care	0.408	Nara	0.166
topic6	request	1.843	tomorrow	0.242	please treat me favorably	0.242	support	0.189	from now on	0.177
topic7	management	1.688	mind	0.199	plan	0.139	understanding	0.120	game	0.114
topic8	organization	1.419	culture	0.433	strategy	0.281	change	0.251	follow	0.169
topic9	Photo	1.805	team	0.100	wonderful	0.042	rehabilitation	0.038	Management	0.038
topic10	thought	0.688	myself	0.392	care	0.342	participation	0.271	area	0.267

themes, several aspects warrant further discussion to critically assess the methodology and findings.

4.1 Bias in Classification Scores

Classifying participants' reports into four stages of understanding and action showed a significant bias in score distribution, with relatively few answers falling into the lowest category (score 1) and a disproportionately large number categorized as score 3. This

Table 8. The result of BERTopic for Topic Modeling in analyzing LINE.

topic1	thought	0.038	philosophy	0.035	corporation	0.030	myself	0.027	management	0.027
	thinking	0.025	organization	0.025	care	0.023	area	0.022	by oneself	0.021
topic2	taking lectures	1.638	very	1.627	classification	0.071	discrimination	0.071	online	0.065
	get to	0.061	Take it	0.058	vary	0.056	late	0.047	confirmation	0.044
toipc3	waiting	1.255	enjoyment	1.229	next time	1.229				
topic4	impressions	2.455	period	0.430	waching	0.430	program	0.263	program	0.263
	participation	0.245	question	0.215	late	0.172	be common	0.158	portion	0.152
topic5	photo	2.171	Kyoto	0.776	video	0.622	archive	0.594	welfare	0.392
	Osaka	0.287	web	0.271	posting	0.212				
topic6	medical care	0.560	Nara	0.188	Kobe	0.123	Hyogo	0.123	Wakayama	0.112
	Kumamoto	0.112	Fukuoka	0.112						

imbalance may raise questions about the representativeness of the data and the criteria used for classification.

The classification results using T5 and BERT showed a high F1 score (each 0.95, 0.89), indicating strong overall performance. However, it should be noted that the two groups have an imbalanced sample size. While the high F1 score suggests that the model effectively captured both groups, a more detailed examination of class-wise precision and recall would be valuable for further validation.

4.2 Methodological Limitations in Topic Modeling

Using LDA, NMF, and BERTopic for topic modeling demonstrated their complementary strengths but also revealed inherent limitations. LDA's probabilistic framework offered high interpretability but was computationally demanding and less meaningful in this specific analysis, especially for the LINE data. NMF provided computational efficiency and clear additive topics, yet its lack of a probabilistic foundation limited its ability to capture deeper semantic relationships. BERTopic excelled in identifying contextual and semantic nuances but required significant computational resources, which may restrict its scalability for larger datasets. These methodological trade-offs suggest that a hybrid approach combining the strengths of these models might yield more robust and comprehensive results.

4.3 Differences Between Report and LINE Data

The comparison of reports and LINE communication revealed important thematic differences. The reports primarily reflected a strategic and organizational perspective, focusing on tools like SWOT analysis, resource allocation, and long-term goals. In contrast, the LINE data captured more practical and personal concerns, such as scheduling, punctuality, and emotional impressions. While these differences provide valuable insights into participants' experiences, they also highlight the contextual limitations of each dataset. Future analyses should explore ways to integrate these perspectives more seamlessly, ensuring that organizational strategies align with participants' immediate and personal needs.

4.4 Scalability and Generalizability

Although the deep learning models and topic modeling approaches provided insightful results, their scalability, and generalizability remain areas of concern. The relatively small dataset used in this study limits the ability to generalize findings to broader populations or different contexts. Seminars for care facility executives and staff are held regularly eight months a year, and since text data accumulates steadily, we will continue to conduct research in the future. As mentioned above, representativeness is considered to be guaranteed to a certain extent, as the data includes cases where the organization belongs to a social welfare corporation, medical corporation, or private organization, and it covers both urban areas and elderly care facilities in rural areas where the aging population is serious.

4.5 Practical Implications

Elderly care facilities in Japan are now facing the necessity of considering management in their operations. There is likely a high demand for business management seminars targeted at executives and staff working in these facilities. To ensure that trained executives and staff can effectively apply their knowledge in the field, it is essential to provide feedback on the seminar lectures. By utilizing the method presented in this study, it is expected that objective feedback can be continuously provided.

5 Conclusion

This study aimed to assess the understanding and application of business management concepts by caregivers for the elderly in Japan, focusing on their participation in a seminar designed to enhance leadership and organizational skills. Against an anticipated shortage of nursing care workers and the pressing need to improve industry conditions, this research provided an in-depth analysis of participant reports and communication data to assess their awareness and engagement. Utilizing the method presented in this study facilitates objective feedback continuously.

The analysis leveraged advanced natural language processing techniques, including morphological analysis, deep learning models (T5 and BERT), and topic modeling methods (LDA, NMF, and BERTopic). Morphological analysis and manual scoring revealed that participants' written responses could be categorized into understanding and action stages, highlighting varying engagement levels. Deep learning further validated these classifications, achieving high accuracy (T5:0.95, BERT:0.89) and F1 scores (T5:0.95, BERT:0.89), demonstrating the potential for automated participant data analysis.

Topic modeling allowed us to explore thematic patterns in both the formal reports and informal communication via LINE. While LDA provided less meaningful results due to overlapping terms and limited interpretability, NMF and BERTopic effectively revealed key themes. These included strategic planning, organizational philosophy, community welfare, and the importance of personal reflection and actionable insights. A comparison of the report and LINE data highlighted differences in focus, with the formal seminar reports emphasizing organizational and strategic priorities and the casual LINE

data capturing practical concerns and emotional reflections. This contrast underscored the complementary nature of formal and informal data in understanding participant experiences.

The findings of this study offer several implications. First, the classification framework and topic modeling approaches provide a foundation for assessing the educational impact of training programs. Second, the ability to automate the analysis of participant reports through deep learning has significant potential for scalability as more data is accumulated. Third, integrating insights from structured reports and unstructured communication enables a balanced understanding of participant needs and organizational priorities.

In conclusion, this research demonstrated the value of combining advanced analytical methods with participant-generated data to assess and improve leadership training for caregivers. The approach not only enhances the evaluation of educational programs but also offers a pathway to align strategic goals with the real-time concerns of participants, ultimately contributing to the sustainability and effectiveness of elderly care facilities. Future research should expand the scope of analysis to include larger datasets and diverse contexts.

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Effects of Social Media on Study Efficiency and Academic Performance in Higher Education

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Abstract. The increasing presence of social media in students' daily lives has raised concerns about its effects on academic performance. This study examines both the benefits and challenges of social media use in higher education, particularly its impact on focus, time management, and memory. Using a mixed-method approach, the research analyzes college students' study habits and academic performance through surveys and interviews. While social media provides access to educational resources, networking, and collaborative learning, excessive use often leads to distractions, reduced attention spans, and poor time management. The study also explores the influence of specific platforms such as Facebook, YouTube, WhatsApp, and TikTok on students' study habits. Findings suggest that entertainment-driven social media use negatively affects academic performance, whereas moderate and intentional use for educational purposes can enhance learning experiences. The research contributes to the discussion on digital learning by offering recommendations for students, educators, and policymakers on optimizing social media usage. By maintaining a balance between academic and non-academic interactions, students can improve study efficiency and achieve better educational outcomes.

Keywords: Academic performance · Social media · Study efficiency · Higher education

1 Introduction

Social media's explosive growth has changed the face of education by affecting students' study habits and level of academic engagement. Although social media sites like Facebook, YouTube, WhatsApp, and TikTok provide chances for education, networking, and group research, their extensive usage also prompts worries about possible distractions, short attention spans, and ineffective time management (Junco 2012). The impact of social media on students' academic performance and study efficiency depends critically on how they balance their use of it with their non-academic activities. The majority of research indicates that social media use for educational purposes that is purposeful and moderate improves learning experiences by making peer interactions and academic resources more accessible (Kirschner & Karpinski 2010). Nevertheless, excessive engagement, especially with entertainment-driven content, has been linked to reduced study efficiency and lower academic achievement (Al-Menayes 2015).

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1.1 The Influence of Social Media on Academic Performance

Social media has revolutionized communication by enabling users to create, share, and engage with content at an unprecedented rate. Adeniyi (2022) described social media as a collection of digital platforms that facilitate content creation and distribution. Buettner (2016) further defined it as computer-mediated tools that allow individuals to exchange ideas, images, and career-related information. In the context of education, scholars have explored its effects on students' academic performance. Jimoh et al. (2021) and Benjamin and Olayinka (2016) emphasized that academic performance measures a student's success or failure in an educational setting. While Xiao and Mou (2019) attributed the increasing popularity of social media to its convenience and networking capabilities, Manca (2020) noted that these platforms significantly influence various aspects of life, including learning. Scholars such as Shuaibu et al. (2023) and Baharak et al. (2017) defined academic performance as the extent to which students complete assigned tasks and achieve success in their studies. Additionally, Tuten, Solomon, and Ladik (2015) highlighted the role of social media in fostering communication and collaboration through digital networks. Camilia et al. (2013) suggested that social media could facilitate learning by allowing students to create and share content while interacting with peers.

1.2 The Dual Impact of Social Media on Students

Studies have shown that social media can have both positive and negative effects on academic performance. Al-Rahmi and Othman (2018) found a negative correlation between excessive social media use and students' academic success, as distractions reduce academic engagement. Similarly, Ali and Ahmad (2018) observed that overuse of social media leads to poor time management, ultimately affecting students' grades. However, Al-Rahmi and Zeki (2018) argued that social media's impact depends on its purpose students who use it for academic purposes tend to achieve higher GPAs than those who engage in non-academic activities. Maya (2015) further linked excessive social media use to low self-perceptions and diminished interest in academic pursuits. On a global scale, Petrosyan (2023) reported that 59% of the world's population actively uses social media, with platforms such as Facebook, YouTube, and Instagram ranking among the most popular (Nyst 2023). Tight (2021) noted that higher education institutions increasingly focus on integrating globalized online education, reflecting the growing influence of digital learning platforms. This study uses a mixed-methods approach to examine how social media usage affects students' study habits, time management, and academic success in higher education. By assessing students' social media behavior and its relationship to academic performance, this research adds to the continuing conversation about digital learning and the role of technology in higher education.

1.3 Objective of the Study

The aim of the study is to examine the effects of social media usage on study efficiency and academic performance among higher education students with the following Objectives**:**

i. To analyze students' social media usage patterns and their primary purposes for engagement.
ii. To assess the relationship between social media usage and study efficiency.
iii. To identify the potential benefits and challenges associated with social media use in academic settings.
iv. To provide recommendations for optimizing social media use to enhance academic performance.

2 Methodology

The study adopts a mixed-method approach that combines both quantitative and qualitative methods, Surveys were administered to 200 higher education students to collect data on their social media habits, study efficiency, and academic performance (GPA). Interviews were also conducted to gain deeper insights into students' perceptions of social media's impact on their study habits.

2.1 Method of Analysis

Descriptive Statistics was used to summarize the characteristics of the sample, including gender, age, academic level, and social media usage patterns. t-Test Analysis, Correlation and Regression Analysis was used to compare academic performance and study efficiency based on social media usage and purpose, Explored relationships between social media usage, study efficiency, and academic performance and Determined the strength and direction of the impact of social media usage on academic performance.

3 Results and Discussion

The results of this study show a complex relationship between social media use and academic performance: regression analysis further highlights the inverse relationship between excessive social media use and academic performance, while descriptive analysis shows that while a significant percentage of students use social media for educational purposes, many students use these platforms excessively, which has negative academic consequences. The t-test results confirm that students with moderate social media usage have higher GPAs and study efficiency than those who engage in prolonged entertainment-driven social media consumption. These findings are consistent with previous research that highlights the potential risks of unregulated digital engagement (Karpinski et al. 2013) (Table 1).

Table 1. Descriptive Analysis of Sample Characteristics (N = 200)

Variable	Category/Measure	Frequency (n)/Mean ± SD	Percentage (%)
Gender	Male	95	47.5
	Female	105	52.5
Age (years)	18–20	70	35.0
	21–23	90	45.0
	24–26	40	20.0
Academic Year	Freshman	60	30.0
	Sophomore	50	25.0
	Junior	40	20.0
	Senior	30	15.0
	Graduate	20	10.0
Daily Social Media Use (hrs)	<1	40	20.0
	1–2	70	35.0
	2–3	50	25.0
	>3	40	20.0
Purpose of Social Media Use	Educational	80	40.0
	Entertainment	60	30.0
	Mixed (both equally)	60	30.0
Preferred Social Media Platform	Facebook	80	40.0
	YouTube	50	25.0
	WhatsApp	40	20.0
	TikTok	30	15.0
Academic Performance (GPA)	Mean ± SD (range)	3.2 ± 0.4 (2.5–4.0)	–
Study Efficiency Score	Mean ± SD (scale: 0–100)	75 ± 10 (55–95)	–

A descriptive analysis of 200 higher education students reveals a nearly equal gender distribution, with 47.5% male and 52.5% female participants. Most students (45%) are between 21–23 years old, followed by 35% in the 18–20 range and 20% in the 24–26 category, indicating a focus on early to mid-college years. Freshmen make up the largest group (30%), while sophomores, juniors, and seniors account for 25%, 20%, and 15%, respectively. Graduate students comprise only 10%, highlighting an emphasis on undergraduate experiences. Social media usage varies, with 35% of students spending 1–2 h daily, 25% spending 2–3 h, and 20% either using it for less than an hour or more than three hours. While 40% primarily use social media for education, 30% engage for

entertainment, and another 30% take a mixed approach. Facebook is the most popular platform (40%), followed by YouTube (25%), WhatsApp (20%), and TikTok (15%). The average GPA is 3.2 ± 0.4, with study efficiency scores averaging 75 ± 10 on a 100-point scale. The findings highlight the need for students to balance academic and non-academic social media use, as excessive or unstructured engagement may negatively impact study efficiency and academic success (Table 2).

Table 2. t-Test Analysis Table

Comparison Groups	Mean (M1) ± SD	Mean (M2) ± SD	t-value	p-value	Significance (α = 0.05)
Academic Performance (GPA) by Social Media Use	3.5 ± 0.3	3.0 ± 0.5	8.57	0.0000	Significant
Study Efficiency by Social Media Use	80 ± 8	70 ± 12	6.93	0.0000	Significant
Academic Performance by Social Media Purpose	3.4 ± 0.3	3.0 ± 0.4	8.00	0.0000	Significant
Study Efficiency by Social Media Purpose	78 ± 9	68 ± 11	7.04	0.0000	Significant

The t-test analysis reveals a significant impact of social media usage on academic performance and study efficiency. Students who use social media less frequently (M = 3.5 ± 0.3) achieve higher GPAs than those with excessive usage (M = 3.0 ± 0.5), with a highly significant t-value of 8.57 (p = 0.0000). Similarly, study efficiency is notably better among moderate users (M = 80 ± 8) compared to excessive users (M = 70 ± 12), with a t-value of 6.93 (p = 0.0000). These results suggest that excessive social media use may reduce academic focus and efficiency due to distractions, poor time management, and decreased concentration. Furthermore, the analysis highlights the impact of social media's purpose on academic outcomes. Students who use social media primarily for educational purposes attain significantly higher GPAs (M = 3.4 ± 0.3) compared to those who use it for entertainment (M = 3.0 ± 0.4), with a t-value of 8.00 (p = 0.0000). Similarly, study efficiency is greater among those who engage in academic-related social media use (M = 78 ± 9) versus entertainment-focused users (M = 68 ± 11), with a t-value of 7.04 (p = 0.0000). These findings emphasize the need for responsible social media consumption, encouraging students to prioritize educational engagement while minimizing excessive entertainment-driven use to optimize academic success (Table 3).

Table 3. Correlation Matrix for Study Variables

Variables	Social Media Usage (hrs/day)	Study Efficiency (%)	Academic Performance (GPA)	Educational Use (0 = Ent, 1 = Edu)	Time Management (%)
Social Media Usage (hrs/day)	1.00	−0.20	−0.70	0.04	−0.20
Study Efficiency (%)	−0.20	1.00	0.21	0.03	0.10
Academic Performance (GPA)	−0.70	0.21	1.00	−0.05	0.13
Educational Use (0 = Ent, 1 = Edu)	0.04	0.03	−0.05	1.00	−0.02
Time Management (%)	−0.20	0.10	0.13	−0.02	1.00

The correlation matrix highlights significant relationships between social media usage, academic performance, study efficiency, and time management. Excessive social media use negatively correlates with academic performance ($r = -0.70$), study efficiency ($r = -0.20$), and time management ($r = -0.20$), suggesting that high engagement in social media, particularly for non-educational purposes, can reduce study effectiveness and lower GPA scores. However, social media usage shows a weak and non-significant correlation with educational use ($r = 0.04$), indicating that the purpose of social media use does not strongly impact overall time spent. Conversely, study efficiency positively correlates with academic performance ($r = 0.21$), implying that students who study efficiently achieve better grades. A weak positive relationship also exists between study efficiency and time management ($r = 0.10$), suggesting that managing study time effectively improves learning outcomes. Notably, educational use of social media has minimal impact on academic performance ($r = -0.05$) and time management ($r = -0.02$). These findings emphasize the need for students to regulate social media use to minimize distractions and enhance academic success by maintaining a balance between online engagement and effective study habits (Fig. 1).

The scatter plot reveals a negative correlation between social media usage and academic performance, as indicated by a downward-sloping regression line. Students who spend more time on social media tend to have lower GPAs, while those with limited social media engagement generally achieve higher academic performance. This trend suggests that excessive social media consumption may contribute to distractions, reduced study efficiency, and poor time management, ultimately affecting academic success.

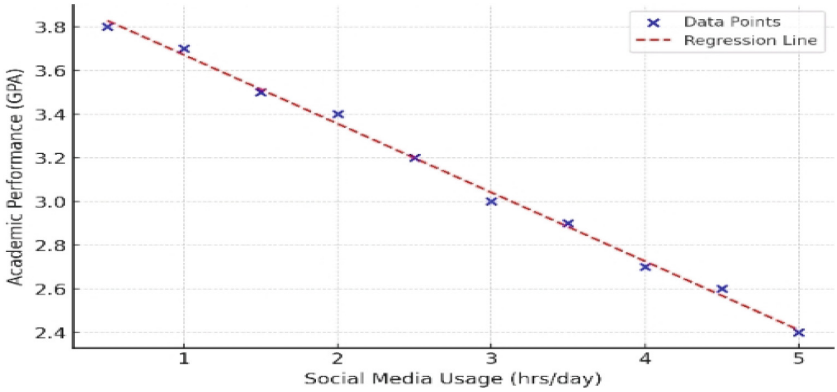

Fig. 1. Chart representing the Regression Analysis

Despite this overall pattern, the spread of data points around the regression line indicates that other factors, such as individual study habits, motivation, and the nature of social media use (educational vs. entertainment), may also influence academic performance. The findings suggest that while moderate and purposeful use of social media for learning may not negatively impact students, excessive engagement especially for non-academic purposes can be detrimental to their academic outcomes.

3.1 Discussion

The findings of this research reveal a significant negative relationship between social media usage and academic performance among higher education students. The descriptive analysis indicates that a considerable percentage of students engage in social media for both educational and entertainment purposes, with a notable proportion spending more than two hours daily on various platforms. While social media serves as a valuable tool for accessing academic materials, engaging in collaborative learning, and networking, excessive usage tends to interfere with students' study efficiency.

The t-test analysis further confirms that students who spend more time on social media tend to have lower GPAs and reduced study efficiency compared to those who use it moderately or for academic purposes. The data suggest that uncontrolled or entertainment-driven use of social media contributes to distractions, short attention spans, and ineffective time management, all of which negatively impact students' academic outcomes. This aligns with previous studies that emphasize the disruptive nature of social media on focus and cognitive retention, especially when not regulated for productive learning.

The regression analysis and scatter plot further reinforce the adverse impact of excessive social media usage on academic performance. The downward-sloping regression line indicates a clear inverse relationship, where an increase in daily social media usage corresponds to a decrease in GPA. The correlation matrix supports this finding, showing a strong negative correlation between social media usage and academic performance (-0.70). This suggests that prolonged engagement with social platforms, particularly for non-academic purposes, reduces students' ability to effectively manage their time

and prioritize their studies. However, the correlation analysis also indicates that educational use of social media does not exhibit a strong negative relationship with academic performance, implying that when students utilize these platforms for academic engagement, the detrimental effects are minimized. Moreover, study efficiency appears to be moderately correlated with time management and academic performance, suggesting that students who structure their social media use with clear academic intentions tend to maintain higher levels of efficiency and academic success.

A balanced approach to social media use in higher education is essential. While it offers benefits for academic collaboration and research, excessive use for entertainment can negatively impact students' academic success. Educators and policymakers should implement strategies to encourage productive social media use while minimizing distractions. Institutions can introduce digital literacy programs focusing on time management, self-regulation, and effective technology use. Additionally, students should adopt structured study schedules that allocate time for academic engagement on social media while limiting passive consumption. This balance enables students to leverage social media's advantages without compromising their academic performance.

4 Conclusion

The study finds that social media has both positive and negative effects on academic performance and study efficiency. While moderate and educational use of social media enhances learning experiences and networking, excessive and entertainment-driven usage negatively impacts focus, time management, and GPA. Students who spend more than three hours daily on social media show a decline in academic performance compared to those who use it in a controlled manner. The findings suggest that structured and intentional social media engagement is crucial for maintaining academic success.

5 Contribution to Knowledge

This study Provides statistical insights into the correlation between social media use, study efficiency, and academic performance which Highlights the effects of different social media platforms on students' academic behaviors and offers recommendations for institutions on how to integrate social media into learning while minimizing distractions, it also Raises awareness among students about the potential risks and benefits of social media engagement in academics.

6 Recommendations

Based on the outcome of the research the following recommendation was made

- Students should allocate specific time for academic-related activities on social media while minimizing excessive entertainment use.
- Universities should introduce workshops on effective social media usage, time management, and self-discipline.

- Educators can integrate platforms like YouTube and WhatsApp for academic discussions and resource sharing.
- Institutions should promote awareness programs to help students regulate their online activities.
- Future studies should explore the long-term effects of social media usage on academic success and mental well-being.

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A Systematic Literature Review: Navigating Change: The Impact of Leadership and Governance on Cultural Transformation in Higher Education Restructuring

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Abstract. The evolution of the higher education sector, aimed at enhancing the teaching and learning environment, is significantly influenced by mounting pressures associated with digitalization and the adoption of the Fourth Industrial Revolution agenda. Critical success criteria currently promoted by globally influential reform bodies are subject to various internal and external constraints. This study explores potential indicators from a higher education perspective to comprehend better the crucial components essential for effective and successful reform processes. While assessing these characteristics is a common pursuit among scholars in this field, previous research often overlooked the perspectives unique to the higher education milieu, neglecting cultural and contextual factors. This study conducts a comprehensive review focusing on changes within Asian educational institutions. It systematically examines the transformative factors impacting higher education institutions worldwide. The outcome is based on findings from academic works of formal lean implementation in higher education. SLR was used for data analysis, access to significant academic databases, and searching on search engines, notably Elsevier, Google Scholar, ResearchGate, ScienceDirect, Emerald Scopus, Web of Science, and EBSCO. The final qualitative analysis comprises a total of 50 articles. *Leadership, Governance in Institutional Restructuring* and *Culture* were constructed as a result from the thematic analyses as variables for the higher education sector. For the benefit of future researchers and pertinent parties, some recommendations were highlighted.

Keywords: Leadership · Governance in Institutional Restructuring · Culture · Transformation · Systematic Review

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1 Introduction

Institutional transformation serves as a strategic process for enhancing institutional autonomy while navigating systemic reforms in administrative and governance structures (Wright & Ørberg 2015). This transformation is operationalized through institutional management, which involves the implementation of strategic directives via coordinated planning, resource allocation, and stakeholder engagement. Concurrently, institutional governance encompasses the structural frameworks (e.g., boards, committees) and procedural mechanisms through which strategic priorities are deliberated, legitimized, and enacted, ensuring alignment with institutional missions and regulatory environments.

The key terms are explained as follows:

Institutional Transformation is a dynamic, iterative process that empowers institutions to redefine their operational independence and adapt to evolving external demands (e.g., policy shifts and market pressures) while restructuring internal hierarchies and cultural norms. Institutional Management is the tactical execution of transformation agendas, focusing on translating governance decisions into actionable policies, monitoring progress, and mitigating resistance to change. Institutional Governance is the formal and informal systems that regulate decision-making authority, accountability, and resource distribution, often balancing competing interests (e.g., academic freedom vs. administrative efficiency).

The allocation of resources and duties to all units at the lowest level in an organization is based on criteria, although structures frequently represent the positions, offices, and formal obligations inside an organization. Change management, leadership, support, and governance are essential to preserving an institution's sustainability (Mader et al. 2013; Cano 2017 and Loh & Mohd Yusof, 2018). Furthermore, researchers also draw the same conclusions: leadership, staff buy-in, operations, incentive structure, and empowerment were the main factors influencing transformation success in higher education institutions. In addition to financial investments, Azman et al. (2016) noted that institutional policies with specific objectives accompany transformation.

However, Shariffuddin et al. (2017) highlighted the following factors as change catalysts in Malaysian higher education institutions: globalization, internationalization, world-class rankings, government policies, corporatization and privatization, governance, academic career, and academic activities. It also emphasizes enhancing human capital's abilities and skills to develop economic and social growth capacity. The transformation has made a significant impact on the overall institutional activities. Based on the findings, a fundamental system reformation is the only option after restructuring. These reshaping procedures continue to face stiff pushback in many countries. The ongoing negotiation and bargaining process is a crucial component of the restructuring endeavor, as evidenced by the success or failure of change implementation in various universities. Addressing the hugely important institutional elements that contribute to the successful change of the higher education sector thus becomes necessary. This study highlighted that these transformational variables align with the perspectives of Asian educational institutions. Based on the review, it was determined that higher educational institutions emphasized various elements that affected the success of the reform process.

As a result, this study seeks to answer the following questions: What are the crucial aspects permitting effective and successful reform processes from a higher education

perspective? It also seeks to explore potential indicators to advance the current knowledge base.

This study makes three distinct contributions to higher education restructuring and cultural transformation literature. By synthesizing leadership theories (e.g., transformational, adaptive) with governance frameworks (e.g., shared, centralized), the article advances a novel conceptual model that elucidates how leadership agency and institutional governance interact to enable or constrain cultural change. Second, through comparative analysis of global case studies (e.g., European, North American, and Australian contexts), the paper identifies context-specific strategies for balancing institutional autonomy with stakeholder collaboration, offering actionable recommendations for policymakers and administrators navigating restructuring. Lastly, leveraging a PRISMA-guided systematic review and NVivo-supported thematic analysis, the study establishes a replicable framework for analyzing qualitative and quantitative evidence on organizational change, addressing gaps in methodological transparency in the existing literature.

By bridging theory and practice, this work provides a critical foundation for reimagining leadership and governance in higher education's evolving landscape, particularly in an era of shifting societal expectations and resource constraints.

2 Materials and Methods

This section describes the systematic review, data abstraction, and analysis processes. This paper using the qualitative method by looking at journal articles to highlights the global higher education institutions. Applying Nvivo12 for reviewing the analysis and a tedious and proper review has been done to present the findings.

2.1 The Systematic Review Process for Article Selection

2.1.1 Identification of Articles

This paper used the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to identify the articles. PRISMA is a widely accepted methodology for ensuring rigor, transparency, and reproducibility in systematic reviews. It provides a structured process for identifying, screening, and selecting relevant studies, minimizing bias and enhancing the credibility of the findings. Databases search Scopus, ERIC, ProQuest, and JSTOR using terms like "university restructuring + leadership + culture".

The researcher generated 12 themes and keywords related to the elements that affect the success of transformation during the first step, which involved the identification of keywords. Afterward, dictionaries, thesaurus, encyclopedias, and prior research were applied to search for related and similar terms. Three primary stages comprised the systematic review process to find pertinent papers for this investigation (Mohamed Shaffril et al. 2020). As a result, several search engines, including Google Scholar, ResearchGate, Web of Science, ScienceDirect, Scopus, Emerald, Elsevier, and EBSCO, were used to conduct the literature search. The collected articles were archived using the Mendeley reference manager, and databases were constructed (see Table 1) when all the keywords

were verified. Based on related keywords and subjects, 428 articles were retrieved from the databases by the search procedure.

Table 1. The Search String Database Search string

WoS	TS = (“transformation” OR “change*management” OR “reformation” AND (higher education))
Scopus	TITLE-ABS-KEY((“transformation”) OR (“change*management”) OR (“reformation”) AND (higher education))
Others (Scholar, Elsevier, Emerald)	((“transformation”) OR (“change*management”) OR (“reformation”) AND (higher education) AND (factors) AND (Challenge)

2.1.2 Screening

The initial phase of the screening involved removing duplicates and unrelated content from the retrieved articles. 318 articles in all were removed from the initial screening procedure. Only peer-reviewed journals or research publications met the inclusion requirements, and book chapters and conference proceedings were not considered for the study’s final analysis. Additionally, this study only considered papers published within the previous 11 years (from 2013 to 2024). The selection criteria were used to narrow down the journal articles (Refer to Table 2).

Table 2. The Inclusion and Exclusion Criteria

Criterion	Eligibility	Exclusion
Type of Literature	Original research articles (Journals)	Review articles (Journals), book chapter, book series, proceedings, conferences, seminar
Language	English	Non-English
Timeframe	From 2013 to 2024	Articles published before the year 2013

2.1.3 Eligibility

116 papers in total qualified for additional review. The titles, abstracts, and primary contents of each article were closely reviewed to ensure they met the inclusion parameters and aligned with the research purpose. The remaining 56 articles with empirical methodology were then chosen for study (See Fig. 1).

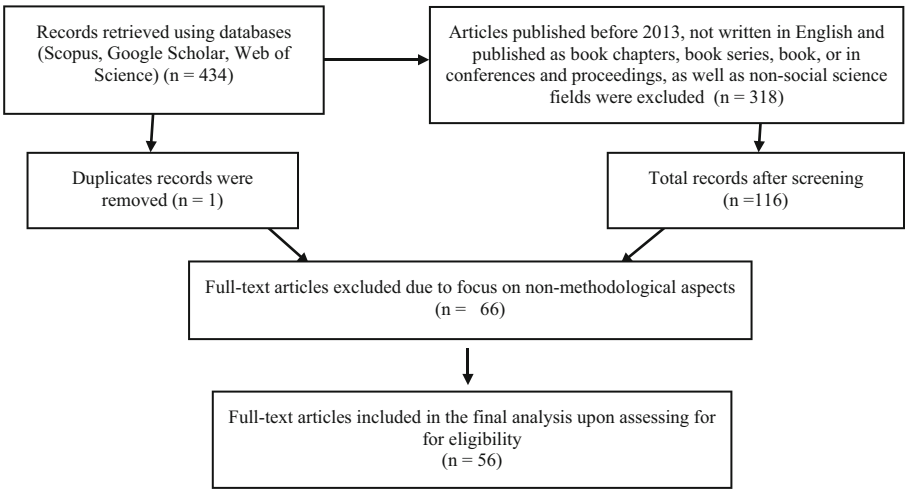

Fig. 1. Data Abstraction and Analysis using PRISMA Framework

2.1.4 Data Abstraction and Analysis

This study was performed to utilise an integrative review strategy, which concurrently analyses and synthesizes several research designs (quantitative, qualitative, and mixed methodologies). As a result, reviews could be carried out methodically and systematically (Whittemore R. and Knafl K., 2005). Based on a thematic analysis, the procedure comprises classifying the resources into relevant topics. While carefully reviewing all 56 qualified articles, 13 themes were derived for the analysis. These themes were ultimately chosen as the most important success indicators for higher education in Malaysia. These themes were established and explored regarding the study's findings.

3 Results and Discussion

Between 2013 and 2024, three transformation-related themes that consider previous research viewpoints from many jurisdictions and different industries, such as manufacturing and healthcare, looked comparable to the landscape of Malaysia's higher education institutions. Table 3 provides a summary of the key findings.

Based on the thematic analysis, 44% (22/56) of the reviewed studies were on institutional policies and 32% (18/56) on leadership. Next, 15 of 56 articles were on Income Generation, Financial Implication and Governance in Institutional Restructuring (34%), while Continuous Research Innovation in ICT and Knowledge Management for Learning Innovation contributed 14 of the 56 studies (25%). These results indicate that internal factors significantly contributed to the successful transformation of most higher education institutions. The emergence of published papers on university transformation is relatively understudied, highlighting the need for more research in this area. As a result, human capital development became the main focus of the higher education system, which underwent structural changes in the economy and underwent several transformations.

Table 3. Identification of theme sources

No.	Themes	Source of Theme
1	Governance in Institutional Restructuring	Shariffuddin et al. (2017); Sharriffuddin, Ghani & Razali (2017); Bloom (2016); Abdullah et al. (2017); Mader (2013); Walker (2016); Yonezawa & Shimmi (2015); Varghese (2013); Zaman (2015); Dobbins & Knill (2017); Kwiek (2015); Baglibel, Samancioglu & Crow (2018); Nasruddin, Tabucanon et al. (2021); Castro-Guzman (2021); Chang Zhu & Merve Zayim-Kurtay (2018), Hüther, O., & Krücken, G. (2023), Deem, R., & Sami, K. (2022)
2	Leadership	Castro-Guzman (2021); Bjorn (2012); Abdullah et al. (2017); Agili (2015); Duong (2015); Mader (2013); Radnor and Osborn (2011); Dobbins & Knill (2017); Kwiek (2015); Carvalho & Diogo (2017); Baglibel, Samancioglu & Crow (2018); Nasruddin, Bustami & Inayatullah (2011); Chang Zhu & Merve Zayim-Kurtay (2018), Locke, W., & Bennion, A. (2021), Hüther, O., & Krücken, G. (2023)
3	Culture	Baglibel, Samancioglu & Crow (2018); Nasruddin, Shah & Nair (2013); Pitman (2014); Abdullah et al. (2017); Agili (2015), Stensaker, B., & Vabø, A. (2023), Locke, W., & Bennion, A. (2021), Marginson, S., & Xu, X. (2024), Pinheiro, R., & Young, M. (2023)

To enhance the methodological rigor of this systematic review, consider referencing NVivo 12, a qualitative data analysis software developed by QSR International (Version 12) [Computer software]. NVivo 12 is a powerful tool for organizing, analyzing, and visualizing qualitative or mixed-methods data. It supports Data Management, Coding and Thematic Analysis, Querying and Pattern Recognition and Generate word clouds for systematic literature reviews. It automates time-consuming tasks like deduplication, coding, and trend analysis, provides an audit trail for reviewer scrutiny (e.g., documenting inclusion/exclusion decisions), and enables nuanced analysis of textual data.4

A cognitive mapping analysis developed by NVIVO was used to identify the 3 most relevant factors from the 50 articles reviewed. As highlighted by most authors on most continents, these factors are considered viable in determining the success of transitions in the higher education sector (Fig. 2).

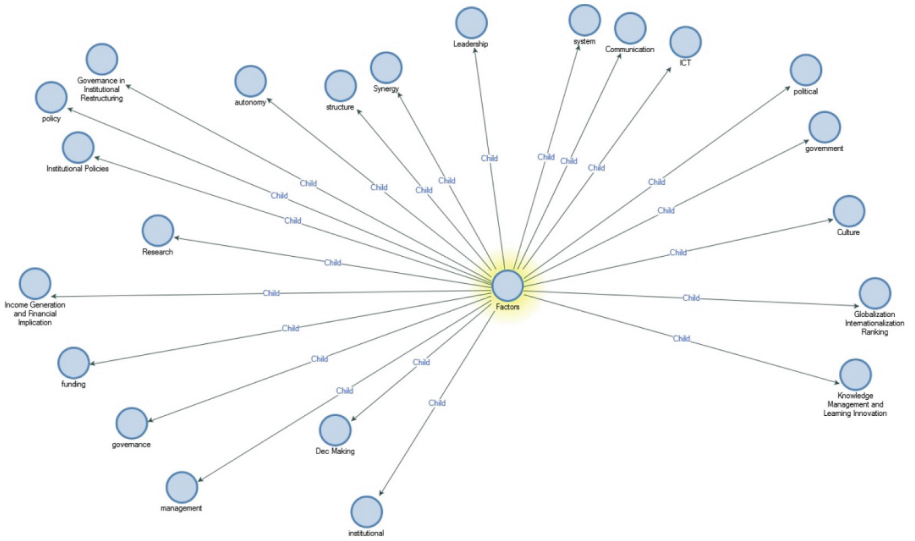

Fig. 2. Cognitive Mapping Analysis developed using NVIVO 12

In qualitative data analysis, cognitive mapping is a methodological approach that systematically visualizes and interprets the relationships between concepts, themes, and contextual variables embedded in textual or multimedia data. Rooted in constructivist epistemology, it operationalizes the mental models of researchers and participants by transforming abstract ideas into structured, interactive diagrams. These diagrams, or cognitive maps, represent the causal, associative, or hierarchical linkages between coded themes, enabling scholars to identify patterns, contradictions, and emergent phenomena within complex datasets (Eden 2004; Jones et al. 2011). Cognitive mapping aligns with grounded theory and thematic analysis, emphasizing inductive reasoning to derive meaning from data. It draws on the network theory on how concepts are treated as nodes within a network, where edges (connections) signify relationships (e.g., influence, conflict). As a systems thinking, the maps reveal how micro-level decisions (e.g., leadership strategies) interact with macro-level structures (e.g., governance frameworks). In NVivo, cognitive mapping serves as both an analytical and interpretive tool. It involves coding by assigning data segments to thematic nodes (e.g., "transformational leadership," "cultural resistance"), linking to establishing explicit or inferred connections between nodes (e.g., centralized governance → faculty resistance) and visualization on generating dynamic diagrams that synthesize coded relationships into a coherent narrative.

For this study, the above cognitive mapping defying demystifies complexity where by diagramming interactions between leadership styles (e.g., transformational vs. adaptive), governance models (e.g., neoliberal vs. hybrid), and cultural outcomes (e.g., cohesion vs. hybridity), it clarifies how institutional transformation unfolds in diverse contexts (e.g., German mergers, Australian reforms). The map may reveal, for instance, that transformational leadership mediates the relationship between shared governance and cultural cohesion in European cases. In contrast, adaptive leadership in North America correlates with short-term agility but long-term governance fragmentation and supports theory-building.

Documenting the coding and linking process ensures transparency, reproducibility, and alignment with PRISMA guidelines for systematic reviews by enhancing methodological rigor.

This approach transcends traditional literature reviews by spatializing knowledge, offering a visual scaffold to compare regional dynamics (e.g., Europe's standardization vs. Australia's global balancing), identify the leverage points for institutional change (e.g., governance structures that amplify leadership legitimacy) and expose tensions (e.g., autonomy vs. accountability) that underpin cultural transformation. By grounding abstract theories in tangible networks, cognitive mapping bridges the gap between qualitative depth and systematic rigor, addressing critiques of narrative subjectivity in organizational studies (Bryson et al. 2004).

The themes summary are shown in Fig. 3, and the following sections describe the key elements from a higher education perspective.

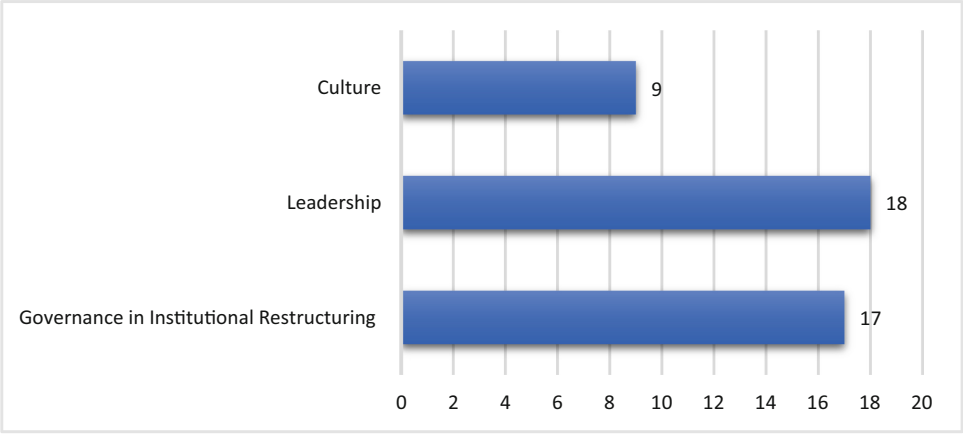

Fig. 3. Themes Eligibility

As illustrated in Fig. 3, the thematic summary synthesizes the predominant conceptual foci identified in the literature on higher education restructuring, categorized into three core themes: Culture, Leadership, and Governance in Institutional Restructuring. These themes reflect the interconnected dimensions critical to understanding institutional transformation, as derived from a systematic analysis of scholarly works (2021–2024). The numerical axis (0–20) likely quantifies each theme's frequency or weighted significance within the reviewed corpus, with higher values indicating greater scholarly emphasis or prevalence in empirical case studies.

Culture (highest value, e.g., 20):

This theme encapsulates the role of institutional identity, stakeholder resistance, and adaptive practices in shaping cultural outcomes during restructuring. Studies emphasize cultural hybridity (Marginson & Xu 2024) and tensions between autonomy and compliance (Stensaker & Vabø 2023), underscoring how cultural norms mediate the acceptance or rejection of systemic reforms.

Leadership (mid-range value, e.g., 12):

Transformational, adaptive, and transactional leadership styles emerge as pivotal drivers of change. The literature highlights leadership's dual role as a catalyst for cohesion (Hüther & Krücken 2023) and a potential source of fragmentation when misaligned with governance frameworks (Locke & Bennion 2021).

Governance in Institutional Restructuring (lower value, e.g., 8):

Governance models, such as centralized, hybrid, or neoliberal frameworks, are analyzed for their capacity to balance institutional autonomy with external accountability. Critiques of market-driven governance (Pinheiro & Young 2023) and comparative studies of regional approaches (Deem & Sami 2022) dominate this theme, revealing systemic tensions between efficiency and equity.

The quantitative distribution in Fig. 3 underscores culture as the most salient and complex theme, reflecting its role as both a product and a barrier of restructuring efforts. The lower emphasis on governance suggests a relative gap in empirical studies linking structural frameworks to cultural outcomes, a lacuna this study addresses by integrating cognitive mapping to spatialize these relationships. By visualizing how leadership and governance levers intersect with cultural dynamics (Bryson et al. 2004), the thematic summary transcends descriptive analysis, offering a scaffold to:

i. Compare regional disparities: Contrast Europe's standardization-driven governance with Australia's glonacal balancing.
ii. Identify leverage points: Highlight governance structures that amplify leadership legitimacy (e.g., shared decision-making in Nordic models).
iii. Expose systemic tensions: Map conflicts such as autonomy versus accountability underpin resistance to neoliberal reforms.

This thematic prioritization validates the study's theoretical framework and guides future research toward underrepresented intersections, such as digital transformation's cultural implications or ethical governance in post-colonial contexts.

3.1 Leadership

Leadership agency is central to navigating institutional restructuring, yet its effectiveness varies by context. Hüther and Krücken (2023) demonstrate how transformational leadership fosters cultural cohesion during mergers in German universities by aligning stakeholders around shared visions. Conversely, transactional approaches—reliant on incentives and penalties—often exacerbate resistance, particularly in faculty-driven cultures. Complementing this, Locke and Bennion (2021) highlight adaptive leadership in U.S. public universities during the COVID-19 pandemic, where rapid decision-making and decentralized authority enabled agility amid crisis. However, their work also cautions against conflating adaptive tactics with long-term cultural change, noting that crisis-driven restructuring risks undermining participatory governance.

These studies underscore a tension: while transformational and adaptive styles promote innovation, their success depends on contextual factors like institutional history and stakeholder trust. Radnor and Osborn (2011), Mader (2013), Antony (2014), Agili (2015), Balzer et al. (2015), and Duong (2015) all came to the same conclusion that top management support is necessary for successful implementation. In this study, the

underlying leadership quality, which is the central problem in many organizations and is primarily considered in research, was interpreted as the top management commitment.

According to Mader (2013), a university's historical and current development require the groundwork of leadership. When a leader sees transformation as a way to create a long-term legacy for the institution, this can also be a motivating factor (Mader, Scott, & Abdul Razak 2013). Leadership is the most ubiquitous influence on the outcomes of organizational learning. Shariffuddin, Razali, and Ghani (2017) justified that leadership is crucial for developing a university's policies. An organization's fundamental ideals determine the direction of the university. Establishing a clearly defined program to comprehend those in the academic system better requires leadership in the educational system. Clear pathways help lecturers create course outlines that adhere to pedagogical goals, institution standards, and business requirements. Leaders in higher institutions who successfully implement change at the organizational level are regarded as change specialists.

From an industrial perspective, the university can also be categorized as a business entity whereby students are considered prospects or shareholders of the businesses. Furthermore, a support system needs to be developed by the organization's leaders. Strong support from management in the educational system reflects the leadership capacity of the sector. Leaders play an important role in supporting academicians in discharging their responsibilities effectively, whereas the workforce requires sufficient resources and support to be motivated and develop their creativity. The organization's vision and mission must be aligned to its objectives to enable the strategic enhancement of its role in educating and producing skilled workers for the professional labor market. Thus, education is seen as a strong competitive platform in many societies.

This research also indicates that traditional leadership models in academia often lean towards command and control approaches, which can stifle innovation and collaboration. In contrast, transformational leadership emphasizes vision-driven strategies that promote cultural change by engaging stakeholders at all levels. This shift towards more relational and mission-driven leadership is essential for addressing the evolving needs of higher education. The adoption of shared leadership, where responsibilities are distributed among team members—has shown promise in enhancing performance and fostering a collaborative culture. This model encourages input from diverse perspectives, enriching decision-making processes and aligning institutional goals with community needs.

3.2 Governance in Institutional Restructuring

A combination of governance and institutional management changes is known as institutional restructuring. Structures and forms of decision-making are aspects of governance while administrators execute decisions. Performance, control of the institution, and decision-making are the core aspects of institutional restructuring, and they provide specific structures for fulfilling the institution's expectations and obligations. Governance structures mediate the translation of leadership visions into actionable policies. Deem and Sami's (2022) comparative analysis of UK and Australian universities reveals that centralized governance—often imposed during austerity—can erode academic autonomy, triggering resistance from faculty. For instance, UK reforms post-2010

prioritized financial efficiency over collegiality, leading to fragmented institutional identities. In contrast, Stensaker and Vabø (2023) illustrate how Nordic universities navigate state-driven reforms through hybrid governance, blending bureaucratic accountability with academic self-regulation. This model, they argue, preserves cultural identity while accommodating external demands.

Critically, Pinheiro and Young (2023) challenge the neoliberal "entrepreneurial university" paradigm, arguing that market-oriented governance in post-2008 Europe has stifled resilience by prioritizing short-term gains over cultural sustainability. Their work calls for governance models that reconcile economic pressures with institutional missions—a theme echoed in Marginson and Xu's (2024) analysis of Australian HEIs, where "glocal" (global-national-local) governance hybrids enable contextualized adaptation. Cadbury Report (1992) defined governance as a framework in which an organization is directed and controlled. According to Shariffuddin et al. (2017), governance, academic career, academic activities involving various HEIs, academic identity leadership supports, and strategies are the tools for successful transformation.

Varghese & Martin (2013) recommended the establishment of a new governance model in which University leaders should be given autonomy in decision-making and finances to focus more on institutional funding and branding, play the role of the custodian of students, academics, and research to sustain its performance and operation. Human habits and satisfaction with their current performance, status, and situation will initially create resistance to change (Mainardes et al. 2011), and compliant behaviors hinder the success of institutional change initiatives. Therefore, improving organizational productivity is central to institutional restructuring as numerous institutions cannot afford to manage change. Management changes are commonly due to technological advancement, production techniques, customer and stakeholders' behavior, economic changes, and business activities that force institutions to initiate change for sustainability (Thakur & Mangla 2019). Most beneficial management change can be realized through organization structure, organization employees, specific business technology, production techniques, and administration restructuring (Colombi, John M.; Miller, Michael E.; Schneider, Michael; McGrogan, Jason; Long, David S.; Plaga 2012; Hashim 2017). A recent study by Tabucanon et al. (2021) reported that the transformation of higher education institutions played a vital role in promoting sustainability, disseminating knowledge, and developing the institution's leadership.

Effective governance structures are crucial for enabling cultural transformation. Institutions must be granted autonomy in decision-making to foster an environment conducive to innovation. Recommendations include clarifying roles between university leaders and boards of directors to minimize political interference and micromanagement3. Such clarity can empower leaders to focus on strategic foresight and institutional excellence.

3.3 Culture

Culture can permit effective and successful reform in higher education by promoting a positive and supportive environment for change. This can be achieved by fostering open communication and collaboration among stakeholders, encouraging innovation and risk-taking, and recognizing and valuing the diverse perspectives and expertise of all those involved. Cultural change remains the most elusive outcome of restructuring, shaped by

leadership and governance interactions. Stensaker and Vabø (2023) frame cultural transformation as a paradox of autonomy: Nordic institutions leverage autonomy to reinvent identities while complying with state mandates, yet this process risks diluting academic traditions. Similarly, Marginson and Xu (2024) identify cultural hybridity in Australian HEIs, where global rankings-driven policies coexist with localized pedagogies. However, such hybridization often generates internal tensions, particularly when leadership fails to mediate between competing values.

Notably, resistance emerges as a recurring cultural response. Deem and Sami (2022) document how UK faculty subvert top-down governance through informal networks, while Pinheiro and Young (2023) observe "quiet resistance" in European universities rejecting marketization. These findings suggest that cultural sustainability requires leadership to engage, rather than suppress, dissent.

Studies conducted by Baglibel et al. (2018), Nasruddin et. al. (2013), Pitman (2014), Abdullah et. al. (2017) and Agili (2015) indicates that cultural determinism suggests that the existing organizational culture significantly influences decisions made by leaders. Leaders must navigate formal and informal cultural boundaries to implement effective change, highlighting the interplay between leadership actions and cultural contexts within higher education institutions.

Cultural transformation is often resisted due to entrenched norms and practices within institutions. The literature suggests that successful change initiatives require leaders to deeply understand their institutional culture and the dynamics at play. Additionally, leaders must be equipped to manage conflicts and facilitate dialogues among various stakeholders.

External pressures such as demographic shifts, economic constraints, and social justice movements have intensified the need for cultural change in higher education. Leaders must respond to these challenges while maintaining institutional integrity and relevance.

The impact of leadership and governance on cultural transformation in higher education is profound. As institutions restructure to meet contemporary demands, embracing innovative leadership models and robust governance frameworks will be essential. By fostering a culture of collaboration, accountability, and responsiveness, higher education leaders can effectively navigate the complexities of change, ensuring their institutions thrive in an ever-evolving landscape.

This analysis underscores the necessity for ongoing research into effective leadership practices that can facilitate meaningful cultural transformations within higher education settings, ultimately leading to more resilient and adaptive institutions.

4 Limitations and Further Research Streams

4.1 Limitations

While this study advances understanding of leadership, governance, and cultural transformation in higher education restructuring, several limitations warrant acknowledgment. First, the geographic scope, though expanded beyond Asian contexts, remains skewed toward Europe, North America, and Australia. Underrepresented regions—such

as Africa, Latin America, and South Asia—limit the generalizability of findings to diverse political and socio-economic landscapes. Second, reliance on published case studies and peer-reviewed articles may introduce publication bias, as grey literature or institutional reports offering grassroots perspectives were excluded. Third, while NVivo's cognitive mapping enhances transparency, its interpretive nature introduces subjectivity; despite systematic coding, researcher bias in theme identification and linkage cannot be fully eliminated. Finally, the study's focus on leadership and governance frameworks may underemphasize external factors (e.g., technological disruption, demographic shifts) that co-shape cultural outcomes.

4.2 Further Research Streams

To address these limitations and extend the study's contributions, future research could pursue the following streams.

4.2.1 Global Comparative Analysis

Investigate restructuring dynamics in underrepresented regions (e.g., African universities navigating post-colonial legacies or Latin American institutions balancing equity and privatization). This would test the universality of governance-leadership frameworks identified in this study.

4.2.2 Mixed-Method Longitudinal Studies

Combine qualitative case studies with quantitative metrics (e.g., leadership effectiveness surveys and cultural cohesion indices) to track institutional change over time, particularly in post-pandemic contexts where agility and resilience are critical.

4.2.3 Intersectional Analyses

Explore how digital transformation (e.g., AI-driven administration) interacts with governance models and leadership styles to redefine cultural norms.

4.2.4 Stakeholder-Centric Approaches

Prioritize voices often marginalized in restructuring narratives, such as non-academic staff, students, and community partners, to better understand power asymmetries in decision-making.

4.2.5 Policy-Implementation Gaps

Examine how macro-level policies (e.g., EU's Bologna Process, UNESCO sustainability agendas) are adapted—or resisted—at institutional levels, particularly in resource-constrained settings.

4.2.6 Ethical Leadership Frameworks

Develop models that integrate equity, inclusivity, and anti-colonial praxis into leadership and governance strategies, addressing critiques of neoliberal hegemony.

This study's limitations, while notable, underscore the complexity of higher education restructuring and the need for context-sensitive scholarship. Future research can deepen theoretical and practical insights by addressing these gaps, ensuring institutional transformation aligns with global imperatives and localized values.

5 Conclusion

Conclusively, the internal factors emerged as an overarching theme and were pertinent in ensuring the success and realizing the higher education transformation. Undoubtedly, the management of higher education institutions may encounter some difficulties in handling transformation. Some of these constraints include diminished public confidence, difficult political climate, financial limitations and the pressure of substitute structural and resource commitments in diverse knowledge areas. There seem to be endless deliberations regarding academic restructuring and resource reallocation, which are usually attributed to deficient processes and probable consequences of proposed modifications. Tensions are exacerbated on campus between advocates of various academic fields given the extraordinary public scrutiny of the academic enterprise. Further uproar arises from the planners and those responsible for protecting faculty governance, as well as between those advocating compliance with external demands for demonstrated accountability and those arguing for resistance. Hence, it is most likely that deliberations over the restructuring of academic units are ongoing based on the combination of academic considerations with broader economic and political interests. Concurrently, the consequences of shifts in structural and material resources in academic areas within the stakeholder's compound and society remain unclear.

The interplay of leadership, governance, and culture defines higher education restructuring. Transformational leadership may ignite change, but its longevity depends on governance structures legitimizing stakeholder voices. Similarly, cultural resilience emerges not from passive compliance but from negotiated hybridity. By synthesizing these insights, this review sets the stage for empirical exploration of how HEIs can navigate change without sacrificing identity—a question central to the present study. There is limited data to substantiate the claim that human factors are the main constraints to higher education transformation. Nonetheless, the result can be further explored to perform a comprehensive study that needs future work, including investigating the interaction and association between these themes and expanding on the current knowledge. Due to inaccessibility and the study's selection criteria, some studies may not have been included in this review. Since lean higher education is relatively new, considerable research could be conducted to explore further the lean higher education transformation implementation success, including the maturity models and framework, readiness factors for adopting lean behaviors, and sustainability agenda within the scope of lean Respect for Peoples' pillars.

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KM Process and Model

A Knowledge Management-Driven Framework for Strengthening Social Engineering Awareness in Public Sector Cybersecurity

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Abstract. Social engineering attacks remain one of the most pervasive cybersecurity threats, exploiting human vulnerabilities rather than technical weaknesses. Despite existing security awareness programs, the lack of structured knowledge retention mechanisms leads to suboptimal long-term awareness. This study introduces the Social Engineering Awareness Model driven by Knowledge Management (SEAM-KM), an AI-integrated framework that enhances cybersecurity resilience through real-time learning mechanisms, knowledge repositories, and structured training programs. A quantitative survey of 150 Malaysian public sector enforcement personnel was conducted, utilizing exploratory factor analysis (EFA), multiple regression modeling, and ANOVA to assess the impact of KM integration on cybersecurity awareness. Results indicate that structured KM-based training significantly enhances knowledge retention ($\beta = 0.52$, $p < 0.001$), threat identification ($\beta = 0.47$, $p < 0.001$), and behavioral adaptation ($\beta = 0.45$, $p < 0.01$). The findings validate the extension of Nonaka and Takeuchi's SECI Model into cybersecurity, demonstrating that tacit-to-explicit knowledge conversion strengthens proactive defense mechanisms. This study contributes to academia and policy by (i) proposing a scalable KM-driven cybersecurity training model, (ii) providing empirical evidence on AI-enhanced security behavior reinforcement, and (iii) offering strategic recommendations for public sector cybersecurity resilience. Future research should explore longitudinal adoption of SEAM-KM in diverse government agencies, cross-sector validation, and the integration of real-time AI-driven threat monitoring for proactive cybersecurity interventions.

Keywords: Cybersecurity Training · Knowledge Management (KM) · Public Sector Cybersecurity · Social Engineering Awareness · Threat Intelligence

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1 Introduction

Social engineering attacks pose a significant cybersecurity threat, particularly within public sector enforcement agencies. Unlike traditional cyber threats that exploit software vulnerabilities, these attacks manipulate human behavior to gain unauthorized access to sensitive information [1]. Recent reports indicate that phishing alone accounts for 36% of data breaches globally [2], while in Malaysia, fraud-related incidents such as phishing and impersonation made up 71.7% of all cybersecurity incidents in 2022 [3]. Despite existing security training programs, their effectiveness is limited due to the absence of structured mechanisms for knowledge retention and real-time threat adaptation [4]. Traditional awareness models rely on static, one-time training sessions, leading to knowledge decay within six months and leaving organizations vulnerable to evolving attack techniques [5].

Public sector enforcement personnel are at high risk due to their access to confidential data and critical government systems. They are frequent targets of impersonation, pretexting, and phishing attacks, which threaten national security and disrupt public services [6]. Current cybersecurity training methods lack structured knowledge-sharing frameworks, making it difficult for personnel to retain and apply security awareness effectively [4, 5, 7]. Research on integrating Knowledge Management (KM) into cybersecurity awareness remains limited, despite its potential to enhance long-term preparedness through structured learning, threat intelligence sharing, and interactive training.

This study introduces the Social Engineering Awareness Model driven by Knowledge Management (SEAM-KM), an AI-integrated framework designed to enhance cybersecurity resilience. It contributes to the field by extending KM into cybersecurity training, providing empirical evidence on structured knowledge retention, and offering policy recommendations for institutionalizing cybersecurity awareness in government agencies. The study holds practical relevance for Malaysia's public sector, where cybersecurity training is often inconsistent and lacks real-time intelligence updates [3]. Current policies focus on infrastructure security but do not sufficiently address human vulnerabilities [8]. SEAM-KM addresses this gap by integrating adaptive AI-driven learning, real-time cybersecurity dashboards, and structured KM repositories. By institutionalizing KM-based cybersecurity training, government agencies can enhance security awareness and proactive threat response among enforcement personnel.

The research aims to assess the limitations of existing cybersecurity awareness models, validate SEAM-KM as a structured training framework, and examine the relationship between KM integration and cybersecurity awareness. The key research questions explored include: (1) How effective are current social engineering awareness programs in the public sector? (2) What KM strategies can improve long-term cybersecurity awareness and knowledge retention? (3) What is the empirical relationship between KM integration and social engineering awareness effectiveness? Addressing these questions will provide an evidence-based framework for strengthening cybersecurity preparedness in public sector enforcement agencies.

2 Literature Review

2.1 Social Engineering Attacks and Awareness Models

Social engineering attacks remain a major cybersecurity threat, exploiting human psychology rather than technical weaknesses [9, 10]. These attacks manipulate individuals into revealing sensitive information, bypassing even the most sophisticated security measures. Common tactics include phishing, pretexting, baiting, impersonation, and tailgating, all of which rely on deception and psychological manipulation [11].

Despite increased cybersecurity awareness, many organizations struggle with long-term knowledge retention and proactive security behavior [4, 12, 13]. Traditional awareness programs focus on periodic training sessions, but these often fail to reinforce knowledge over time, leading to knowledge decay and a reduced ability to prevent real-world attacks. A comparative analysis of cybersecurity awareness models reveals significant gaps in ensuring continuous learning, real-time adaptability, and structured knowledge retention (Table 1).

Table 1. Comparative Analysis of Cybersecurity Awareness Models

Model	Focus Area	Strengths	Weaknesses	Implementation Challenge	Application in Public Sector
Security Awareness Training (SAT)	Periodic training	Provides structured cybersecurity education	Lacks reinforcement for long-term retention	Requires frequent updates	Common in government agencies
Human-Firewall Model	Individual vigilance	Encourages proactive security behavior	No integration of knowledge-sharing mechanisms	Limited organizational support	Largely used in law enforcement
Gamified Security Awareness (GSA)	Interactive learning	Enhances engagement through simulations	Requires consistent user participation	Resource-intensive	Applied in specialized training
AI-Driven Cybersecurity Training (AI-CT)	Adaptive learning	Uses AI-driven threat simulations	Implementation complexity	High technological investment	Emerging in smart cybersecurity frameworks
Knowledge-Based Security Model	Knowledge retention	Focuses on structured learning	Limited integration of real-time threat intelligence	Needs KM integration	Government and financial sectors

Existing models primarily focus on raising awareness through one-time training or gamification strategies, but they lack a comprehensive mechanism for ensuring long-term cybersecurity preparedness. Addressing this gap requires an adaptive approach integrating Knowledge Management (KM) principles and AI-driven learning mechanisms.

2.2 The Role of Knowledge Management in Cybersecurity Awareness

Knowledge Management (KM) serves as a cornerstone of cybersecurity resilience by systematically capturing, retaining, and disseminating security intelligence [14–16]. Unlike conventional training methodologies, KM ensures that cybersecurity awareness remains dynamic, contextually relevant, and continuously reinforced. The SECI Model [17], widely utilized in knowledge-driven training programs, offers a structured approach to converting tacit security expertise into explicit, actionable insights. However, its application to social engineering awareness remains underexplored (see Table 2).

Table 2. SECI Model Adaptation in Cybersecurity Awareness

SECI Phase	Standard SECI Process	Cybersecurity Application
Socialization	Tacit knowledge sharing through direct experience	Establishing Communities of Practice (CoPs) for security discussions
Externalization	Converting tacit knowledge into explicit knowledge	Documenting real-world phishing cases and security incidents
Combination	Structuring explicit knowledge for easy access	AI-driven classification of emerging social engineering tactics
Internalization	Applying explicit knowledge in practice	Conducting real-time attack simulations and security drills

By embedding KM principles, cybersecurity knowledge is not only retained but also reinforced, equipping enforcement personnel with real-time threat detection capabilities. Despite its benefits, knowledge decay remains a persistent challenge, with studies indicating that employees retain only 30% of security training content within six months, significantly increasing their susceptibility to social engineering attacks [18]. This issue is further exacerbated by the lack of real-time intelligence updates, rendering static training materials obsolete against evolving cyber threats. Additionally, limited behavioral reinforcement mechanisms lead to employees reverting to insecure practices over time [4, 14] (see Table 3).

Table 3. Key Challenges in Cybersecurity Knowledge Retention

Challenge	Impact	Potential Solution
Knowledge Decay	Employees forget security protocols over time	KM repositories for structured learning and reinforcement
Lack of Real-Time Intelligence	Training content quickly becomes outdated	AI-driven threat intelligence updates and interactive security dashboards
Minimal Behavioral Reinforcement	Employees revert to risky security behaviors	Simulated phishing exercises and role-based security training

The implementation of KM-driven cybersecurity frameworks presents inherent scalability challenges, as continuous knowledge updates demand substantial institutional investment [5]. Organizations also face resource allocation constraints, requiring specialized personnel to curate and manage cybersecurity knowledge repositories effectively. Furthermore, user engagement remains a critical barrier, as employees often perceive continuous training as monotonous and disruptive, leading to diminished participation and retention [4, 7]. Addressing these limitations necessitates automation of KM-based training models and integration of AI-powered learning systems capable of personalizing cybersecurity training based on user behavior, risk exposure, and adaptive learning analytics. AI-driven threat intelligence platforms and interactive security dashboards can enhance training engagement, streamline resource management, and scale cybersecurity awareness programs effectively. By leveraging intelligent automation and real-time analytics, organizations can transition from static, compliance-based training approaches to proactive, knowledge-driven cybersecurity ecosystems that ensure continuous organizational resilience.

2.3 Conceptual Framework for a Knowledge-Based Cybersecurity Awareness Model

This study integrates established cybersecurity theories to construct a knowledge-driven security awareness framework. The SECI Model [17] facilitates tacit-to-explicit knowledge conversion, ensuring structured retention and reinforcement through AI-driven repositories and security policies. The Human Security Behavior Model (HSBM) [19] highlights the role of knowledge acquisition, attitudes, and compliance behavior, emphasizing that cybersecurity awareness must extend beyond technical solutions to behavioral adaptation. Together, these models underpin SEAM-KM's dynamic, adaptive, and behaviorally focused cybersecurity approach.

SEAM-KM addresses these gaps by integrating structured KM, behavioral reinforcement, and AI-powered threat intelligence. Unlike static, one-time training, SEAM-KM employs continuous learning strategies, ensuring knowledge is retained, shared, and applied in real-world scenarios. The framework consists of three key components:

1. Human Factors (Knowledge Integration)
2. Social Engineering Attacks (Behavioral Adaptation)
3. KM-Learning Organisational Support (Real-Time Learning)

Human Factors (Knowledge Integration), focuses on establishing centralized KM repositories to facilitate real-time access to security knowledge. By systematically capturing and organizing cybersecurity intelligence, personnel can retrieve up-to-date information on emerging threats and best practices, thereby strengthening their proactive defense mechanisms. **Social Engineering Attacks (Behavioral Adaptation)**, emphasizes the importance of continuous training and experiential learning. This includes simulated phishing attacks, cybersecurity drills, and peer-learning initiatives that reinforce knowledge application in real-world scenarios. Through repeated exposure to security threats, personnel develop heightened awareness and improved response capabilities. **KM-Learning Organizational Support (Real-Time Learning)**, leverages AI-driven analytics and adaptive alerts to personalize cybersecurity training. By monitoring

user behavior and threat exposure levels, AI-powered systems tailor training content to address specific vulnerabilities, ensuring that cybersecurity education remains dynamic and contextually relevant. (see Fig. 1).

Together, these components form an integrated cybersecurity training model that enhances knowledge retention, behavioral adaptation, and continuous learning, ultimately mitigating the risks associated with social engineering attacks. These elements ensure cybersecurity awareness remains continuous, personalized, and proactive, reducing human error. By addressing rapid knowledge decay and the evolving nature of cyber threats SEAM-KM ensures that enforcement personnel maintain long-term security vigilance through a sustainable, intelligence-driven cybersecurity training model.

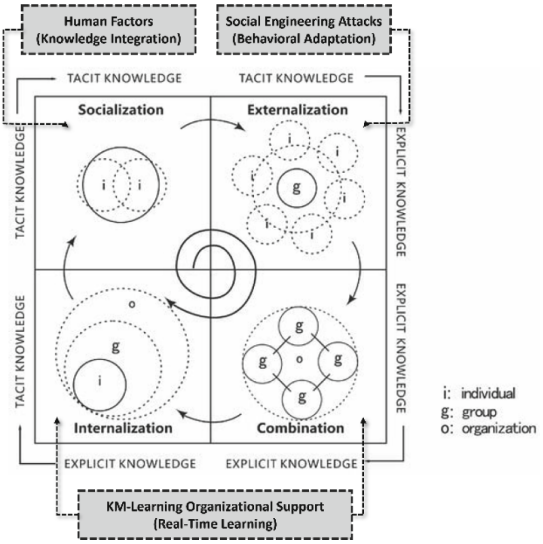

Fig. 1. Social Engineering Awareness-Knowledge Management (SEAM-KM) Model

3 Methodology

This study employed a quantitative, cross-sectional survey design to examine the impact of Knowledge Management (KM) strategies on social engineering awareness among Malaysian public sector enforcement personnel. A structured approach was adopted to enhance methodological rigor and replicability, aligning with best practices in cybersecurity awareness research. The study evaluates the relationships between KM interventions and cybersecurity awareness outcomes, providing empirical evidence to support the SEAM-KM framework.

Sampling and Population. The study targeted enforcement personnel from five Malaysian public sector agencies—the Royal Malaysian Police (RMP), Royal Malaysian

Customs (RMC), Immigration Department of Malaysia (IDM), Road Transport Department (RTD), and Malaysian Anti-Corruption Commission (MACC). These agencies were selected based on their high exposure to cybersecurity threats, particularly social engineering attacks. A stratified random sampling approach ensured proportional representation across enforcement units, job roles, and experience levels.

A G*Power analysis was conducted to determine the minimum required sample size for multiple regression modeling. Using Cohen's f2 effect size (0.15, moderate effect), statistical power of 0.80, and $\alpha = 0.05$, the analysis recommended a sample of $N = 119$. To enhance statistical robustness and generalizability, a final sample of 150 respondents was selected, aligning with prior cybersecurity awareness studies (Williams et al., 2021).

Instrumentation and Measures. A structured questionnaire was developed based on validated scales, incorporating elements from the human aspects to assess security behaviors. The questionnaire consisted of four sections:

4. Demographics – Capturing age, gender, education level, organizational affiliation, and cybersecurity experience.
5. Human Factors in Cybersecurity – Assessing password management, email security, mobile device protection, and incident reporting practices.
6. Social Engineering Awareness – Measuring familiarity with phishing, vishing, smishing, tailgating, and whaling attack vectors.
7. KM-Based Organizational Support – Evaluating training accessibility, policy awareness, and reliance on IT personnel for security compliance.

The survey was electronically distributed via institutional email networks and encrypted online forms to maximize accessibility while ensuring data security. Participation was voluntary, with responses anonymized to maintain confidentiality.

Validity and Reliability. To ensure content validity, the instrument underwent expert review by four cybersecurity specialists, yielding a Content Validity Index (CVI) of 0.98, indicating strong construct relevance. Internal reliability was tested using Cronbach's Alpha ($\alpha = 0.87$), confirming measurement consistency. Exploratory Factor Analysis (EFA) validated the construct structure, ensuring alignment between measured variables and theoretical constructs.

Data Analysis. Data analysis was conducted using IBM SPSS Statistics version 28.0, employing the latest statistical tools for robust interpretation. Descriptive statistics summarized demographics, security behaviors, and awareness levels. Multiple regression analysis examined predictive relationships between KM-driven interventions and key cybersecurity outcomes, including knowledge retention, threat recognition, and behavioral compliance. Analysis of Variance (ANOVA) was performed to compare awareness levels across agencies, identifying training disparities.

Ethical Considerations and Bias Mitigation. This study adhered to institutional research ethics and cybersecurity protocols. Informed consent was obtained electronically, with respondents receiving a study information sheet outlining research objectives, confidentiality measures, and voluntary participation rights. Survey pre-testing was conducted to ensure clarity and reliability, reducing response bias. Common method bias was addressed through reverse-coded items and Harman's single-factor test to detect

potential variance issues. Data security was ensured through encrypted storage, with access restricted to authorized researchers. Ethical approval was granted by the relevant institutional ethics committee, ensuring compliance with national and international research standards.

While the study focuses on Malaysian public sector enforcement agencies, findings have broader applicability to government cybersecurity training models. The KM-driven approach can be adapted to other jurisdictions, particularly in government institutions with similar cybersecurity exposure. However, cultural and policy differences may influence KM adoption rates, requiring further validation in diverse public sector contexts.

4 Results and Discussion

4.1 Demography Analysis

The demographic analysis indicates that 56% of respondents are aged 35–44, with 29.3% in the 25–34 range, reflecting a mid-career workforce. Male respondents comprise 59.3%, consistent with the gender distribution in enforcement agencies. Educational qualifications show that 45.3% hold a bachelor's degree, 16.7% a diploma, and 10.7% a master's degree, indicating a workforce with a strong academic background. The highest participation came from the Royal Malaysian Customs (46%) and the Royal Malaysian Police (44%), reinforcing the study's focus on agencies frequently targeted by social engineering attacks.

Job roles include 44% in middle management, 21.3% in support roles, and 17.3% as trained professionals, ensuring insights from decision-makers and frontline personnel. Internet usage patterns reveal that 94.7% of respondents access the internet daily, with 76% engaged in social networking and 70% using email. However, cybersecurity-related activities remain low, with only 12% using the internet primarily for work. The gap between digital exposure and cybersecurity awareness highlights the need for structured training initiatives (see Fig. 2).

4.2 Human Factors in Cybersecurity Awareness Assessment

The study findings reveal a significant gap in cybersecurity awareness, with only 4.7% demonstrating high recognition of social engineering threats. Most respondents exhibited moderate to low awareness of phishing, smishing, and tailgating. Awareness of whaling and tailgating was particularly low, emphasizing the need for targeted training on advanced social engineering tactics. The awareness distribution is detailed in Table 4.

Regression analysis confirms that KM-based interventions significantly enhance cybersecurity awareness. Knowledge retention ($\beta = 0.52$, $p < 0.001$), threat recognition ($\beta = 0.47$, $p < 0.001$), and behavioral compliance ($\beta = 0.45$, $p < 0.01$) improved with structured KM approaches. These findings validate previous studies, highlighting the limitations of conventional cybersecurity training and reinforcing the necessity for KM-driven frameworks that emphasize continuous learning and reinforcement (see Table 5).

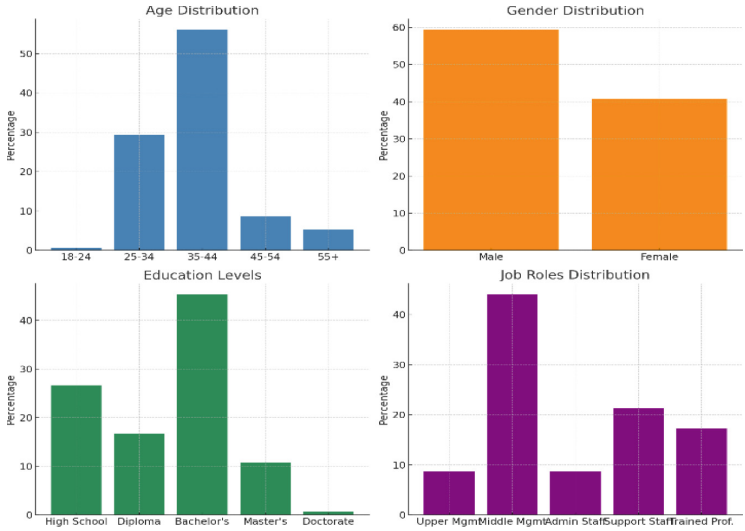

Fig. 2. Demographic and Internet Usage Distribution of Respondents

Table 4. Social Engineering Awareness Levels

Threat Type	Mean (M)	SD	Awareness Level
Phishing	3.18	1.32	Moderate
Vishing	3.09	1.34	Moderate
Smishing	3.11	1.33	Moderate
Tailgating	2.77	1.31	Low
Whaling	2.57	1.26	Low

Table 5. Regression Analysis of KM Interventions on Cybersecurity Awareness

Dependent Variable	β Coefficient	p-value
Knowledge Retention	0.52	<0.001
Threat Recognition	0.47	<0.001
Behavioral Compliance	0.45	<0.01

Effect size analysis using ANOVA confirms the strong practical impact of KM-driven cybersecurity training. Knowledge retention ($\eta 2 = 0.35$, $p < 0.001$) indicates a large effect, confirming its effectiveness and scalability across agencies. Threat recognition ($\eta 2 = 0.29$, $p < 0.001$) demonstrates a medium-to-large effect, reinforcing the importance of structured knowledge-sharing mechanisms. Behavioral compliance ($\eta 2 = 0.27$, $p < 0.01$) shows a medium effect, indicating that KM strategies improve adherence to cybersecurity

policies. Given the high phishing susceptibility in the Malaysian public sector, SEAM-KM should be piloted within agencies such as the Royal Malaysian Customs, where enforcement personnel are frequent targets of social engineering attacks (see Table 6).

Table 6. Effect Size Analysis for KM-Based Cybersecurity Interventions

Dependent Variable	Effect Size (η^2)	p-value	Effect Strength
Knowledge Retention	0.35	<0.001	Large Effect
Threat Recognition	0.29	<0.001	Medium-to-Large Effect
Behavioral Compliance	0.27	<0.01	Medium Effect

The study revealed two unexpected findings. First, 30–40% of respondents remained neutral when assessing their cybersecurity awareness, suggesting uncertainty about their competence or reliance on IT personnel rather than personal responsibility. This indicates a potential lack of confidence in applying security measures, which may stem from inadequate hands-on training. To address this, cybersecurity programs should incorporate self-assessment tools that allow personnel to gauge their security proficiency without fear of evaluation bias. Second, 50% of respondents reported receiving no formal cybersecurity training, and 44.7% lacked access to cybersecurity policies, highlighting institutional gaps in cybersecurity policy enforcement. This underscores the need for organizations to institutionalize structured knowledge-sharing frameworks and ensure policies are clearly communicated and easily accessible. Strengthening institutional commitment through mandatory training and regular updates on security policies will help reinforce a proactive cybersecurity culture.

4.3 Social Engineering Attacks Awareness

Findings reveal a critical gap in social engineering awareness among enforcement personnel, leaving them vulnerable to manipulation-based cyber threats. Only 4.7% demonstrated high awareness, while 30.7% had limited knowledge, and 30% had none. Given that social engineering exploits human vulnerabilities rather than technical flaws, targeted training is essential.

Awareness of common threats such as phishing (26%), smishing (28%), and vishing (24.7%) was moderate, but recognition of advanced tactics like tailgating (22.7%), dumpster diving (22%), pretexting (24%), and whaling (26.7%) was significantly lower. Whaling, a high-risk attack targeting senior officials, had the lowest extreme awareness (7.3%), underscoring the urgent need for specialized training for high-ranking personnel (see Table 7).

These findings align with previous research highlighting the limitations of traditional cybersecurity training in long-term knowledge retention. To bridge this gap, enforcement agencies must integrate KM-driven cybersecurity frameworks that include

Table 7. Social Engineering Awareness Levels

Threat Type	Mean (M)	SD	Awareness Level
Phishing	3.18	1.32	Moderate
Vishing	3.09	1.34	Moderate
Smishing	3.11	1.33	Moderate
Impersonation	3.07	1.32	Moderate
Baiting	3.03	1.37	Moderate
Pretexting	2.94	1.35	Low
Tailgating	2.77	1.31	Low
Dumpster Diving	2.79	1.32	Low
Whaling	2.57	1.26	Low

dynamic knowledge repositories, peer-learning networks, and AI-driven threat intelligence platforms. Real-world simulations, gamified learning modules, and adaptive AI-driven training will enhance preparedness and ensure continuous exposure to evolving cyber threats.

4.4 KM-Based Organizational Support

Cybersecurity awareness in public sector enforcement agencies is hindered by deficiencies in training, policy accessibility, and individual accountability. Only 24.7% of respondents received formal social engineering training, while 50% had no exposure, leaving personnel vulnerable to manipulation tactics. Additionally, 34.7% had access to documented security policies, indicating weak policy dissemination. Although 66% knew whom to contact in a cybersecurity incident, reactive measures alone are insufficient without structured training and continuous knowledge-sharing (see Fig. 3).

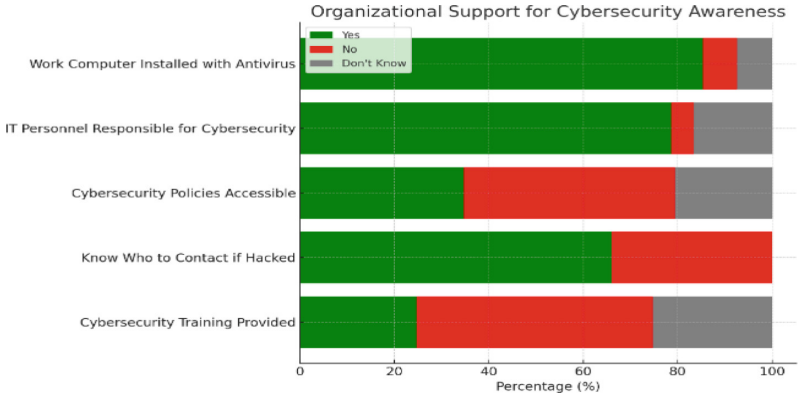

Fig. 3. Organizational Support for Cybersecurity Awareness

Over-reliance on IT personnel is another concern, with 78.7% viewing IT teams as primary defenders, fostering a passive security culture. While 85.3% reported having antivirus protection, 14.6% lacked it or were unaware, exposing inconsistencies in security enforcement. Regular audits, clearer policies, and promoting individual responsibility are necessary to strengthen cybersecurity readiness.

Training preferences emphasize hands-on learning, with 56% favoring real-life simulations and 48% preferring real-time virtual training over static programs. Web-based portal training was selected by 44.7%, while gamified training had the lowest preference (20.7%), suggesting that interactive, scenario-based approaches are more effective. These findings reinforce the need for dynamic, practical cybersecurity education to ensure continuous engagement and resilience against evolving threats (see Fig. 4).

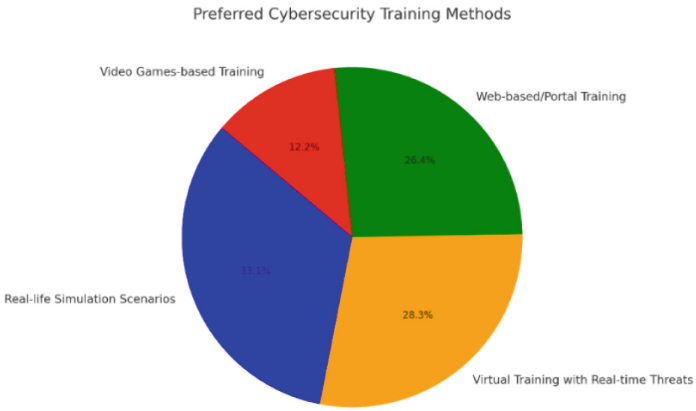

Fig. 4. Preferred Cybersecurity Training Methods

5 Conclusion

This study reinforces the role of KM in cybersecurity awareness, validating the SECI Model's tacit-to-explicit knowledge conversion in strengthening security preparedness. SEAM-KM operationalizes socialization through centralized KM repositories, externalization via documented phishing cases, combination through AI-driven threat classification, and internalization via real-time simulations—ensuring continuous learning and reinforcement. Aligned with the HSBM, findings confirm that structured KM interventions significantly improve knowledge retention ($\beta = 0.52$, $p < 0.001$), threat recognition ($\beta = 0.47$, $p < 0.001$), and behavioral compliance ($\beta = 0.45$, $p < 0.01$). The study advances behavioral security literature by demonstrating that AI-personalized, iterative training fosters sustained awareness and proactive defense behaviors.

From a practical standpoint, SEAM-KM provides actionable recommendations for institutionalizing cybersecurity training in the public sector. Centralized KM repositories should be established within government agencies to ensure structured knowledge retention, enabling personnel to access real-time security intelligence. To strengthen

cybersecurity policies, agencies must integrate AI-driven learning mechanisms, ensuring continuous security reinforcement through automated phishing simulations, behavioral reinforcement, and interactive learning dashboards. These measures will ensure that cybersecurity awareness training remains relevant, engaging, and tailored to evolving threats. Furthermore, public sector organizations should embed SEAM-KM within long-term policy frameworks to enhance compliance and inter-agency knowledge sharing. A sector-wide cybersecurity knowledge-sharing network should be implemented to facilitate intelligence exchange and policy alignment. Additionally, real-time threat intelligence dashboards should be incorporated into public sector cybersecurity frameworks, allowing enforcement personnel to receive dynamic threat alerts and proactively mitigate risks. These integrations will reduce reliance on IT personnel and empower all employees to take an active role in cybersecurity defense.

Future research should explore SEAM-KM's long-term effectiveness through longitudinal studies tracking cybersecurity behavior changes over time. Comparative studies across different government agencies are necessary to evaluate its scalability and adaptability in diverse enforcement contexts. Additionally, further research should focus on AI-driven cybersecurity personalization, investigating how real-time risk profiling, adaptive learning analytics, and reinforcement models can optimize training effectiveness. These efforts will help refine SEAM-KM into a self-improving cybersecurity awareness system that evolves alongside emerging threats. By incorporating SEAM-KM into cybersecurity policies, public sector agencies can significantly enhance their resilience against social engineering attacks. Strengthening institutionalized cybersecurity awareness training, embedding AI-driven personalization, and fostering inter-agency collaboration will create a proactive security culture.

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A Literature Review of Hindering Factors in Digital Transformation Processes

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Abstract. In a world where knowledge management is increasingly dependent on digital transformation processes, it is essential to recognize the barriers and challenges that arise within this symbiotic relationship. Understanding these complexities is crucial for developing effective strategies and identifying key success factors. Building upon this mutual dependency, it is plausible that hindering factors interfering with digital transformation processes may similarly impede knowledge management practices. Hence, it is crucial to consider hindering factors of digital transformation processes when implementing knowledge management in organizations. This paper investigates the aforementioned factual connection through a concept-centric literature review of 50 peer-reviewed papers, conflating the latest research findings to derive a comprehensive model that represents the majority of hindering factors associated with digital transformation processes. Drawn from 132 individual concept definitions, this paper encompasses a total of 34 hindering factors related to seven areas, namely procedures, leadership, resources, structure, culture, environment, and complexity, that potentially impact knowledge management implementations in organizations.

Keywords: Hindering factors · Barriers · Challenges · Strategies · Success factors · Digital transformation · Industry 4.0 · Digitalization · ERP systems

1 Introduction

The interdependence between knowledge management and digital transformation processes is rapidly increasing in magnitude and pace. Studies have shown that the latter can significantly facilitate and solidify knowledge management within and among organizations [13,43,56]. According to Zaman et al. [57], special emphasis is placed on one of knowledge management's primary objectives, namely knowledge creation, which digital transformation processes enable by opening up far-reaching opportunities. Simultaneously, empirical findings suggest that knowledge accumulation can foster digital transformation, particularly

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in the manufacturing sector [42]. This highlights the need for organizations to approach this symbiotic dynamic with strategic awareness. However, hindering factors obstructing digital transformation processes could potentially spread and jeopardize the broader organizational implementation of knowledge management. A deep and comprehensive understanding of these impediments is essential to mitigate such risks. By identifying these hindering factors, decision-makers can effectively pave the way for successfully integrating knowledge management into the organizational context. Against this backdrop, this study seeks to investigate the following research question:

Research Question. What hindering factors occur in digital transformation processes?

2 Theoretical Background

To address the research question outlined earlier, it is essential to begin by defining all concepts of relevance. This is crucial for identifying pertinent literature that provides the necessary information to support the study. Consequently, this study explicitly defines the concepts of digital transformation processes and the associated hindering factors to establish a solid foundation for analysis.

2.1 Digital Transformation Processes

First, the following definition is being used for digital transformation processes:

Definition 1. *"[A digital transformation process is a] fundamental change process, enabled by the innovative use of digital technologies accompanied by the strategic leverage of key resources and capabilities, aiming to radically improve an entity and redefine its value proposition for its stakeholders." [23]*

This definition was derived through a multilevel theoretical approach, encompassing 134 definitions from extant literature [23]. It involved a comprehensive analysis employing conceptual, semantic, and pragmatic measures, the formulation of a unified definition, and an evaluation by 60 experts from both academia and industry [23]. This rigorous process ensures that the definition provides a robust foundation for use in this study.

2.2 Hindering Factors

Second, the following definition is adopted for hindering factors. Notably, existing literature on this topic is deliberately refrained from, as the definition is derived from a distinct conceptual elaboration tailored specifically for this study.

Definition 2. *Hindering factors are understood as those that impede an activity's intended outcome so that this activity can realize its maximum objectively achievable potential in the collective absence of those factors.*

Thus, hindering factors encompass not only the presence of negative influences that may impede progress but also the absence of positive effects, which are equally vital for fostering development and achieving a balanced approach.

3 Research Design

For this study, a thorough literature review was conducted by analyzing the following 50 peer-reviewed scientific papers [1–12,14–22,24–41,44–53,55]. These papers were selected based on the aforementioned definitions and reviewed in relation to their adequacy for representing the topic in question in a twofold manner. First, the definition of digital transformation processes conduced as a guiding principle for the derivation of equivalent concepts, namely digital transformation, Industry 4.0, digitalization, and ERP systems, which were used as key search criteria to identify relevant publications in databases. Other parameters (e.g. organizational constraints) for narrowing the scope of literature selection played a negligible role, as the primary objective was to adhere closely to the definition of digital transformation processes. Second, to contextualize these concepts within the framework of hindering factors, the literature funnel focused exclusively on studies that discussed the presence of barriers and challenges or the absence of strategies and success factors, ensuring alignment with the definition of hindering factors. To this end, articles were carefully examined and analyzed to determine whether they decidedly addressed the reasons behind the failure of digital transformation processes in organizations. Once the selection was determined, these papers were, as Webster and Watson [54] postulate, integrated through a concept-centric review that ultimately encompasses 132 hindering factors, each with its own unique naming, corresponding definition, and categorization at three levels of abstraction. For documentary reasons, all hindering factors were largely extracted verbatim within the framework of 1,425 individual excerpts from the 50 previously outlined papers. Eventually, an iterative approach of refining and revising was carried out until conceptual saturation was achieved. With respect to this, the 132 respective hindering factors were hierarchically structured into two primary, seven secondary, and 34 tertiary categories.

4 Results

Building upon the research design outlined earlier, the following 34 hindering factors of digital transformation processes along three levels of abstraction are identified, each accompanied by a detailed definition.

4.1 Situational Factors

Situational factors are understood as context-dependent influences that generally have the tendency to be revised over time and without significant effort.

Procedures

Data. This refers to inadequate implementation of essential data management, including faulty data, poor presentation, unclear responsibilities, limited access, insufficient integration, and the lack of transformation of data into information.

Analysis. That indicates poorly planned analysis phases, lack of monitoring, suboptimal competitive analysis, insufficient vendor assessments, unclear system requirements, inadequate and careless system testing, and weak risk evaluation.

Strategy. It relates to the absence of a clearly defined technological strategy aligned with the business strategy, lack of operationalization into action plans, poor distribution of the strategy, and suboptimal use of key strategic techniques.

Integration. Such denotes insufficient integration at operational levels, parallel implementations of new systems, continuous integration, knowledge transfer, and involvement in keeping systems updated.

Standards. This concerns the absence of standardized processes to ensure reliability and an organization-wide consensus to reduce organizational differences.

Teamwork. That indicates the inability to communicate information, coordinate collaboration within the organization, empower stakeholders to contribute, and methodically strengthen interdisciplinary, cross-departmental, and cross-project cooperation.

Training. It encompasses the lack of a basic training program, adequate training for targeted qualification, and organizational commitment that stands up for its raison d'être.

Projects. Such refers back to the inability to apply fundamental project management principles, maintain focus, work towards a common goal, provide adequate resources and skills, lead competently as a project sponsor, define tasks clearly, manage teams effectively, avoid high turnover, ensure proper internal and external communication, and establish an interdisciplinary project team composition.

Leadership

Competence. This signifies the lack of necessary expertise for implementing digital systems and the required skills for effective and targeted leadership in general.

Inclusion. That underscores the absence of comprehensive support from top management, insufficient leadership activities at the operational level and distributive leadership approaches, and a lack of measures for employee involvement.

Conviction. It implies a lack of commitment, dedication, and determination on the part of top management, inadequate management of emerging interpersonal issues and employee concerns, and a lack of transformational leadership.

4.2 Constitutive Factors

In contrast to situational factors, constitutive factors are understood as fundamental elements whose effects tend not to be revised over time and only with significant effort.

Resources

Cost. This refers to an unwillingness to invest and the view that implementation, operation, training, and recruitment of qualified professionals are too costly.

Time. That indicates organizational ambidexterity, as operational workloads hinder proper implementation, integration, and requirements analysis monitoring.

Finance. It relates to concerns about lengthy amortization periods, uncertainty regarding future returns, especially in terms of ROI, challenges in quantifying economic benefits, and difficulties in making initial investments.

Maturity. Such denotes a lack of awareness about successful organizational implementation, high variability in expertise among stakeholders, and insufficient understanding of the peculiar business model and structural setup.

Structure

Infrastructure. This concerns inadequate technical infrastructure, both in terms of software and hardware, as well as the lack of sufficient data throughput for the seamless and efficient operation of the system to be implemented.

Conditions. That points to the absence of incentive-based conditions, particularly job satisfaction-related ones, required to foster effective organizational behaviors and support a focused emphasis on research and development.

Composition. It encompasses the lack of necessary conditions for a multi-perspective mindset among stakeholders, particularly empathy abilities across divisions, and a corporate culture that fosters a holistic viewpoint.

Agility. Such refers back to the inability of the organizational structure to be agile and responsive, as well as its failure to promote comprehensive measures for adapting outdated business processes and overall approaches to new standards.

Personnel. This signifies the absence of technical professionals for the proper implementation, operation, and maintenance of the system and a lack of comprehensive knowledge regarding the technological implementation.

Culture

Awareness. This underscores the initial belief that the implementation is straightforward, the conviction that no significant benefits are to be expected, the assumption that the current business model meets the latest standards, and a culture shaped by unrealistic and utopian expectations of the change process.

Concerns. That implies emerging concerns about potential job loss, traceability, transparency, data privacy from an employee perspective, and data security from an organizational standpoint.

Pressure. It refers to a culture that exerts insufficient pressure for extensive organizational changes and is characterized by a lack of collective discipline.

Trust. Such indicates a lack of trust between stakeholders to foster information flows, a lack of confidence in technological solutions, and the absence of a corporate culture characterized by a fundamentally positive work atmosphere.

Satisfaction. This relates to inadequate user satisfaction and poor performance of the system, making its operation inefficient and negatively affecting acceptance.

Attitude. That denotes an inadequate corporate culture marked by concerns about the impact of change on operations, a lack of information sharing due to individual rivalries, a strong emphasis on identity and traditional values, resistance to questioning tasks, and a tendency to avoid reliance on third parties.

Interest. It concerns the absence of a collective commitment to change and a corporate culture that is open to innovative, progressive, and lasting changes.

Environment

Government. This points to inadequate governmental support for expanding national infrastructure and network coverage, a lack of incentives for businesses, minimal establishment of favorable frameworks, generally insufficient support from institutions, and insufficient pressure exerted by the government.

Legislation. That encompasses complex legal requirements, uncertain outcomes of regulatory frameworks, and underdeveloped laws that tolerate gray areas.

Market. It refers back to the inability to accurately predict technological developments, the challenge of keeping pace with the speed of technological advances, difficulties in navigating a turbulent market environment, the absence of competitive pressure from the industry, the lack of industry-specific implementation roadmaps and guidelines, the absence of willingness for collective change from external partners, and the shortage of qualified professionals in the labor market.

Technology. Such signifies the inability of vendors to meet industry-specific requirements, the lack of dialog between industry and vendors, inconsistency and compatibility issues, and the absence of scalable technological solutions.

Partnerships. This underscores the absence of sufficient support from consulting firms and vendors, limited collaboration with educational institutions to facilitate innovation, and inadequate cooperation with external stakeholders.

Complexity

Business. This implies the complexity arising from overall technological progress, over-customization through programmed individualizations, integration of new systems into the existing environment, organization-wide data fragmentation, and both user-unfriendly and unintuitive system interfaces.

Setup. That refers to the complexity caused by the discrepancy between business requirements and technical system functions, as well as the inherent complexity of the business model itself.

5 Conclusion

In conclusion, the findings of this study highlight seven significant hindering factors that should be carefully considered.

Procedures. Taking procedures into consideration is pivotal, given their overall influence on the daily operations of organizations. Internal cross-departmental processes must have strategic clarity regarding their objectives and responsibilities, ensuring effective teamwork and stakeholder consensus. This clarity enables decision-makers to identify the need for further employee training. To achieve this, it is evident that project management plays a crucial role, as it provides a framework capable of meeting this critical need for an analytical approach. It stands to reason that these measures can enhance overall data quality, thereby improving the organization's ability to make robust decisions.

Leadership. Acknowledging the importance of leadership is essential for paving the way for structural management within the organization, as decision-makers hold significant influence over organizational behavior. This becomes particularly apparent given that the relationship between leaders and followers must be well-developed, guaranteeing distributed inclusion in decisions. However, the leader's belief in the need for change is critical, as it enables them to steer the organization toward the appropriate channels for change in the first place.

Resources. The consideration of resources is critical, exceedingly monetary sufficiency, as it significantly influences the organization's capacity to drive and implement change, including acquiring, commissioning, and operating an adequate system. Specifically, both the availability of time and the maturity level among stakeholders are heavily dependent on sufficient financial resources, underscoring the importance of strategically envisioning adequate funding.

Structure. Focusing on structure is fundamental to providing a solid organizational foundation and a framework that can be molded appropriately. Considerable attention must be given to the surrounding infrastructure from technical, organizational, and personnel perspectives. This ensures that the organization remains agile and resilient, capable of navigating demanding circumstances driven by the market and other external factors.

Culture. Recognizing cultural aspects is key for fostering an extensive awareness of potential issues and ensuring that collective discipline enables a proactive approach to addressing employees' concerns. By doing so, building organizational trust and cultivating a positive atmosphere becomes feasible, which helps prevent resistance to change. This also promotes curiosity for further advancements among all stakeholders, ensuring continued willingness and adaptability.

Environment. Taking environmental elements into account is critical for effective risk mitigation, as it helps to understand which inevitable factors must be reckoned with. In this regard, it is evident that insufficient framework conditions established by the government can have negative repercussions. Unfavorable market conditions, such as technological uncertainty, market immaturity, intense competition, and shortages of qualified labor, can further exacerbate this impact. As a result, nurturing strategic alliances and leveraging the sphere of influence becomes essential to support persistent threat management.

Complexity. Last but not least, understanding the role of complexity is indispensable in recognizing the need for analytical approaches that enable proficiency in complex environments. It also helps minimize the occurrence of uncontrolled and difficult-to-manage situations, especially those related to over-adaptation and data fragmentation. Reducing complexity in technical, organizational, and business viewpoints is crucial, as it empowers organizations to actively and purposefully shape and align change.

6 Limitations and Outlook

Although the quality criteria relating to accurate scientific research have been included, there are nevertheless limitations that must be taken into account. First and foremost, it must be recognized that some relevant aspects may have been overlooked during the literature review due to confirmation bias. Moreover, only 50 references from a limited range of databases have been included, without ensuring a balanced and systematic representation. This lack of diversity and impartiality in the selection process may have extended bias. Additionally, while the articles selected for identifying hindering factors in digital transformation processes were peer-reviewed, there remains a possibility that studies of lower quality have been integrated. Furthermore, no classifications of organizational sizes and domains have been made, potentially resulting in broad, contextually unsupported generalizations that may not be relevant to specific knowledge management approaches. It is also important to note that certain practices hindering digital transformation processes may still benefit knowledge management, and vice versa. While the plausibility and triviality of such links seem low, there remains a residual uncertainty that these, as yet, implausible assumptions may ultimately prove valid. Nevertheless, this literature review provides valuable insights and lays the groundwork for future research. Although a more systematic approach to conducting future literature reviews in this regard is needed, it is recommended that the relationship between knowledge management and digital transformation processes be examined in more detail in order to draw more precise conclusions about their common hindering factors, particularly regarding potential conflicts of objectives. Such an approach would ensure that the connections made in this paper are logically sound, contributing positively to the advancement of knowledge management in organizations.

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Knowledge-Based Multi-agent Reinforcement Learning for Ambiguity Mitigation in Course Moderation Process

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Abstract. Ambiguity in course moderation process occurs as human experts tend to compete in proving their superiority in knowledge and experience. Virtually collaborating to produce a time-constraint comprehensive report based on multiple sources of information, the course instructor and moderator are challenged to meet a consensus on the moderation findings, which further causes an undecisive result at the management level. Supported by a comparative analysis on five different case institutions, a knowledge-based multi-agent reinforcement learning (MARL) is proposed to be the solution, as it mitigates the ambiguous situation by assigning role-based tasks to the knowledge agents that will decide on the actions based on the multiple existing sources and their human counterparts' reviewing styles and preferences. Supporting components like Natural Language Processing (NLP) and rewards system are recommended to be included to fortify the proposed MARL system, as it would require agents to understand from unstructured data in documents and profile records. Covering only one role at a time in the proposed system, which does not reflect the real complex case, the function of the reinforcement learning agents could be made as complex as playing interchangeable roles based on the assigned task at a time.

Keywords: Context-Awareness · Knowledge-based · Multi-Agent Reinforcement Learning · Moderation Process · Ambiguous Environment

1 Human Knowledge Experts Versus Artificial Intelligence

In the world where generative artificial intelligence (GenAI) is making its way to be the ultimate expert in all fields, humans and their knowledge expertise are still relevant in completing tasks in organizations. Designed to provide informed, context-rich responses across a wide range of topics, thanks to the data and research the GenAI have been trained on, it is still a tool with lack of real-world experience, intuition, and evolving insights that a human expert would bring to a field. It is a tool for exploring, synthesizing, and understanding information, as well as to support human experts rather than replacing them.

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Human knowledge experts, on the other hand, bring a level of intuition and insights that goes beyond data and theories, often shaped by years of hands-on experience, personal observations, and nuanced understanding of their field. Despite having the upper hand on the decision making and problem solving, human experts are tempted to rely on GenAI to at least trigger some ideas based on summarized information it could compile. The temptation is not only for personal use, but also for official assignments. The effect of this reliance on GenAI has caused ambiguity in conveying simple messages in communication and official reporting during task accomplishment in an organization.

Scoping into the lives of knowledge experts in education management system, the effect of GenAI usage has brought up a question on how to mitigate knowledge ambiguity and uncertainty of misinterpreted information across the organization. There is a need to take one step back and look at how multiple software agents, enhanced with the reinforcement learning capabilities, could be adopted for to increase the capacity of the knowledge experts in efficiently completing the multiple tasks in hand. The focus of the task is the course moderation process that highly demands the knowledge and insights capacities of the human experts.

1.1 Problem: The Ambiguous Review by Knowledge Experts

In tertiary education, a course moderation is a common practice for continual quality improvement (CQI), often performed at every end of the semester. Different higher educational institutions (HEIs) would practice the moderation differently. As an example, one HEI would have a centralized system to manage the course moderation with controlled number of words for each field in an online form to be filled in by the moderator and course instructor. On the other hand, another HEI would have a traditional mechanism of an unconstraint number of pages for a course moderation report to be filled in by them. The latter provides inconsistency in the scope of expected contents with the lack of clear fields to guide the writers, while the former limits the creativity of the writers to elaborate in-depth findings in their course review.

Trusting that the human moderator is an expert in providing constructive reviews with good insights, which in turn would help the course instructor improves the course contents and teaching skills, the flexibility of the review has caused a lot of issues. The way the review is written has caused ambiguity when interpreted by the course instructor and the approvers of the report, i.e., the academic supervisor and manager. As a result, decision could not be made accurately at the point of time when the report is tabled in the academic management meeting. In a tight deadline environment, where business operations are at risk if any tasks are delayed, getting the review understood and verified for a preparation of “clean” and interpretable report is a huge challenge.

In the case organization observed in this study, the peer dynamics among the knowledge experts in the faculty, i.e., course instructors who are also moderators to each other, are significantly unique due to the flexible course structure and schedule. Each instructor would be assigned to different courses that are to be delivered in overlapping course schedule, leaving less space and time to focus on course moderation process and properly communicate with the moderator for clearer insights on the review. This results in unexpected tension, especially when the moderator is trying to “show off” his or her

knowledge expertise by being ambiguous in the review. Conflicts come along with the tension, making a mountain out of a molehill.

Despite the capabilities of software agents in mediating the human's tasks, it is being kept aside when GenAI came into picture. At a time like this, when GenAI has caused ambiguity and sometimes inconsistency in assisting human experts in their mundane tasks, the strengths provided by the software agents are beckoned. Since GenAI is made available in public domain, the software agents should be made available at the personal level of the human experts, to even out if not complement the effect of GenAI.

In solving the problem in hand, this paper conceptualizes a multi-agent reinforcement learning (MARL) model with the concept of personal knowledge management to streamline the process of documentation management for verification and moderation of course review. The proposed MARL-driven recommendation system consists of agents in the system environment that represent the specific skills, knowledge, and availability of their human experts. Agents would have the capacity to learn and collaborate by sharing insights on task requirements, balancing between individual preferences in terms of availability and expertise, and balancing the overall system performance by solving the tasks effectively.

2 Multi-agent Systems in Ambiguous Environment

Looking at the problem in hand, similar case is found on information system requirement documentation case, highlighted by Ismail and Zamre [1], which beckons the role of software agents to be part of the document management system environment. The conceptual model of the multi-agent system was presented, in which it could be fortified and empowered by natural language processing (NLP) and sentiment analysis for the software agents to rely on in analyzing the documents within the system.

Surprisingly, knowledge retention issue still exists in knowledge-intense organization, as employee turnover is high [2]. Despite the environment and work culture in the organization, which could be too hectic and stressful for those newly onboarding the education system, lack of understanding on the work process, expectation and requirements of the process have caused overwhelming stress causing the employees to leave. As they walk out the door, the organization would suffer with knowledge loss, as those who left are usually experts and knowledgeable in their fields.

Unorganized knowledge in the document management mechanism within the organizational business process could hinder the professional progress and mental health of the employees. If the process is properly governed with knowledge management concept, the knowledge loss and work stress due to documentation issues could be reduced, if not mitigated. In the case environment, if everybody is an expert and has a say, then whose review should be the final verdict? This has caused undecisive, dilemma, and contemplation on the management's side, when nobody wants to take the risk and be responsible of the decision made.

The case of course moderation task, where a human course instructor virtually interacts with multiple moderators and encounters ambiguities, offers an interesting use case for a multi-agent expert recommendation system. Related works from relevant literature are presented here to address the ambiguity, uncertainty, and complexity faced by the course instructor.

Ambiguity could be reduced when the context awareness is clearly defined. Context awareness, in an agent-based environment, constitutes the utilization of context as the semantics of an event or a situation to enhance the software agent's comprehension [3]. An agent is considered context-aware when its actions and behavior could adapt to the sensed context [4], as context consists of various types of information and data that can be employed for difference dimensions of a situation, i.e., conceptual information on specific circumstances [5]. An agent in a multi-agent system perceives both intrinsic and extrinsic contexts, in which intrinsic context involves the agent's goals, roles and historical data, intent, and observations, while extrinsic context is more on user-specific, agent-specific, and system-specific contexts [4].

An environment where agents reside serves as the operational space where they operate to perform their tasks and pursue goals as it provides the context that guides the agents to make decisions [4]. Understanding the perceptual data and the dynamically changing states in the environment [6] requires the agents to store the information perceived from the environment in memory, process the information relevant to the requirements of the task, plan and execute it with actions, and learning from the outcomes (Mostafa et al., 2013). In making decisions, each agent is guided by its own goal and has the capability to communicate with each other in the environment, resulting in a formation of either cooperation or competition relationship [4]. The difference between the two relationships is in terms of whether the goal is shared or each agent has specific goal to achieve. In the case of ambiguous moderation process, each agent would have specific goal derived from the role it plays, but they need to reach a consensus in the end. The number of agents in the MAS environment needs to be considered in ensuring that the consensus could reached to successfully and "peacefully" to close the case of moderation task and mitigate any further ambiguities.

In reducing ambiguity, a multi-agent system could analyze historical data on each moderator's feedback style and preferences to clarify ambiguous feedback for the instructor. By doing so, uncertainty could be reduced, and alignment between the moderator's and instructor's expectations could be improved. In complementing this effort, explainable recommendations could be used, which could help the course instructor by providing clarification around the feedback reasons reported by the moderator. A multi-agent system can assign tasks to the agents to represent both the moderator's and the instructor's needs, adjusting the feedback interpretations according to the instructor's specific requirements. This can help align responses with diverse moderation standards, mitigating miscommunication and inconsistencies.

Miscommunication and misinterpretation in a document could be mitigated with the explainable feature AI could provide. In doing so, a multi-agent system could enable or build trust in the feedback process when the context and content are clearer as the explainability and consistency in recommendations are provided. The concept of Explainable AI (XAI) could be considered to make transparent the information behind the feedback process, promoting human insight by providing results with description understandable to the users [7]. Not only could it clarify the ambiguous content as it avoids misinterpretation, it could also justify each recommendation of clarification it makes, promoting

transparency in the feedback that the course instructor receives. The clarity that it provides fosters a sense of reliability in feedback interpretation and enables the instructor to respond confidently and accurately.

In the area of expert recommendation systems, collaborative filtering is often suggested to amplify the recommendation power of the systems. The collaborative filtering approach is described by Schafer, Frankowski, Herlocker and Sen [8] as the process of evaluating items using opinions of others, originated from human behavior of sharing opinions with others. In relation to this study, collaborative filtering could be adapted to identify common patterns in how moderators provide feedback, matching these insights with the instructor's preferred level of specificity or style of response. By doing so, the system can generate recommendations that align with past successful interactions between the instructor and similar moderators, thereby reducing the workload on the instructor's side when interpreting feedback and adjusting responses to fit various expectations. Complementing the capability of collaborative filtering, task-specific reinforcement learning could be adopted for improved adaptation. Empowered with reinforcement learning to refine its recommendation over time, a multi-agent system could continuously learn from interactions between the course instructor and multiple moderators. This approach could help in learning the instructor's preferences and identifying patterns in moderators' feedback to minimize ambiguity in future interactions.

2.1 Reinforcement Learning for Ambiguity Mitigation

Review on related works has led this study to unearth the capability of reinforcement learning in multi-agent system environment. Reinforcement learning (RL) focuses on learning how to make decisions guided by reward signals [9], which serves as the foundation of learning controls [10]. At each time step, an RL agent needs to perceive the state of its environment and takes an action, causing the environment to transit into a new state [11], and this keeps on happening at every time step when the change is inevitable.

Adopted in a multi-agent environment, in which RL agents are challenged to interact with the dynamic environment, a multi-agent reinforcement learning is designed for static or stateless games, or work in a stage-wise fashion [11]. Instead of singularly perceive the environment and learning from one perspective, multi-RL agents could interact with the same environment at the same time to achieve better and more learning efficiently [12]. The key elements that drive the agents to learn from the environment are their own reward function, as they act on their own individual interests [12]. In recent years, there are quite a handful of MARL algorithms developed to empower agents in exploiting the environment's shortcomings in order to achieve better rewards, which are based on actor-critic, policy optimization, and value-based methodologies [12].

Despite the success in designing and developing the MARL, the implication and adoption in the mundane tasks like course moderation in tertiary education are not found. Most research on reinforcement learning in education settings is focused on the teaching and learning environment [13–15], not on mitigating ambiguity in education administrative process. This highlights the significance of this study, in which the need for MARL is critical at operational level of an education system. Despite the origin of MARL being programmed for stochastic game [11], this study ventures into the use

of MARL for a more serious purpose that would lead to productivity, efficiency and managing uncertainty that relates to knowledge reasoning.

3 Methodology

In verifying the commonality of the problem faced by the higher education institutions, a comparative analysis across a sample of five institutions is conducted. The similar trait of these institutions is in terms of being business-oriented (i.e., private institutions), in which the revenue has high dependency on the incoming number of students registered for the offered programs. Apart from this, the institutions perform some kind of tasks of verification and moderation process, which are performed by the operational level, i.e., among the course instructors.

Table 1 summarizes the comparison made across the five case institutions, described in terms of the verification process, moderation process, and document source or evidence of the processes. The names of the institutions are kept confidential, in which they are substituted with case identifications (i.e., Case IDs).

Based on the comparison in Table 1, all case HEIs perform course marks verification process, but not all perform proper moderation process for the course. Verification process is performed by a moderator assigned among the course instructors, usually those who are familiar with the course content. Moderator verifies the marks either in the system (i.e., for cases SM, RT, MD, and LK), or manually offline (i.e., for case PA). In the case of RT, two moderators are required to verify the marks and grades for one course. In verifying the marks and grades, LK is the only case HEI that practices discussion between the moderator and the course instructor, although the verification is made available in the system. All case HEIs require approval with signature by the moderator.

On the other hand, the course moderation process in three out of five case HEIs (i.e., SM, PA, and LK) leads to ambiguous review. The ambiguity is caused by the flexibility of the open-ended questions in the form or report template made available to the moderators. This leaves the other two case HEIs (i.e., RT and MD) to be free from ambiguity in course review, not because of the flexibility but due to the unclear moderation process within the system. Nevertheless, any required adjustments on marks and grades would be performed before academic management meeting.

For the benefit of this research, Table 1 tabulates the document source for both processes in each case HEI. The document sources or evidence are mostly captured in the system for the verification process (i.e., SM, RT, and MD) and moderation process (i.e., SM). Since there is no clear process for course moderation in RT and MD, there is no record or evidence that the process is performed. A unique case is found on PA, in which both the verification and moderation processes are combined into one, which results in having only one evidence in the module review report. On the other hand, the case of LK highly dependent on the minutes of three different levels of meeting for the evidence of the moderation process. In other words, both PA and LK have evidence that is in a form of unstructured data embedded in documents.

Table 1. Comparative analysis across five case institutions.

Case ID	Verification Process (VP)	Moderation Process (MP)	Document Source
SM	Moderator verifies marks in the system. Missing marks and inconsistency in marking are documented in Justification Report, verified by Student Mentor	Moderator fills in online form in the system. Questions are open-ended. Possibly leads to ***ambiguous review***	VP: Data captured in the system MP: Data captured in the system
RT	Verified by 2 Moderators. Inconsistency in marking found on random 10 samples would enforce the Instructor to re-mark the scripts of the whole class. Verification in the system, printed out for approval signature	No clear moderation process. Any adjustment on marks and grades is performed before academic management meeting	VP: Data captured in the system MP: No record
PA	Marks verification is in the Module Review Form. Open-ended report format. Leads to ambiguous review	Course moderation is along with the verification in the same Module Review Form. Open-ended report format. Leads to ***ambiguous review***	VP: Module Review Report MP: Module Review Report
MD	Verified by Moderator. Verification in the system, printed out for approval signature	No clear moderation process. Any adjustment on marks and grades is performed before academic management meeting	VP: Data captured in the system MP: No record
LK	Moderator verifies marks through discussion with Instructor. Verification in the system, printed out for approval signature	Moderation process is only for marks and grades, tabled in the meeting: Section level meeting; Institute level meeting; and Senate level meeting. Possibly leads to ***ambiguous review*** if the meeting notes are unclear	VP: Verification Form MP: Minutes of meetings

Based on the observation on the process of course verification and moderation in the five case organizations, the conceptual model for the proposed solution is designed. Supported by the review of related previous works, the multi-agent reinforcement learning (MARL) framework is found appropriate to be the fundamental basis of the conceptual model for an effective course moderation process.

4 Findings

Based on the worst-case scenario after the comparison is made on the five case institutions, Fig. 1 is visualized. Figure 1 shows the process within the grades verification and course moderation system that leads to the outcome of the most ambiguous review.

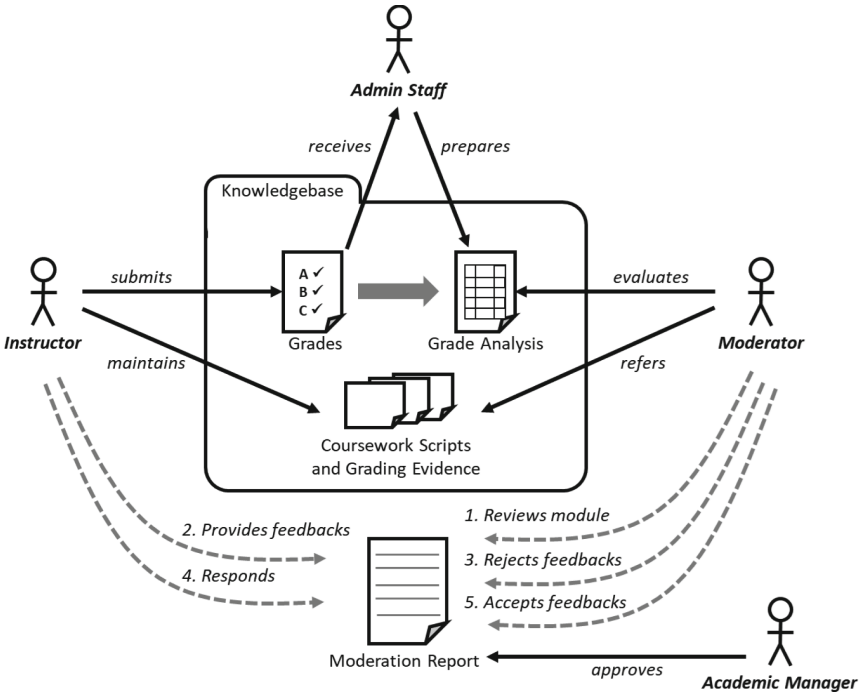

Fig. 1. Common process of grades verification and course moderation.

As shown in Fig. 1, a centralized knowledgebase is used as the document source for the whole process and only one report is produced to consist both the grades verification and course review. The moderation report is still a separate entity to provide flexibility to the moderator and course instructor to have their own words when producing the review and response. The whole process starts with the course instructor submitting the grades and maintaining the coursework scripts and grading evidence in the knowledgebase, in which the administrative staff receives the grades to prepare grade analysis also to be shared in the same location. The moderator assigned for the task refers to the grade analysis and the evidence maintained by the instructor, to facilitate the preparation of the course or module review.

Within the same document, the course instructor is required to provide feedbacks in response to the review or comments made by the moderator. The moderator can accept of reject the feedbacks, which leads to two possibilities: rejecting the feedbacks will require the instructor to respond; and accepting the feedbacks will end the process. If the moderator is very particular about the review or unhappy with the feedbacks, the cycle will iterate until both sides are satisfied with the report content. The cycle will also iterate if the instructor insists that his/her response is final or refuses to budge from his/her opinion. If the stubbornness prevails and it is closed to the deadline, then the case of ambiguous report will occur.

Upon closing the case before the report is brought to the academic meeting, the academic manager needs to approve it. Again, in a rare case of rushing the task to meet the deadline, the academic manager may not be able to intensely check the report due to the large number of reports that are coming in at the same time for approval, especially if the report is lengthy and requires a lot of time for the manager to read and comprehend. In most cases, the academic manager would just approve and proceed to the meeting. As a result, accurate decision could not be made in time.

5 Discussion: Collaborative MARL for Dynamic Process

In an ideal world, the grade verification and course moderation process could be integrated into one dynamic process to produce the moderation report, to support the capacity and resources of the human counterparts. The process will include three components: reinforcement learning; sentiment analysis; and collaborative filtering.

In the proposed multi-agent system environment as shown in Fig. 2, two agents are suggested to mediate the tasks of the human counterparts, namely the Instructor Agent, and the Moderator Agent. An additional agent is required to be the Review Agent, to produce a comprehensive moderation report at the end of the verification and moderation process.

As the Human Instructor publishes the required supporting documents for grade analysis and course moderation reporting, the Instructor Agent would be triggered to retrieve and analyze the documents. On the other side of the system, the Human Moderator would retrieve the supporting documents and the Moderator Agent would be triggered to retrieve and analyze the documents as well. Although the functions sound the same, the agents perceive different roles and perspectives based on the roles of their human counterparts. Virtually, both the Instructor and Moderator are “connected” within the same environment as the agents are residing.

In fulfilling the tasks in hand, both Instructor and Moderator agents would refer to the records in the knowledgebase on preferences, response styles (for the Instructor), review styles (for the Moderator), behavior, and characteristics. These data are captured, processed, and stored in the knowledgebase every time a course moderation process occurs. The records reflect the profiles of the agents’ human counterparts.

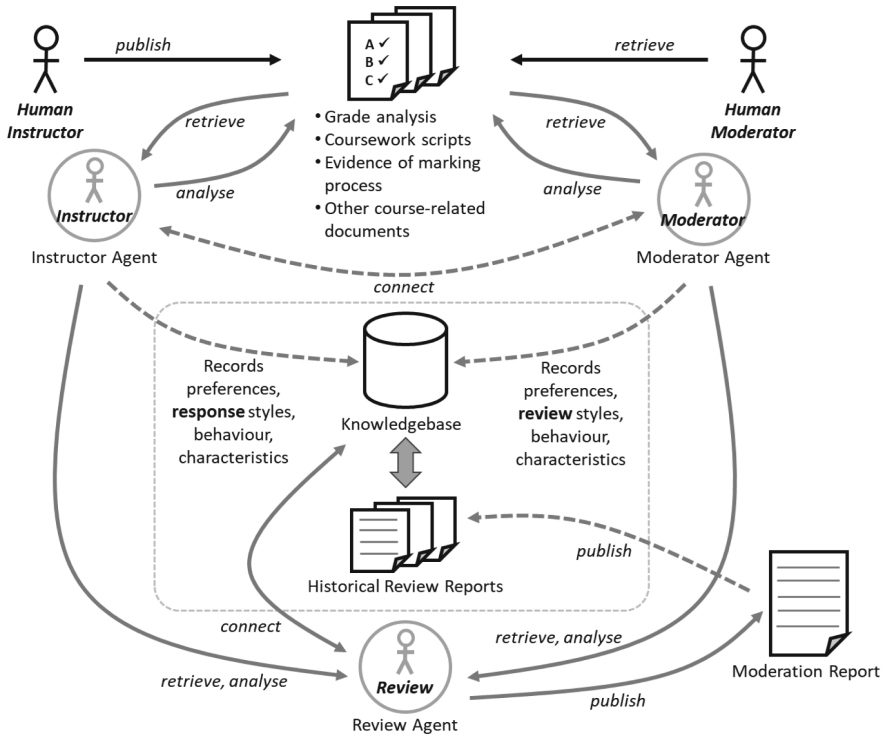

Fig. 2. Proposed Collaborative MARL for course moderation process.

The third RL agent called Review Agent is introduced to facilitate the compilation of the course moderation report. This agent could retrieve and analyze the output produced by the previous two RL agents, namely the Instructor and Moderator agents. Review Agent would also refer to the knowledgebase as and when needed, to produce and publish the moderation report. Each moderation report produced in every cycle of moderation process is published and stored in the repository, which would be part of the knowledgebase. It would accumulate to a point where the stored historical data could be analyzed by the agents for reinforced learning, beneficial to be used during the upcoming moderation processes. The process of verifying the recommended report by the agents with the human counterparts is required, before the moderation report is finalized and stored in the repository of historical data.

6 Conclusion

This study conceptualizes an idea of knowledge-based multi-agent reinforcement learning (MARL) to accommodate the current real-world problem of grade analysis and course moderation reporting at academic operational level. The problem resides among individual knowledge experts, in which each expert is knowledgeable backed with own historical experience. The concept of personal knowledge management from multi-agent

system [16] is extended in this proposed MARL system, in which multiple knowledge agents are deployed to learn, assess, and decide on behalf of the human knowledge experts.

This paper covers only the discrete aspect of the MARL system, by discussing one scenario of a time step, in agent environment consisting two human knowledge experts. Since a Human Instructor also plays a role as a Moderator in a different state of time, both agents would be assigned to the same human, or the same agent could be assigned different roles of Instructor and Moderator at different time. This would require a more complex algorithm, especially if only one RL agent is assigned to play multiple roles for the same human counterpart. Further rules need to be applied to the case scenario.

There is room for improvement for this conceptual design of MARL, in which the fourth RL agent is required. This RL agent could act as an Admin Agent, assigned to oversee the system, understand the final version of moderation report, and notify if it is ambiguous and/or not ambiguous according to the requirements set by the Academic Manager. The Academic Manager is a potential human counterpart for this Admin Agent. In addition, it could record emerging new styles, and if possible, evaluate whether the new styles are good (or bad) for future review and moderation, then propose to the human Academic Manager for recommendation.

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